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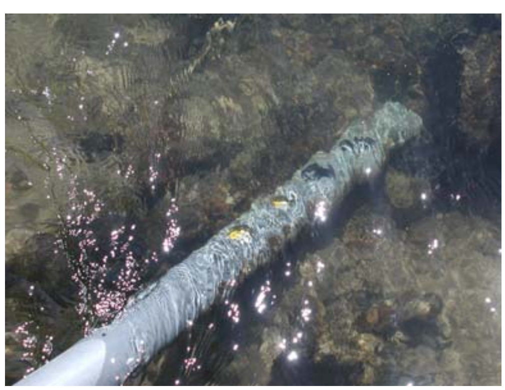

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EXECUTIVE SUMMARY

The principal goal of the Truckee River suspended sediment study was to estimate the sediment loads for the Truckee River in California, and to characterize the existing range of sediment loads and variability according to total amount, maximum, duration, timing and frequency of sediment transport events. Our primary objective in support of this goal was to develop a sediment surrogate that could be measured continuously in the Truckee River. This work supports development of numeric targets and load allocations for the Truckee River sediment Total Maximum Daily Load (TMDL) in California. The report is divided into three chapters: 1) Develop a model to predict suspended sediment concentrations from multiple variables, including turbidity; 2) Estimate suspended sediment loads; and 3) Assess spatial and temporal properties of turbidity.

Transport changes in suspended sediment concentration (SSC) due to natural or human-induced causes are difficult to characterize because SSC varies rapidly and unpredictably during storm events. Capturing the extreme variation in SSC during storms requires sampling at high temporal frequency, which is usually impractical and expensive. As such, easier-to-measure surrogate variables are monitored continuously with in-situ instrumentation. Thus, a continuous turbidity record, supplemented with selected measurements of SSC to derive the turbidity-SSC relationship, can provide an efficient and cost effective method for estimating transported suspended sediment loads.

Our project builds on and extends previous work by the U.S. Geological Survey (USGS) in the choice of the general class of statistical modeling techniques-regression methods. First, we use multivariate regression techniques, which allows for inclusion of multiple variables characterizing the river processes to the model. Second, since the Truckee River is expected to have high variability in sediment and turbidity, we explored parametric as well as nonparametric (robust) statistical techniques. Third, since we have evidence from previous work that the relationship between turbidity and sediment may be nonstationary, we used local regression models. These allow for different functional relations to be built for different parts of the data set that increases the overall fit of the model to the data. Additionally, since extreme sediment discharge events may be of major interest, we made every effort to capture them with our models, and not discard them (before modeling) as outliers. Fourth, we included error estimates (confidence intervals) for the predictions made using our models.

The primary data sources for building the model and calculating sediment loads were flow, measured by the USGS at three sites, and turbidity measured by the California Department of Water Resources (CalDWR) at four sites. In addition, the turbidity instrumentation measured water temperature and specific conductivity. In order to develop a statistical relationship between suspended sediment concentrations and the explanatory variables (here discharge, turbidity, specific conductivity, and water temperature), SSC samples needed to be collected throughout the year as the explanatory variables varied. Therefore SSC was collected monthly at all four turbidity collection sites and weekly during snowmelt. Additionally, SSC was collected at Farad during thunderstorm events.

Model Development to Predict Suspended Sediment Concentrations

We developed a multiple linear regression model (MLR) for predicting SSC from various combinations of turbidity, water temperature, stream flow and specific conductivity:

a) Full model: turbidity, flow, water temperature and specific conductivity;

b) Turbidity, water temperature and specific conductivity;

c) Flow only; and

d) Water temperature only

Models with fewer predictive variables were explored because it is often the case that only one or two (e.g., flow, temperature) of these variables are measured continuously in the field. A statistically "good" model with few predictive variables could be very useful for future studies. As part of the process of developing the predictive models, the statistical relationships between individual variables were analyzed.

The "best" model developed was one in which SSC was predicted from all four explanatory variables (turbidity, flow, water temperature, and specific conductivity). The R^2 was 0.73, that is, the explanatory variables explained about 73% of the variability of SSC. From a statistical standpoint, this was found to be a "good" model, in that the mathematical assumptions under which the model was constructed satisfied statistical diagnostic tests. In this model, site was not found to be significant, so one equation can be used for all four sites (rather than a separate equation having to be used for each site).

The model developed to predict SSC from three explanatory variables (turbidity, water temperature and specific conductivity; flow removed from the model) explained about 58% of the variation in SSC. In this model, site was significant and it was necessary to develop a separate predictive equation for each site. The model with flow as the only explanatory variable resulted in a multiple R^2 value of 0.39, but the statistical properties of this model were not good. There was no statistical relationship between SSC and water temperature, so a model could not be built with temperature as the only explanatory variable.

Suspended Sediment Load Estimates

Loading amounts and variability of suspended sediment was evaluated for four locations on the main stem of the Truckee River between Tahoe City and Farad. Data collected prior to June 2002 were not used in load calculations as the turbidity sensors were not calibrated prior to this date. None of the sites had a complete set of turbidity data during the 13 month 2002/2003 period, with two to four months of turbidity data missing from each site. This precluded calculation of annual loads. Instead, we present calculation of monthly suspended sediment loads for each site during the June 2002 to July 2003 period. In addition to calculating monthly loads, loading of specific sediment events (e.g., thunderstorms, snowmelt runoff) was assessed.

Suspended sediment concentration was first calculated using the "best" predictive model described above (SSC as a function of turbidity, flow, water temperature, and specific conductivity). Flow estimates at Bridge 8 were unavailable since there is no USGS gage at that location, and attempts to obtain flow using a pressure transducer failed due extensive equipment failure. Therefore the "best" predictive model could not be used for estimating SSC at Bridge 8, and the regression model using only turbidity, specific conductivity, and water temperature was used to calculate SSC for Bridge 8. This allowed comparison of SSC among stations over the study period.

Suspended sediment load (SSL) is the product of estimated concentration *SSC* (in unit of mass per volume) and discharge *Q* (in units of volume per time). Because flow was not available for Bridge 8, sediment loads were calculated using flow from both Tahoe City (~6 miles upstream) and Near Truckee (~6 miles downstream). Clearly, the true sediment loading lies somewhere in between these two estimates. Resulting load calculations using flow from the two different sites differed by as little as 5% during baseflow and as much as 600% during spring snowmelt. For simplicity, Bridge 8 sediment loads reported here were calculated using Near Truckee flows for the purpose of comparing its temporal variability to the other sites.

Monthly suspended sediment loadings ranged from ~5 to 6 tons/month (Tahoe City, October to December 2002) and up to ~61 million tons/month (Farad, June 2002). The highest monthly loadings at the three stations occurred during the snowmelt period, with peaks occurring at different times: peak monthly loading occurred in May 2003 for Near Truckee at ~270,000 tons; it occurred in June 2003 at Bridge 8, at ~290,000 tons; and it occurred in June 2002 at Farad at 61 million tons. The peak monthly loadings at Tahoe City occurred in July 2002 and July 2003 (343, and 264 tons respectively) and are likely related to increased dam releases at that time of year since the snowmelt season was over by the end of June in both years.

For the purpose of determining how loads calculated in the present report compare to previous estimates using different predictive models, SSL estimates for Farad calculated as a function of turbidity, flow, specific conductivity, and water temperature ("best model", this report) were compared to SSL estimates for Farad calculated as a function of flow only using the regression equation developed for Farad (R^2, 0.78) in the DRI (2001) report. Loads calculated as a function of flow only using the DRI (2001) equation were consistently less than SSLs calculated as a function of turbidity, flow, specific conductivity and water temperature using the equation developed in the present study. The difference was less during base flow periods (August to November 2002), but were 2 to 6 orders of magnitude higher during March, June, and July, as well as December. This comparison underlines the care that must be taken in comparing suspended sediment loads estimated with different methods. In addition, it points to the much better estimates of suspended sediment loading that can be obtained when turbidity data (in addition to other variables) is available.

Understanding the impact of sediment to the beneficial uses and the ecosystems of the Truckee River basin is an important component of TMDL development. For example, a small to moderate load of sediment that occurs over a long time period (e.g., days) may be more detrimental to biota than a very large pulse of sediment that only lasts an hour. Future studies to establish the linkage between sediment loading and beneficial use impairment will benefit from knowledge of the temporal aspects of sediment loading, including timing, frequency, maximum, duration of sediment.

Throughout the year, sediment is entrained and transported down the Truckee River. These processes tend to increase during certain times of the year when discharge increases, during spring snowmelt, as well as during thunderstorm events. We tend to think of the spring snowmelt as one big event. However, upon detailed evaluation of the sediment loading patterns during snowmelt, it is apparent that there is typically a diurnal pulse of sediment that follows the daily melting patterns of the snow. For this reason, these daily pulses of sediment associated with snowmelt were considered as events, along with sediment pulses that occur during thunderstorms. Dam releases produced a third type of sediment releasing event. This was especially apparent at the Tahoe City site, which is just downstream of the Tahoe City dam that regulates flow of the Truckee River from Lake Tahoe.

In the course of the 13 month data record, each site had a different number of sediment events (in order of decreasing numbers): Bridge 8 had 94 events; Farad had 74 events; Near Truckee had 33 events; and Tahoe City had 6 "regular" events, and 10 "dam" events. It should be noted that each site had missing data, usually at different time periods, which hampers interpretation of these data. Even so, it is remarkable that Bridge 8 had nearly twice the number of days of missing data as the nearest downstream site, Near Truckee, yet Bridge 8 had three times the number of sediment loading events at Near Truckee. This implies frequent loading of sediment from tributaries or other sources above Bridge 8, which settles out before reaching Near Truckee.

The minimum detectable event produced a suspended sediment load of 0.3 tons at Tahoe City and between 1.5 and 2.8 tons at other sites. The maximum sediment loads during a single event were, in order of decreasing loads: 2,762,152 tons at Farad June 1-2, 2002; 227,869 tons at Bridge 8 June 7-9, 2003; 106,812 tons at Near Truckee May 29-30, 2003; and 27 tons at Tahoe City July 29-30, 2003.

The diurnal signal of sediment loading during snowmelt was most regular and pronounced at Near Truckee, with the load varying an order of magnitude between the low (~2 pm) and the peak (~11pm). For example, the sediment load at Near Truckee varied between ~38 tons/hour and ~952 tons/hour during a diurnal cycle on June 7, 2003. While the diurnal sediment load cycle was also regular at Tahoe City, the difference between low and peak is much less (~0.008 tons).

Events at Tahoe City also included different regimes of water release at the dam, determined by obvious breaks in slope of the average daily loading. These "dam" events were typically much longer in duration, ~5 to 39 days, with higher event loads of up to ~1,000 tons, than "regular" (e.g., thunderstorm) events which lasted ~1 day, and less than 28 tons per event. The higher loads of dam events were in part due to the long durations of these events.

The sediment loading of individual events, considering all sites together, exhibited a near normal distribution, with events producing between 64 and 256 tons of sediment being the most frequently occurring. The highest frequency of sediment event durations, were in the 25 to 38-hour range, that is about a day to a day and a half. The dominance of this temporal signal is in part due to the snowmelt events, which tended to follow a diurnal melting and loading pattern. Intensity of events (tons/hour) occurred most frequently in the 1 to 8 tons/hour range. The four sites differed in the event intensity. In order of event intensity, from lowest to highest were Tahoe City in the 0.25 to 2 tons/hour range; Bridge 8 in the 1 to 4 tons/hour range; Farad in the 2 to 16 tons/hour range; and Near Truckee in the 256 to 1,024 tons/hour range. In other words, Near Truckee had more loading in less amount of time than the other sites.

Temporal and Spatial Variation of Turbidity

The temporal turbidity analysis consisted of calculating summary statistics including mean, median, maximum, and minimum turbidity during snow melt, summer storms, rain-on-snow events, and base flow. An estimate of the autocorrelation function for turbidity was also included, which demonstrates persistence and any long-range dependence of turbidity time series. In addition to examining the temporal characteristics of turbidity, spatial turbidity patterns were also explored, for a possible dependence and/or relation between turbidity at different sites. If such a relationship were established, it could be used to predict turbidity at other stations.

Turbidity was relatively low in late fall and winter and increased during the snow melt period. Volatility (spikiness) was the highest in summer and fall. Average daily turbidity was significantly correlated between spatially adjacent stations (i.e., immediate up and down stream stations), during some seasons, for some pairs of stations. In some cases, correlations were improved when lag functions were introduced. Autocorrelation analysis of the turbidity time series showed that the persistence patterns of high turbidity were different in all locations and also differed by season. In general, turbidity conditions persisted longer at Tahoe City during the winter and spring seasons than at Bridge 8, Near Truckee, or Farad.

Recommendations

The predictive models developed here were based on relatively few high turbidity observations compared to those with moderate turbidity. To improve on the predictive equations, we recommend obtaining more time matched SSC and field turbidity samples at high turbidity levels. Further analysis of the differences (e.g., goodness of fit and diagnostic tests) between models with different numbers of explanatory variables (e.g., from turbidity only) may prove useful. Model development would also be improved by the addition of flow data at Bridge 8. More frequent maintenance of the turbidity sensors would improve the temporal data record, and allow the calculation of annual sediment loads.

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CHAPTER 1: INTRODUCTION

The principal goal of the Truckee River suspended sediment study was to estimate the sediment load for the Truckee River in California, and to characterize the existing range of sediment loads and variability according to total amount, maximum, duration, timing and frequency of sediment transport events. Our primary objective in support of this goal was to develop a sediment surrogate that could be measured continuously in the Truckee River. This work supports development of numeric targets and load allocations for the Truckee River sediment Total Maximum Daily Load (TMDL) in California.

The report is divided into three chapters: 1) Develop models to predict suspended sediment concentrations from multiple variables, including turbidity; 2) Estimate suspended sediment loads; and 3) Assess of spatial and temporal properties of turbidity. The main tasks in each chapter are:

Prediction of Suspended Sediment Concentrations

- Analyze statistical relationships between individual variables
- Predict suspended sediment concentration from turbidity, flow, water temperature and specific conductivity, and analyze error and confidence intervals
- Identify information needed to improve the predictive power of the relationship between suspended sediment concentrations and explanatory variables

Suspended Sediment Load Calculations

- Calculate suspended sediment concentration calculations, using predictive equation developed in the Prediction of Suspended Sediment Concentrations
- Calculate suspended sediment loads
- Determine characteristics of suspended sediment events

Assess Temporal and Spatial Properties of Turbidity.

- Analyze temporal and spatial properties of turbidity over the entire season
- Analyze temporal and spatial properties of turbidity during different seasons
- Analyze temporal and spatial properties of high turbidity period

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CHAPTER 2: PREDICTION OF SUSPENDED SEDIMENT CONCENTRATIONS

Introduction

Transport changes in suspended sediment concentration (SSC) due to natural or human-induced causes are difficult to characterize because SSC varies rapidly and unpredictably during storm events. Capturing the extreme variation in SSC during storms requires sampling at high temporal frequency, which is usually impractical and expensive. As such, easier-to-measure surrogate variables are monitored continuously with in-situ instrumentation (e.g., Hasholt, 1992). Previous studies (Leopold and Maddock, 1953; DRI, 2001) have shown a strong relationship between SSC, turbidity, and stream flow. It has been found that turbidity is a much better predictor than water discharge for estimating SSC (Lewis, 1996). The preferred method of turbidity measurement is with Nephelometric turbidimeters, which measure light scattered at an angle (APHA, 1985).

In addition to particle size distribution and color, turbidity is also affected by particle shape, composition, water color, and organic material in the water column (Gippel, 1995). Temporal variations in these properties, both seasonally and within storm events, can confound turbidity measurements, but adequate relations between field turbidity and SSC can be found in most situations (Gippel, 1995). In previous studies a linear relationship was found to be best for fine sediments (r^2, 0.9999) and nearly as good for fine sands (r^2, 0.995), with a quadratic fit improving the relationship for fine sands (r^2, 0.9997) (Lewis, 1996). Thus, a continuous turbidity record, supplemented with selected measurements of SSC to derive the turbidity-SSC relationship, can provide an efficient and cost effective method for estimating transported suspended sediment loads.

Recent research in the Trout Creek (tributary to Lake Tahoe) watershed indicates that the functional form of the turbidity-SSC relationship may be different for low and high turbidity intervals (Smolen *et al*., 2002). Preliminary analyses also revealed a relationship between turbidity and water temperature. Although the causes of this relationship are not certain, during the high flows of spring runoff, when temperatures are low, the amount of sand suspended in the water column likely increases, producing an increased turbidity signal. However, studies by Lewis (1996) and Foster *et al*. (1992) have shown that the sensitivity of nephelometric turbidimeters to fines is much greater than to sands. The Trout Creek study shows that a stream flow of 30 cfs resulting from spring snowmelt may be associated with a different suspended sediment concentration than a stream flow of 30 cfs from a late-summer thunderstorm. It is this non-uniqueness of the stream flow–SSC relationship that warrants inclusion of temperature, in addition to turbidity and flow, in the analysis.

Statistical regression methods have been successfully used by the USGS (2000c) to establish a relationship between sediment and turbidity for the Little Arkansas River in Kansas. The USGS (2000c) method was a simple (i.e., parametric and univariate) regression of logarithm of TSS on logarithm of NTU. Their results are encouraging and in general terms are consistent with results from Trout Creek (Smolen *et al*., 2002). Our project builds on and extends the USGS (2000c) work in the choice of the general class of statistical modeling techniques-regression methods. We used our experience from the Tahoe basin and statistical sophistication to extend the USGS (2000c) analysis in four ways. First, we used multivariate regression techniques. This allows for inclusion of multiple variables characterizing the river processes, such as flow and temperature, to the model. Second, since the Truckee River is expected to have much more variability in sediment and turbidity than a midwestern river, we explored parametric as well as nonparametric (robust) statistical techniques. Third, since there is evidence from the Trout Creek study that the relationship between turbidity and sediment may be nonstationary, we used local regression models. These allowed for different functional relations to be built for different parts of the data set that increases the overall fit of the model to the data. Additionally, since extreme sediment discharge events may be of major interest, we made every effort to capture them with our models, and not discard them (before modeling) as outliers. Fourth, we included error estimates (confidence intervals) for the predictions made using our models, which was not part of the USGS (2000c) report.

Methods

The methods used to determine the relationship between suspended sediment and turbidity were correlation analysis and Multiple Linear Regression (MLR). Correlation analysis focuses on finding relationships between variables. The two main types of relationships we can assess are linear and monotonic relationships. The strength of linear association between variables is typically measured using Pearson correlation coefficient. Monotonic relationship between x and y means, that as x increases, y increases (increasing relation) or as x increases, y decreases (decreasing relation). The strength of a monotonic association is often measured using Kendall and/or Spearman correlation coefficients. For a casual reference on the statistical methods described here, please see Helsel and Hirsh (2002). For a rigorous mathematical treatment of linear statistical models and methods, please see Johnson and Wichern (1992).

<u>Multiple Linear Regression (MLR)</u>

Multiple Linear Regression is a statistical tool for development of linear functional relationships between a response (y) and several explanatory variables (x_1, … ,x_n). Such a relationship is assumed to be of the following linear form:

$$y = a_1 * x_1 + \ldots + a_n * x_n + e \qquad (2.1)$$

where a_i's are real coefficients, and e is a random error term. The random error is usually assumed to have a normal distribution with mean zero and variance σ^2. For a sample of observations, random errors are also assumed to be independent and identically distributed. We modeled SSC (response) as a linear function of four explanatory variables: turbidity, flow, water temperature, and specific conductivity.

Whenever mathematical modeling is done, one needs to consider two main characteristics of a "good" model. First, the model needs to satisfy the practical goals for which it was designed. Second, the mathematical assumptions under which the model is constructed have to be satisfied. From the practical point of view, our model needs to predict SSC from the explanatory variables as well as possible and the prediction error needs to be as small as possible. Thus, this part of model analysis is directly related to assessment of the prediction error.

<u>Goodness of Fit of Regressions</u>

From a practical point of view, goodness of fit of an MLR model is equivalent to small prediction errors. We have several measures of a MLR fit including: multiple R^2, correlation between the fitted (model predicted) and observed values of the response, mean or median of the residuals, residual standard error, and a "model utility" F-test. Multiple R^2 has a common interpretation as the percentage of total variability in the response that is accounted for by the variability in the predictors via the MLR model. The range of values for multiple R^2 is between 0 and 1. A good model has multiple R^2 close to 1. The linear Pearson correlation between fitted and observed values is between -1 and 1 with a good model having it close to 1.

Residuals and Confidence Intervals in Regression

Residuals are the differences between the observed and fitted values of the response. A good model has small absolute values of the residuals and small residual variance. Mean, or median residuals give us an idea about the size of a typical/average error and residual standard error provides a measure of error variability. Both absolute value of mean/median residual and standard error of the residuals should be small for a good model. The residuals are used for computation of confidence and prediction intervals, and thus are directly associated with accuracy of predictions.

The length of a confidence interval (CI) for the mean response for a given set of values of the explanatory variables depends on the standard error of the residuals. The larger the standard error, the longer the CI, the less accurate the model. A prediction interval (PI) for the response for a given set of predictors is an interval that measures accuracy of the prediction of an individual (one) response. For comparison, a CI measures accuracy of the prediction of mean response. For a given level of confidence, a prediction interval is always longer than the confidence interval. That difference follows from the fact that variability of the mean is smaller than variability of an individual observation. The "model utility" F-test is a statistical test of significance which tests if the MLR model explains significantly more variability in the response than no model at all. It is a common test performed on any MLR model.

To check if the statistical assumptions for MLR are satisfied, we evaluate residuals for normality, independence and constant variance. That is accomplished using residual analysis, which is done mostly graphically. Normality is evaluated by looking at the normal probability plot. If the probability plot is fairly straight we conclude that the normality assumption is satisfied. Constant variance of the residuals is evaluated using several graphs. Typically, we plot the residuals against the response, the order of the observations, and explanatory variables. In this work plotting residuals versus the order of observations would not be informative because the observations do not follow any specific order. Presence of any patterns/trends in these plots precludes independence, normality, or constant variance of the errors.

Transformations in Regression

When fitting a linear model, we often observe some problems with the statistical assumptions. Among the most common are: non-normality of residuals, non-constant variance of residuals and clustering of the response. To remedy residual distribution problems, we often transform the response. A popular transformation that often helps is natural logarithm of the response variable. Once the response is transformed, we fit the model to the new (transformed) response. We can come back to the original response using the inverse transformation. That way we can use a model fit for a transformed response to "recover" predictions for the original one. The downside of transformations is that confidence intervals for the mean prediction for the original variable are very difficult to obtain from the model fit on a transformed response. Prediction intervals are in general easier to get. The main benefit of a transformation is a model that is sound statistically, so that we can perform inference on it.

Dummy Variables in Regression

Another common problem with data sets is clustering on scatter plots of the response versus some (all) explanatory variables. When that happens, we typically use piecewise regression that produces different regression equations for different groups/clusters of the data set. This is often done by introducing dummy variable(s)-qualitative variables that represent/separate groups of data. Dummy variable approach is useful and often practical because it enables a single regression equation to represent multiple groups of data. The dummy variables act like switches that turn various parameters/variables on and off in an equation. Another advantage of a numerically coded dummy variable (e.g., 0 or 1) is that even though it is nominal we can treat it statistically like an interval variable. How do we find the optimal definitions of clusters? Usually, we use a decision rule that employs a measure of fit. The clusters that give the best value of the measure of fit are used for further analysis. In our case, we relied on multiple R^2 value as a measure of fit. We fit regression to data sets with different clusters and choose the clusters that give the best linear fit as measured by the multiple R^2.

Probability Values

We report probability, or p-values for all tests of significance. A p-value smaller than a user-chosen significance level leads to rejection of the null hypothesis. Common levels of significance in the sciences range from 5% to 10%.

Field and Data Methodologies

A detailed discussion of methods and data sources for turbidity, suspended sediment, water temperature, stream flow and conductivity can be found in Chapter 3. At the time flow data was downloaded from the USGS web site, it was still considered preliminary by the USGS. Data collected at four locations were used in the analyses: Tahoe City (TC), Bridge 8 (B8), Near Truckee (NT) and Farad (F) (see Figure 3.1). For all sites the following apply with exceptions noted: continuous turbidity (NTU) was collected in the field and recorded every 15 minutes; temperature is water temperature (^oC) measured in the field and recorded every 15 minutes; flow is instantaneous streamflow at the USGS gage ($ft^3\ s^{-1}$) and recorded every 15 minutes (at TC, NT and F only); suspended sediment concentrations (SSC) ($mg\ l^{-1}$) and laboratory NTU are from DRI integrated field samples collected on specific dates during the study.

The relationship between SSC and NTU (and flow, water temperature and specific conductivity) was analyzed on time-matched measurements done at the finest time scale permitted by the data. Data for this analysis is presented in Appendix A1.

Results

Determining the relationship between suspended sediment concentration, continuous turbidity, flow, water temperature, and specific conductivity was composed of three components:

- Analyze statistical relationships between individual variables
- Predict suspended sediment concentration from turbidity, flow, water temperature and specific conductivity, and analyze error and confidence intervals

- Identify what information is needed to improve the predictive power of the SSC-NTU (and other variables) relationship.

<u>Analyze Statistical Relationship between Variables</u>

As a first step in constructing a model for predicting SSC we examined the relationship between variables to be included in the multiple regression analysis: between SSC and laboratory NTU (NTUlab); between SSC and continuous NTU (NTU); and between stream flow (flow) and continuous turbidity. In addition we examined the relationship between laboratory NTU and continuous NTU.

Determine Relationship between SSC and Laboratory NTU

This analysis included data from all four sites. There is a strong statistically significant linear/monotonic relation between SSC and laboratory NTU. The correlation coefficients estimated from the data from all sites analyzed together, with the p-values for testing if they are significantly different from zero are: Pearson = 0.98 (p-value = 0), Kendall = 0.51 (p-value = 0), Spearman = 0.69 (p-value = 0). The p-values show that all three correlation coefficients are significantly different from zero. That means that the relation between SSC and NTUlab is monotonic (close to linear). We fitted a linear model for SSC as a function of NTUlab, but the linear fit was not appropriate because of problems with residuals (errors) distribution. In an effort to "normalize" the residuals, we took the natural logarithm of the SSC (ln(SSC)) as the new response variable.

Further, we observed two clusters on the scatter plot of ln(SSC) against NTUlab (Figure 2.1). The clusters corresponded to different ranges of NTUlab values. To accommodate clustering in the model, we introduced a dummy/indicator variable based on values of NTUlab. The dummy (NTUlabind) had value 1 for NTUlab <10 and 0 otherwise. The choice of 10 as the boundary between the two indicator values was based on maximum multiple R^2 for any model with that type of indicator. To summarize, when NTUlab < 10 then NTUlabind = 1 and when NTUlab ≥ 10 then NTUlabind = 0.

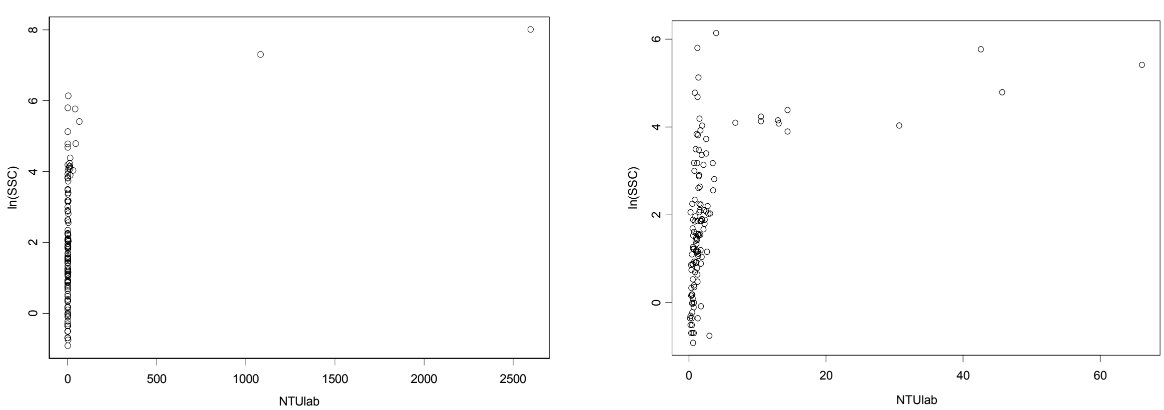


Figure 2.1. Scatter plots of ln(SSC) and NTUlab for all sites. *Left panel*: Full data set. *Right panel:* Close-up of the data showing clusters with NTUlab restricted to less than 500.

We also took into account the interaction between the laboratory NTU and NTUlabind and obtained the following general model:

$$ln(SSC) = 4.5107 + 0.0015*NTUlab – 3.8920*NTUlabind + 0.7459*NTUlab *NTUlabind \quad (2.2)$$

Substituting 0 or 1 for the dummy variable, we separate models depending on NTUlab. The model for ln(SSC) when NTUlab < 10 (NTUlabind = 1) is:

$$ln(SSC) = 0.6187 + 0.7474*NTUlab \quad (2.3)$$

and when NTUlab ≥ 10 (NTUlabind = 0) the model is:

$$ln(SSC) = 4.5107 + 0.0015*NTUlab \quad (2.4)$$

The multiple R^2 for this MLR model is 0.51, so the variability in laboratory NTU explains about 51% of variability in SSC. The “model utility” F- test has p-value = 0, so the model is statistically significant. Furthermore, the correlation between the observed and fitted values of ln(SSC) was 0.714 (Figure 2.2). The diagnostic plots (Figure 2.3) do not show any drastic departures from the statistical assumptions, so we conclude this a reasonable model.

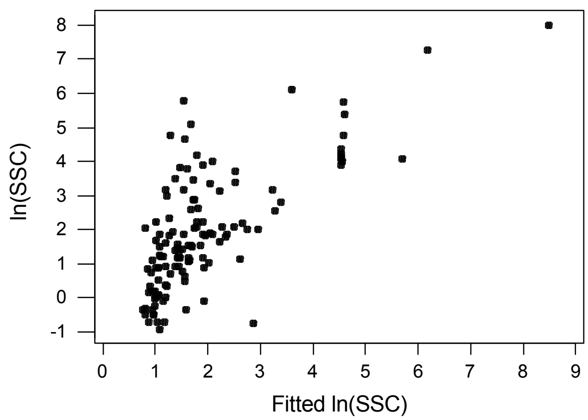


Figure 2.2. Scatter plot of observed and model predicted (fitted) ln(SSC) from NTUlab.

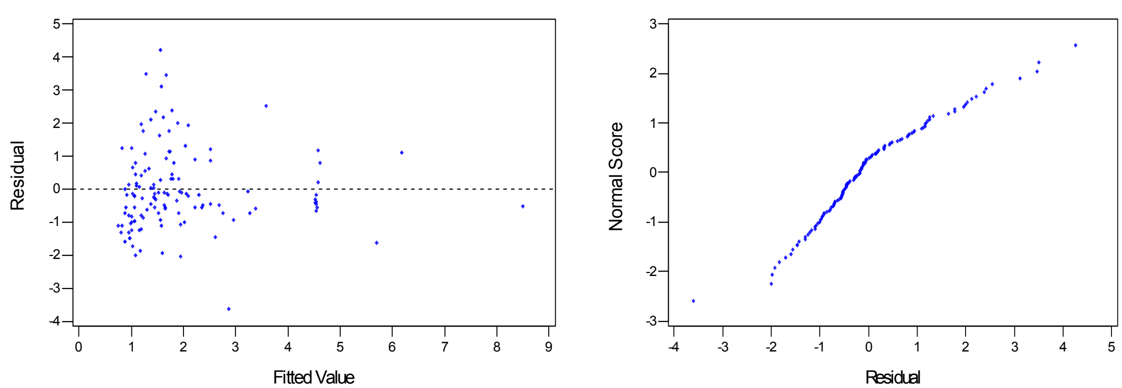


Figure 2.3. Standard diagnostic plots for model predicted ln(SSC) from NTUlab. *Left panel*: MLR residuals versus fitted values of ln(SSC). *Right panel*: Normal score plotted against residuals.

Determine relationship between SSC and continuous NTU

We started with a study of correlations between SSC and continuous NTU, using Pearson, Kendall and Spearman correlation coefficients. The correlation coefficients estimated from the data from all sites together with the p-values for testing if they are significantly different from zero are: Pearson = 0.80 (p-value = 0), Kendall = 0.47 (p-value = 0), Spearman = 0.64 (p-value = 0). The p-values show that all three correlation coefficients are significantly different from zero. That means that the relation between SSC and laboratory NTU is monotonic (in fact close to linear), so a linear model might be appropriate; and the conclusions mimic those for SSC and laboratory NTU above.

Determine relationship between stream flow and turbidity

We determined the correlation between instantaneous and daily mean flow (ft^3/s) and NTU at TC, NT and F for the entire study period and for all seasons. B8 was excluded from this analysis because we did not have flow data for B8. The correlation between flow and NTU is generally low except for spring and fall (Table 2.1).

Table 2.1. Correlations between flow and NTU for all locations and seasons. 'Instant' is the correlation between NTU and instantaneous flow (ft^3/s); 'Daily' is the correlation between daily mean flow and NTU.

	TC		NT		F	
	Instant	Daily	Instant	Daily	Instant	Daily
Winter	0.013	-0.13	0.332	0.399	-0.33	-0.119
Spring	0.072	-0.306	0.509	0.572	0.039	-0.287
Summer	0.017	0.163	0.017	-0.012	0.182	0.185
Fall	0.104	0.192	0.315	0.341	-0.182	-0.11
Entire study period	0.052	0.136	0.190	0.231	-0.101	-0.218

Determine relationship between laboratory NTU and continuous NTU

The data consists of all measurements of laboratory NTU and the corresponding measurements of continuous NTU. The analysis was done for all sites. The Pearson correlation coefficient between continuous NTU and laboratory NTU was 0.81 (p-value = 0), which indicates a significant correlation between laboratory and continuous NTU. Correlation between continuous NTU and laboratory NTU for TC was 0.11 (p-value 0.63), for B8 was 0.36 (p-value 0.084), for NT was 0.97 (p-value 0), and for Farad was 0.84 (p-value 0). To summarize, the correlation between continuous NTU and laboratory NTU was significantly different from zero for the combined data (all sites) and for B8, NT and Farad but it was not significantly different from zero at TC. The correlation analysis shows lack of spatial consistency in the relationship between continuous NTU and laboratory NTU.

Linear models for continuous NTU as a function of laboratory NTU

For the combined data from all sites, we first plotted the natural logarithm of the continuous NTU (ln(NTU), against the laboratory NTU and we observed two clusters on the scatter plot (Figure 2.4). The standard remedy of a dummy variable based on values of NTUlab did not help in this case. That is because the models for the two ranges of NTUlab were very different. To allow for these differences, we built separate models for the two different clusters. The clusters were defined by NTUlab values: cluster 1: NTUlab<10; cluster 2: 10 ≤ NTUlab <100. That left two extremely large observations out of the modeling effort. To summarize, we present two linear models for continuous NTU as a function of laboratory NTU. None of the models works for NTUlab ≥ 100.

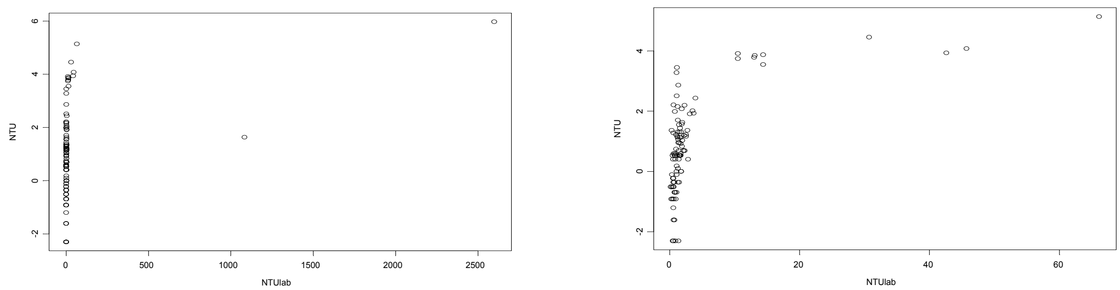


Figure 2.4. Scatter plots of continuous NTU ln(NTU) and NTUlab for all sites. *Left panel*: Full data set. *Right panel*: Close-up of the data showing clusters with NTUlab restricted to less than 100.

Our first model was for values of NTUlab < 10. To find out if the relationship between ln(NTU) and laboratory NTU (NTUlab < 10) is the same for all sites, we performed analysis of covariance using site indicator as an additional explanatory variable. Site appears as a significant predictor (p-value=0), and we conclude that the relation between continuous NTU and laboratory NTU is not the same for all sites. Thus, we ran the regression of ln(NTU) on NTUlab and site as explanatory variables. Since there are four sites, we used three indicator variables (B8, NT and F) and obtained the following general model:

$$ln(NTU) = 0.7234 + 0.3879*NTUlab -1.4093*ind.tc -0.9816*ind.b8-0.9947*ind.nt. \quad (2.5)$$

From this general model, we can derive specific models for each site:

For TC, the model is:

$$ln(NTU) = -0.6859 + 0.3879*NTUlab \quad (2.6)$$

For B8, the model is:

$$ln(NTU) = 0.3355 + 0.3879*NTUlab \quad (2.7)$$

For NT, the model is:

$$ln(NTU) = -0.9947 + 0.3879*NTUlab \quad (2.8)$$

For F, the model is:

$$ln(NTU) =-0.7234 + 0.3879*NTUlab \quad (2.9)$$

The median residual for this model is -0.0773, the residual standard error is 0.9447, and the multiple R^2 =0.4, so the variability in laboratory NTU and sites explains about 40% of variability in continuous NTU. We now report the partial t-tests' p-values for each variable: NTUlab (0.0107), ind.tc (0), ind.b8 (0.0009), and ind.nt (0.0005). The "model utility" F-test was significant with p-value 0. The correlation between the observed and fitted values of ln(NTU) was 0.6324 (p-value=0) (Figure 2.5). The model is also reasonable from the statistical point of view, as evidenced by the two standard diagnostic plots (Figure 2.6).

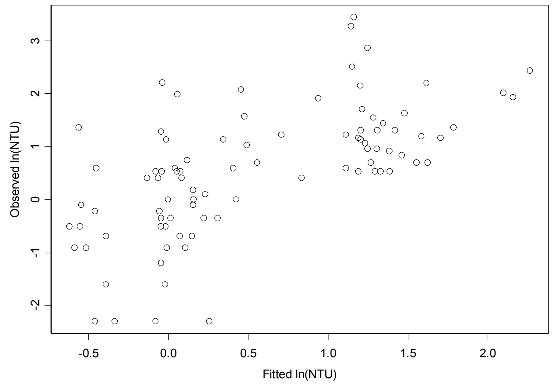


Figure 2.5. Scatter plot of observed and model predicted (fitted) values of continuous NTU ln(NTU) from NTUlab for NTUlab values < 10.

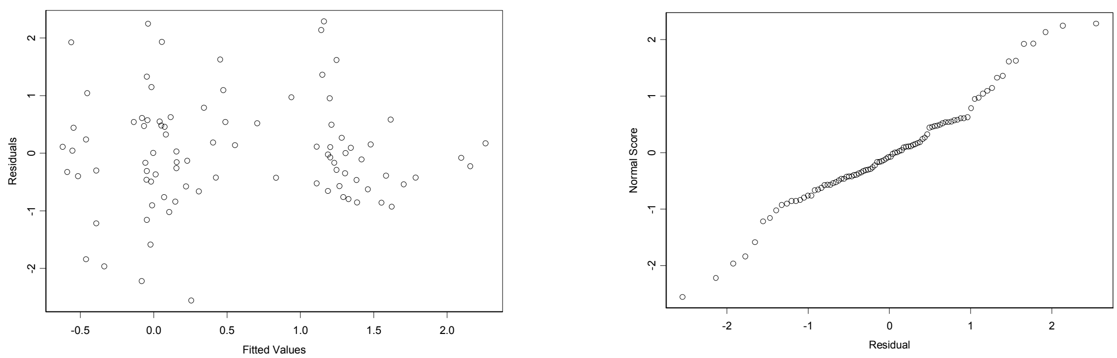


Figure 2.6. Standard diagnostic plots for model of continuous NTU ln(NTU) as a function of NTUlab for NTUlab values < 10. *Left panel*: MLR residuals versus fitted values of ln(NTU). *Right panel:* Normal score versus residuals.

Our second model was for values of 100>NTUlab ≥ 10. We excluded the two largest observations (NTUlab ≥ 100) from modeling because they did not follow the pattern present for NTU <100, and there were two few of them to build a third model. We have observations of NTU ≥ 10 only at NT and F. To find out if the relationship between ln(NTU) and laboratory NTU is the same for NT and F, we performed analysis of covariance using site indicator as an additional explanatory variable. The indicator of TC is a significant predictor (p-value=0.0122), and we conclude that the relation between continuous and laboratory NTU is different at NT than at F. Thus, we run the regression of ln(NTU) on NTUlab and site (NT, ind.nt) as explanatory variables and obtained the following general model:

$$ln(NTU) = 2.905 + 0.0301*NTUlab + 0.5688*ind.nt. \qquad (2.10)$$

To summarize, we display the models by site:

For NT the model is:

$$ln(NTU) = 3.4738 + 0.0301*NTUlab \qquad (2.11)$$

For F the model is:

$$ln(NTU) = 2.905 + 0.0301*NTUlab \quad (2.12)$$

The median residual for this model is -0.0272, the standard error of the residuals is 0.1837, the multiple $R^2 = 0.87$, so the variability in laboratory NTU and site explains about 87% of variability in NTU. The “model utility” F-test has p-value = 0.0007, so the model is statistically significant. The correlation between the observed and fitted values of ln(NTU) is 0.934 (p-value = 0.0001) (Figure 2.7). The model is also reasonable from the statistical point of view (Figure 2.8).

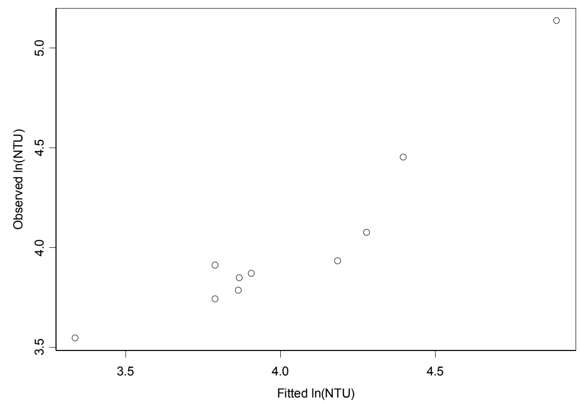


Figure 2.7. Scatter plot of the observed and model predicted (fitted) values of ln(NTU) from NTUlab for 10<NTUlab<100.

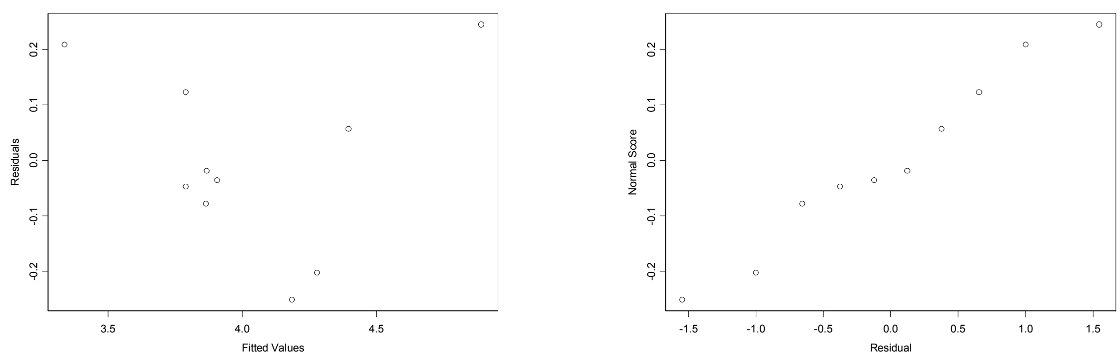


Figure 2.8. Standard diagnostic plots for model predicted continuous NTU ln(NTU) from NTUlab for 10<NTUlab<100. *Left panel:* MLR Residuals versus fitted values of ln(NTU). *Right panel:* Normal score versus residuals.

<u>Predict Suspended Sediment from Turbidity, Flow, Water Temperature and Specific Conductivity</u>

In this section we develop a multiple linear regression model (MLR) for predicting SSC from various combinations of continuous NTU, water temperature, stream flow and specific conductivity:

a) Full model: turbidity, flow, water temperature and specific conductivity;

b) Turbidity, water temperature and specific conductivity;

c) Flow only; and

d) Water temperature only.

Models with fewer predictive variables were explored because it is often the case that only one or two (e.g., flow, temperature) of these variables are measured continuously in the field. A "good" model (as described above in Methods) with few predictive variables could be very useful for future studies.

Models to predict SSC from four explanatory variables: continuous turbidity, flow, water temperature, and specific conductivity

Model development

Before fitting a linear model, we computed Pearson correlation between SSC and flow (0.17, p-value = 0.09); between SSC and water temperature (temp) (0.19, p-value = 0.04) and between SSC and specific conductivity (spcond) (0.003, p-value = 0.97) for this data set. Flow, temperature and conductivity are not significantly correlated with SSC. In fact, the best linear model for SSC as the response had serious problems with statistical properties. In particular, we observed non-normality of the residuals. Additionally, we observed clustering of the SSC data versus values of NTU, (Figure 2.9). Taking ln(SSC) as the new response and introducing dummy variable (NTUind) indicating different clusters of the data (different ranges of NTU values) took care of clustering and the distribution of the residuals. We chose the indicator so that the multiple R^2 for the resulting model was maximized. The cutpoint giving maximum R^2 was NTU = 10. Thus, NTUind was set to 1 for values of the NTU less than 10, and otherwise set to 0. To summarize, when NTU < 10 then NTUind = 1 and when NTU ≥ 10 then NTUind = 0.

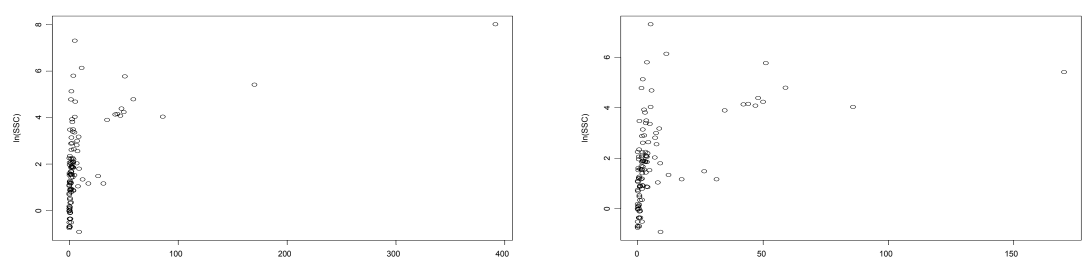


Figure 2.9. Scatter plots of ln(SSC) and continuous NTU for all sites. *Left panel*: Full data set. *Right panel*: Close-up of the data showing clusters with NTU restricted to smaller than 200.

We also checked if lagging flow would improve the model. Moving flow 120 minutes later than time of SSC sample was the best. Our criterion for "best" was the highest correlation between lagged flow and ln(SSC). Finally, we modeled the natural logarithm of the SSC (response) as a linear function of continuous NTU, the indicator variable (NTUind), flow120l (flow recorded 120 minutes later than SSC), water temperature and conductivity. We took into account the interaction between NTUind and each of the explanatory variables. We obtained the following model for all values of NTU:

$$ln(SSC) = 9.4582 – 10.5726*NTUind + 0.0085*NTU + 0.0082*flow120l – 0.1773*temp – 76.1543*spcond + 0.0467*NTUind*NTU - 0.0047NTUind*flow120l+0.2135*NTUind* temp + 85.2155*NTUind*spcond \quad (2.13)$$

Separating the models, depending on the values of NTU (using NTUind), produced the following models:

When NTU < 10 (NTUind =1):

$$ln(SSC) = -1.1144 + 0.0552*NTU + 0.0035*flow120l + 0.0362*temp + 9.0612*spcond \quad (2.14)$$

When NTU ≥ 10 (NTUind = 0):

$$ln(SSC) = 9.4582 + 0.0085*NTU + 0.0082*flow120l – 0.1773*temp – 76.1543*spcond \quad (2.15)$$

The median residual for this model was -0.101, the residual standard error was 1.005, and the multiple $R^2 = 0.7315$, so the variability in the explanatory variables explains about 73% of variability in SSC. The "model utility" F-test has p-value = 0. We now report the partial t-tests' p-values for each variable: NTU (0.0154), flow120l (0.0241), temp (0.0993), spcond (0.0001), NTUind (0.0001), NTUind*NTU (0.4406), NTUind*flow120l (0.1914), NTUind*temp (0.0533), and NTUind*spcond (0.0001). Although some variables are not statistically significant, their presence adds to the overall fit of the model, thus we kept them all. We also tested if site was a significant variable. Site turned out not significant, thus the same model applies to all sites.

Analyze error and confidence intervals

To learn about the prediction errors, we analyzed residuals for the final MLR model with four explanatory variables. The median residual was –0.101 and the residual standard error was 1.005. The observed and fitted ln(SSC) values together with 95% Confidence Interval (CI) and 95% Prediction Interval (PI) for the fitted values are presented in Figure 2.10. We see that the fitted values follow the observations closely for observations that are both small and large. The correlation between ln(SSC) and the fitted ln(SSC) = 0.855, with a p-value =0 (Figure 2.11). The fitted values "smooth" the observations. The fitted values together with the observations on all variables and endpoints of the Confidence Intervals (CIs) and Prediction Intervals (PIs) are included in the supplementary EXCEL file (tua2na_to_gayle_all_results.xls).

Statistical assumptions

To check if the full MLR model is reasonable from the statistical point of view, we analyzed diagnostic plots: residuals versus fitted values and normal probability plot of the residuals (Figure 2.12). Plotting residuals versus the order of observations would not be informative in this case, because the observations do not follow any specific order. The plot of the residuals versus fitted values exhibits no pattern, which indicates a rather constant variance of the error. The normal probability plot of the residuals suggests that there is no drastic departure from normality of the error term. Overall we feel that this model is reasonable from the statistical point of view.

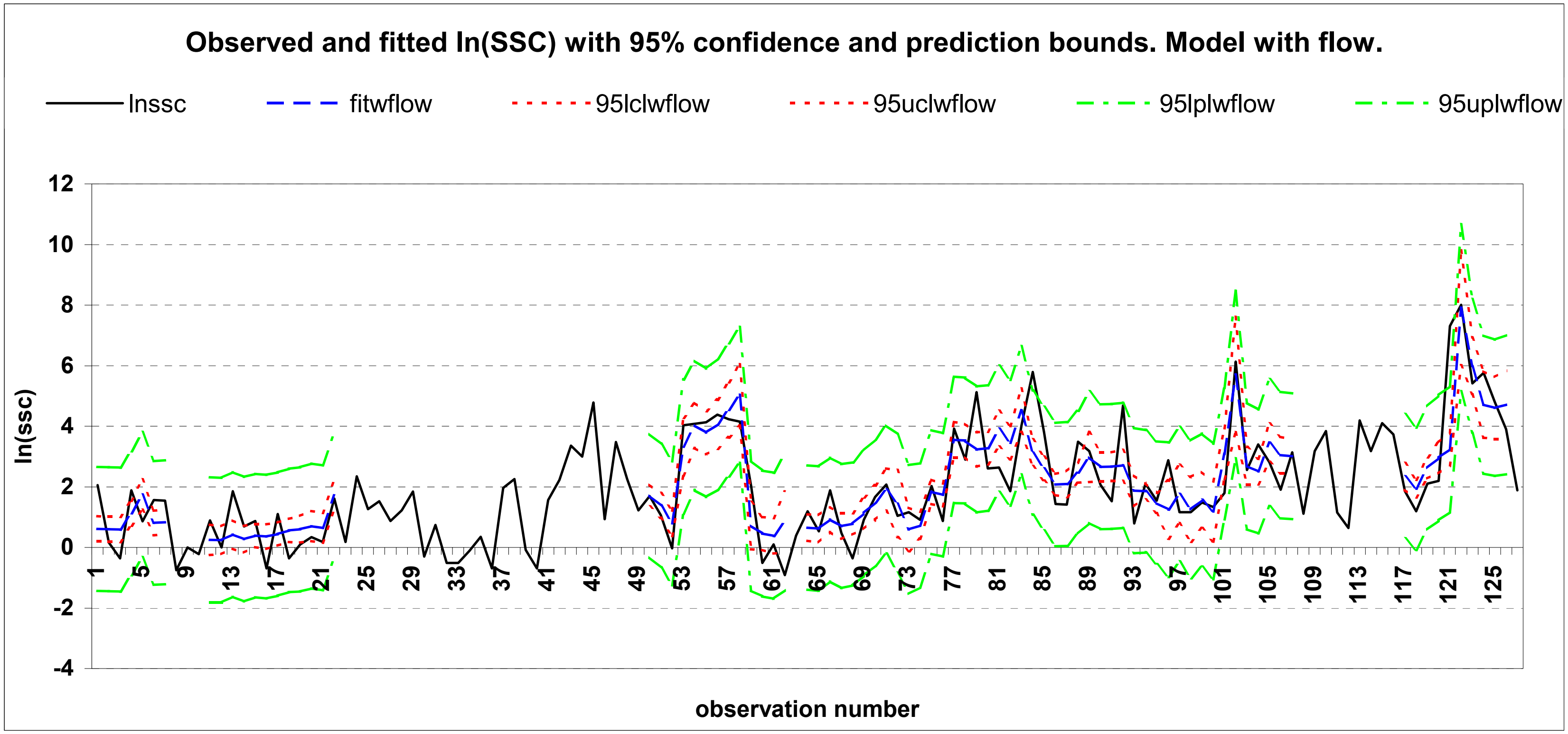


Figure 2.10. Observed and fitted values of ln(SSC) with 95% pointwise confidence (CI) and prediction intervals (PI) for the fitted values using full model with four explanatory variables (NTU, flow, temp, spcond). Variable definitions: “fitwflow” is the predicted value of ln(SSC); “95lcIwflow” is the lower limit of the 95% CI; “95ucIwflow” is the upper limit of the 95% CI; “95lpIwflow” is the lower limit of the 95% PI for predicted value of ln(SSC); “95upIwflow” is the upper limit of the 95% PI for predicted value of ln(SSC).

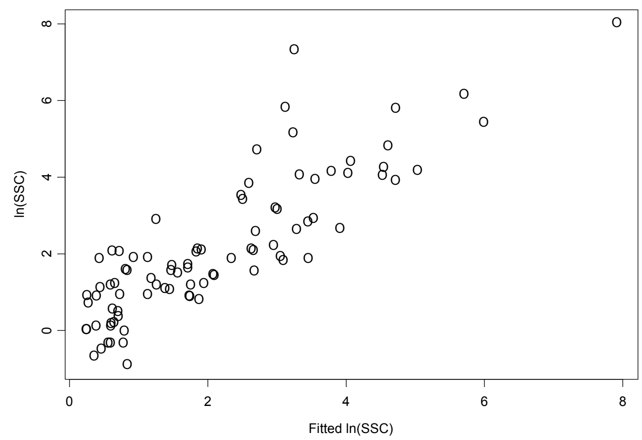


Figure 2.11. Scatter plot of observed and fitted ln(SSC) for model with four explanatory variables.

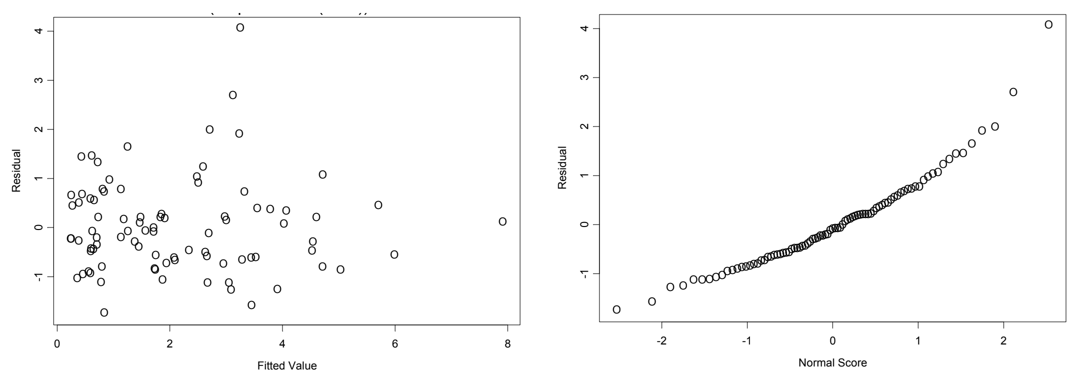


Figure 2.12. Standard diagnostic plots for model predicted ln(SSC) as a function of four explanatory variables. *Left panel:* MLR residuals versus fitted values of ln(SSC). *Right panel:* Normal score plotted against the residuals.

Models to predict SSC from three explanatory variables: continuous turbidity, water temperature, and specific conductivity (no flow)

Model development

We did not have flow measurements for Bridge 8, but we still need a model to predict SSC at that site. Therefore, we fit a model without flow to all available observations. Again, we modeled the natural logarithm of the SSC (response) as a linear function of the continuous NTU, a new indicator variable (NTUind), water temperature and specific conductivity. We chose the indicator variable so that the resulting model has the largest multiple R^2. The new cutpoint for the indicator was NTU=7. We took into account the interaction between NTUind and each of the explanatory variables. Only the interaction between NTUind and NTU was significant. Additionally, we checked if the model should be the same for all sites by adding indicators of three sites (TC, B8, and NT). Site turned out to be significant, making the final model different for different sites. The site indicators are: ind.tc (=1 for TC and 0 otherwise), ind.b8 (=1 for B8 and 0 otherwise), and ind.nt (=1 for NT and 0 otherwise). There is no need for an indicator of F, as that site is defined by all other indicators equal to zero. We obtained the following final model:

$$ln(SSC) = 5.9123 – 1.9249*NTUind + 0.0131*NTU + 0.0356*temp – 30.5481*spcond – 0.3356*NTUind*NTU- 1.1606*ind.tc –0.7554*ind.b8 –0.9614*ind.nt \quad (2.16)$$

The separate models for each site and both ranges of NTU are:

when NTU < 7 (NTUind =1) the models are:

$$For\ TC: ln(SSC) = 2.8268 + 0.3487*NTU + 0.0356*temp –30.5481*spcond \quad (2.17)$$

$$For\ B8: ln(SSC) = 3.232 + 0.3487*NTU + 0.0356*temp –30.5481*spcond \quad (2.18)$$

$$For\ NT: ln(SSC) = 3.026 + 0.3487*NTU + 0.0356*temp –30.5481*spcond \quad (2.19)$$

$$For\ F: ln(SSC) = 3.9874 + 0.3487*NTU + 0.0356*temp –30.5481*spcond \quad (2.20)$$

when NTU ≥ 7 (NTUind = 0) the models are:

$$For\ TC: ln(SSC) = 5.9123 + 0.0131*NTU + 0.0356*temp – 30.5481*spcond-1.1606 \quad (2.21)$$

$$For\ B8: ln(SSC) = 5.9123 + 0.0131*NTU + 0.0356*temp – 30.5481*spcond-0.7554 \quad (2.22)$$

$$For\ NT: ln(SSC) = 5.9123 + 0.0131*NTU + 0.0356*temp – 30.5481*spcond-0.9614 \quad (2.23)$$

$$For\ F: ln(SSC) = 5.9123 + 0.0131*NTU + 0.0356*temp – 30.5481*spcond \quad (2.24)$$

The residual standard error for this MLR is 1.189 with a multiple R^2 of 0.5838, so the variability in the explanatory variables explains about 58% of variability in ln(SSC). The "model utility" F-test has p-value = 0. We now report the partial t-tests' p-values for each variable: NTU (0.0001), temp (0.1312), spcond (0.0009), NTUind (0.0000), NTUind*NTU (0.0009), ind.tc (0.0039), ind.b8 (0.0510), and ind.nt (0.0054). Again, although water temperature is not strictly statistically significant, it adds to the overall fit of the model.

Analyze error and confidence intervals

To learn about the prediction errors, we analyzed residuals for the final MLR model with three explanatory variables. The median residual was –0.208 with standard error of 1.189. The observed and fitted ln(SSC) values together with 95% Confidence Interval and 95% Prediction Interval for the fitted values are presented in Figure 2.13. We see that the fitted values follow the pattern of the observations fairly closely and are of similar magnitude for observations that are both small and large. The correlation between ln(SSC) and the Fitted ln(SSC) = 0.732, with a p-value =0 (Figure 2.14). The fitted values "smooth" the observations.

Statistical assumptions

To check if the MLR model is reasonable from the statistical point of view, we analyzed diagnostic plots: residuals versus fitted values and normal probability plot of the residuals (Figure 2.15). The plot of the residuals versus fitted values seems to exhibit no pattern that indicates a rather constant variance of the error. The normal probability plot of the residuals suggests that there is no serious departure from normality of the error term. Overall we feel that this model is reasonable from the statistical point of view.

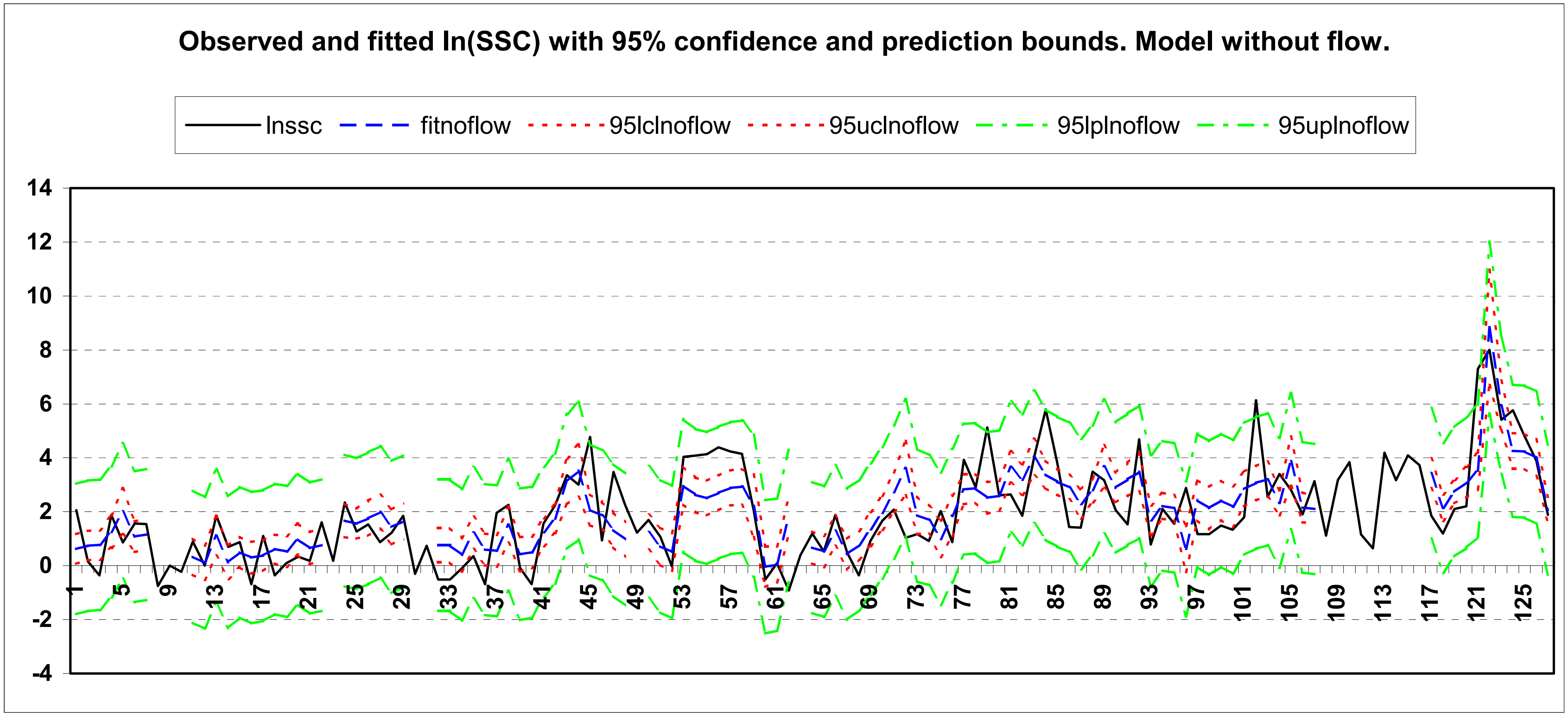


Figure 2.13. Observed and fitted values of ln(SSC) with 95% pointwise confidence (CI) and prediction intervals (PI) for the fitted values using model with three explanatory variables (NTU, temp, spcond). Variable definitions: "fitnoflow" is the predicted value of ln(SSC); "95lcInoflow" is the lower limit of the 95% CI; "95ucInoflow" is the upper limit of the 95% CI; "95lpInoflow" is the lower limit of the 95% PI for predicted value of ln(SSC); "95upInoflow" is the upper limit of the 95% PI for predicted value of ln(SSC).

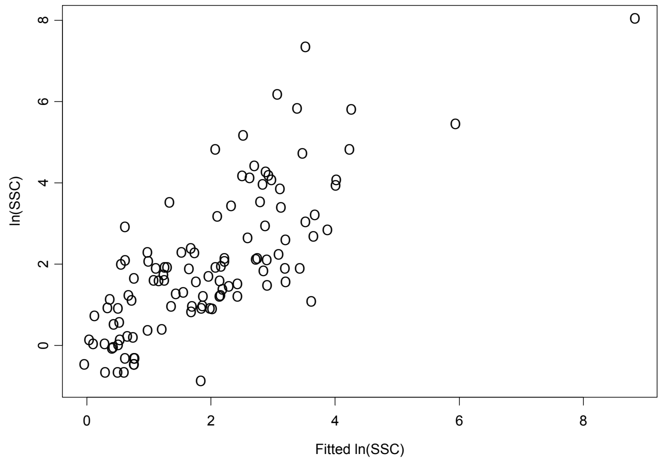


Figure 2.14. Scatter plot of observed and fitted ln(SSC) for the model with three explanatory variables.

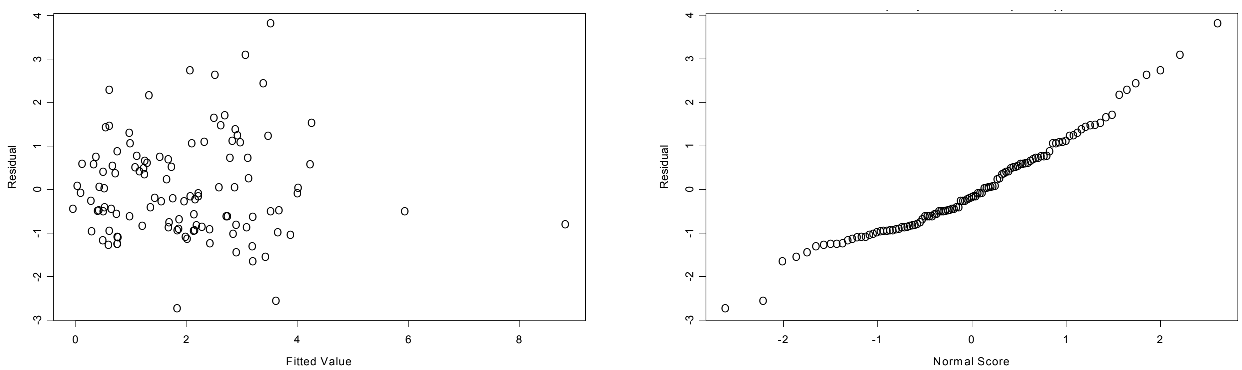


Figure 2.15. Standard diagnostic plots for model predicted ln(SSC) as a function of three explanatory variables. *Left Panel:* MLR residuals versus fitted values of ln(SSC). *Right Panel:* Normal score plotted against the residuals

Models for predicting SSC with flow as the only predictor (TC, NT, F only)

Model development

Modeling results for the model with flow only do not apply to B8, since flow was not available for that site. Our first steps were to fit a model with an indicator of SSC that effectively fit different models to low and high values of SSC. We found that the best breaking point for SSC using the maximum multiple R^2 principle to be 24 mg/L. With that indicator, we looked for the best model with flow as the only other explanatory variable. We also found that site is a significant predictor, so we developed separate indicators for each site. We found a model with very high multiple R^2, but unfortunately unacceptable statistical diagnostics. While searching for the reason why high R^2 coincided with bad statistical properties of the model, we found that the model we built (based on maximizing R^2) essentially worked well only for the low values of SSC (SSC<24 mg/L). That is because our data does not really show any relationship between flow and SSC for high SSC. This is readily observed on the scatter plot of SSC versus flow on Figure 2.16.

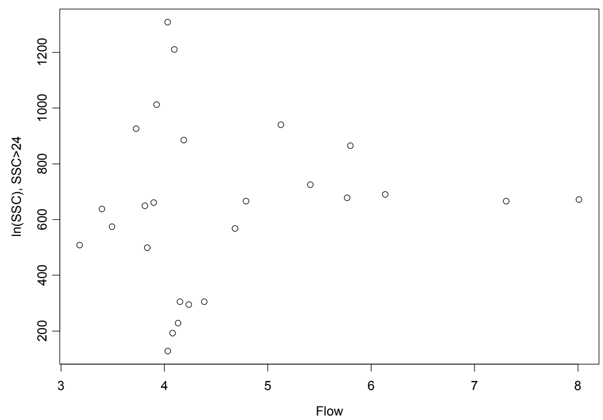


Figure 2.16. Scatter plot of flow versus ln(SSC) for SSC ≥ 24.

Faced with a choice of a good model for low SSC only and a possibly reasonable model for the entire range of SSC, we decided to abandon the path of splitting the models according to SSC and look for a model that would be reasonable for the entire range of SSC values. That led to the following model which maximizes multiple R^2 among all models with flow and site indicators as the only explanatory variables. We also restricted the search to models with relatively significant (p-value less that 0.1) coefficients. The final model has multiple R^2 value of 0.39, median residual of –0.366, residual standard error of 1.406, and the p-value for the overall model significance F-test essentially equal to 0. Unfortunately, the statistical properties of this model, although much better than for the model split according to SSC, still leave a lot to be desired. We show the diagnostic plots later in the section on statistical properties.

The implication of questionable statistical properties of this model include problems with statistical inference. That includes problems with confidence and prediction intervals for predicted ln(SSC). Therefore, although we provide the model predicted ln(SSC) in the data set that includes predictions from all models, we do not list confidence and prediction intervals. The prediction of loads using this model is also questionable. The model that applies to all three locations, TC, NT, and F is:

$$Ln(SSC)=0.9708+ 0.0029*flow-0.7083*ind.tc \quad (2.25)$$

Ind.tc=1 if the observation is from TC, 0 otherwise (that is 0 for NT and F). The separate models for each location are:

$$\text{Model for TC:} \quad Ln(SSC)=0.2625+ 0.0029*flow \quad (2.26)$$

$$\text{Model for NT and F:} \quad Ln(SSC)=0.9708+ 0.0029*flow \quad (2.27)$$

Statistical assumptions

To check if the MLR model is reasonable from the statistical point of view, we analyzed diagnostic plots: residuals versus fitted values and normal probability plot of the residuals (Figure 2.17). The plot of the residuals versus fitted values seems to exhibit no pattern, which indicates a rather constant variance of the error. The normal probability plot of the residuals suggests that there is some departure from normality of the error term. Overall we feel that although this model is statistically significant, its statistical properties are somewhat questionable. That implies difficulties with any statistical inference.

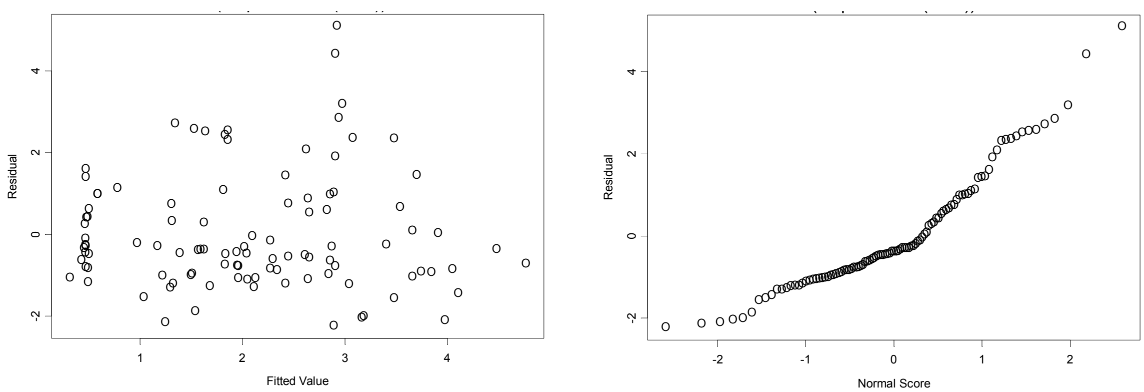


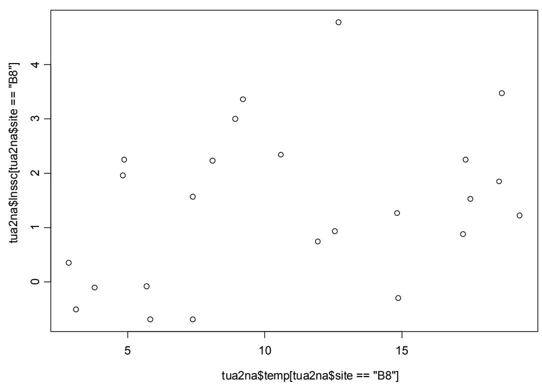
Figure 2.17. Standard diagnostic plots for model predicted ln(SSC) as a function of flow only. *Left panel:* MLR residuals versus fitted values of ln(SSC). *Right panel:* Normal score plotted against the residuals.

Models for predicting SSC with temperature as the only predictor (B8 only)

The scatter plots of water temperature versus SSC and ln(SSC) (Figure 2.18) for B8 show that there is no relationship between them. Thus, we cannot build any models for SSC with temperature as the only explanatory variable.

<u>Information Needed to Improve Predictive Power of the Models</u>

We have several suggestions for how the models presented in this section might be improved. First, we recommend taking more samples with very high NTU values (e.g., during storm events). Note that the models developed here were based on relatively few high NTU observations compared to those with moderate NTU. Second, continuation of regular sampling would provide overall longer data set. Such data could be used to check if the relation between NTU stays stable over time. If not, the models should be adjusted (i.e., derived again) periodically. Further analysis of the differences (e.g., goodness of fit and diagnostic tests) between models with different numbers of explanatory variables may produce useful. Adding reliable flow data for the B8 site would be extremely beneficial for future iterations of model development.



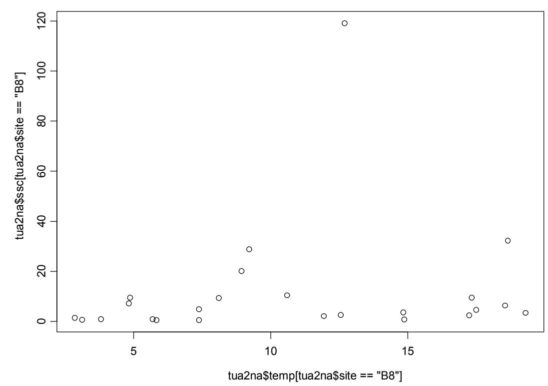


Figure 2.18. Scatter plots of ln(SSC) versus water temperature for Bridge 8 and SSC versus water temperature for Bridge 8. *Left panel:* Scatter plot of ln(SSC) versus water temperature for B8. *Right panel:* plot of SSC versus water temperature for B8.

CHAPTER 3: SUSPENDED SEDIMENT LOAD ESTIMATES

Introduction

Evaluation of suspended sediment loading (SSL) is integral to constructing and implementing the Truckee River sediment TMDL. In this section the loading amounts and variability of suspended sediment is evaluated for four locations on the main stem of the Truckee River between Tahoe City and Farad (Figure 3.1). In addition to calculating loads for longer time periods, loading of specific sediment events (e.g., thunderstorms, snowmelt runoff) was assessed.

The impact of sediment on the beneficial uses and the ecosystems of the Truckee River basin is an important component of TMDL development. For example, a small to moderate load of sediment that occurs over a long time period (e.g., days) may be more detrimental to biota than a very large pulse of sediment that only lasts an hour. Future studies to establish the linkage between sediment loading and beneficial use impairment will benefit from knowledge of the temporal aspects of sediment loading, including timing, frequency, maximum, and duration of sediment.

The original intent was to calculate annual loads for a two year time period during 2001 to 2003. While turbidity data (from which SSC is calculated) are available prior to June 2002 for some stations, the sensors were not calibrated by the Department of Water Resources until June 2002. For this reason the pre 2002 data were not used in the SSC calculations, and the time period evaluated was June 2002 to July 2003. Turbidity data continues to be collected past July 2003, but to allow enough time for statistical analyses and load calculations, the end of July 2003 was selected as an end date for these analyses.

None of the sites had a complete set of turbidity data during the 2002/2003 period, with two to four months of turbidity data missing from each site. This precludes calculation of annual loads. Instead, we present calculation of monthly suspended sediment loads for each site during the June 2002 to July 2003 period. In addition to calculating monthly loads, loading of specific sediment events (e.g., thunderstorms, snowmelt runoff) was assessed.

Methods

Field Measurements

Field collections included continuous measurements of turbidity, water temperature and specific conductivity by the California Department of Water Resources (CalDWR) at four sites on the main stem of the Truckee River (Figure 3.1). The four sites were Farad, Near Truckee, Bridge 8 and Tahoe City. It should be noted that a suitable sampling platform is lacking at the Farad site, but fortunately, sediment samples can be collected 2.5 miles upstream at Floriston, which is also the site where SSC samples were collected for the DRI (2001) study. All sites, except Bridge 8, were co-located with discharge gaging sites operated by the United States Geological Survey (USGS). In an attempt to obtain flow from Bridge 8, DRI installed a pressure transducer and data logger to provide continuous measurements of stage. To convert stage to flow, DRI also made discharge measurements at different flow levels with a Marsh-McBierny flow meter to obtain a rating curve. Unfortunately, both the pressure transducer and data logger, which were equipment, borrowed from another DRI source, failed repeatedly. The outcome is that only a spotty record of useable stage data were collected.

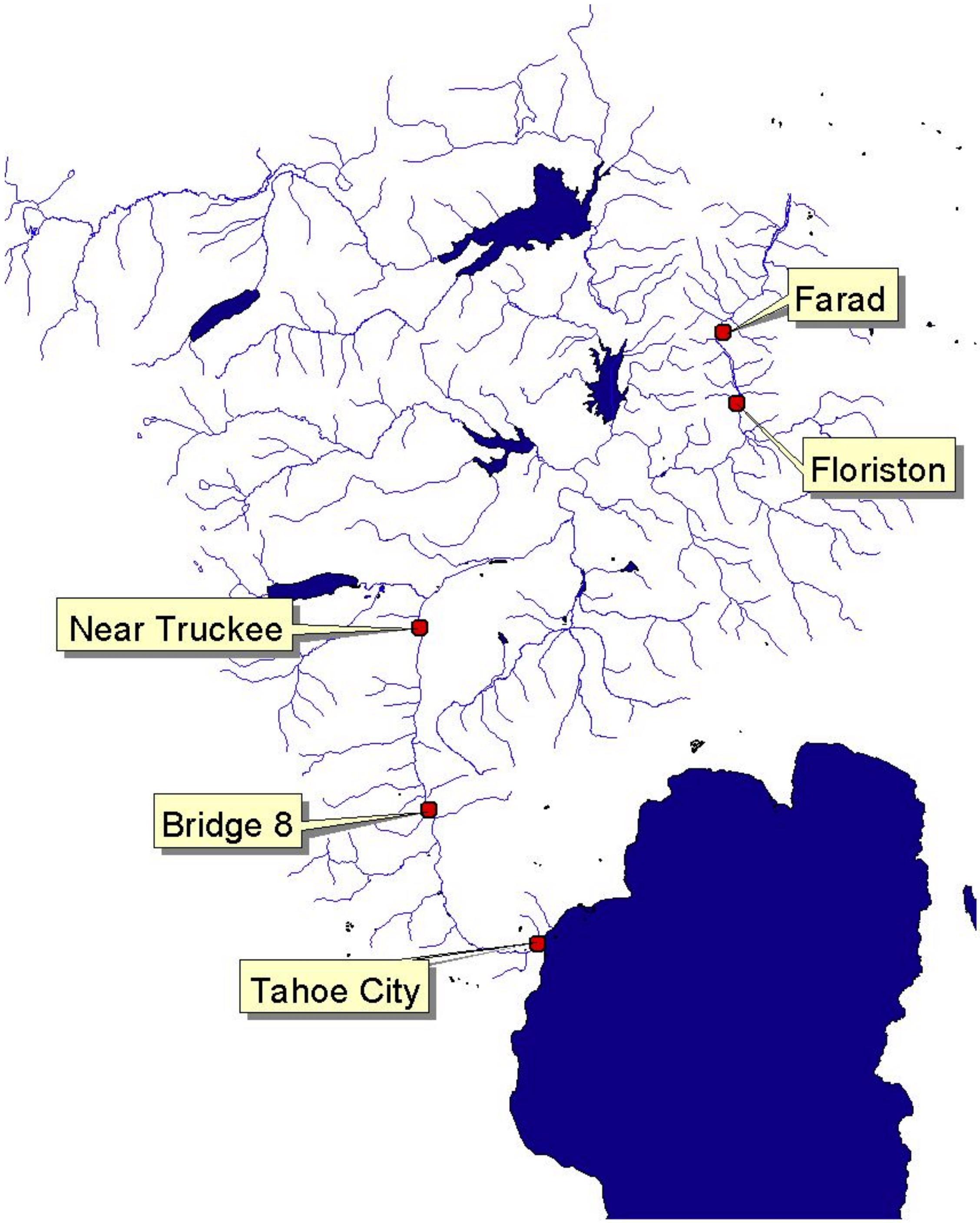


Figure 3.1. Locations of turbidity sensors on the Middle Truckee River.

In order to develop a statistical relationship between suspended sediment concentrations and the explanatory variables (here discharge, turbidity, specific conductivity, and water temperature), SSC samples needed to be collected throughout the year as the explanatory variables varied. Therefore, SSC was collected monthly at all four sites and weekly during snowmelt. Additionally, SSC was collected at Farad during thunderstorm events. Ideally, SSC samples would be collected at all four sites during thunderstorm events. However, time and resources only allowed sampling of one site, since SSC was sampled at frequent time intervals in an attempt to capture the complete hydrograph of the event.

For each SSC sample taken, turbidity was also measured (see laboratory methods below). While turbidity was also measured continuously in the field, these field instruments measure turbidity at only one point in the cross-section and, therefore, the data are site-specific. As a result, it would be impossible to compare the SSC–turbidity relationship at one location to the relationship at another if only site-specific, continuous turbidity data were used. For this reason, it is important to relate the continuous turbidity data (where the data is highly-sensitive to instrument placement, calibration, and sensor) to a measurement that is more absolute and reproducible. This relationship between continuous in situ turbidity and "absolute" turbidity was achieved by analyzing the depth-integrated water samples for turbidity in the laboratory. An additional benefit of analyzing for turbidity in the laboratory is that if one instrument fails or needs to be replaced, new field values can always be related back to "absolute" turbidity and a continuous record can be maintained.

Continuous Turbidity Measurements

CalDWR installed the four turbidity monitoring stations (Figure 3.1) at various times since 1999: Tahoe City in September 1999; Bridge 8 in February 2000; Farad in July 2000; Near Truckee in June 2002. Before June 2002, CalDWR operated these stations on an experimental basis in order to ascertain the robustness of the monitoring devices, the calibration and duty cycle requirements, optimal installation methods, and other operation and maintenance issues. As stated above, consistent calibration of the data was initiated in June 2002.

The continuous turbidity measurements were collected using a YSI 6600 multiparameter monitoring device. Due to the modular design of this device, the YSI 6600 can be configured to measure a variety of parameters by adding various sensors to the basic instrument. In this study, the YSI 6600 was set up to collect temperature, pH, dissolved oxygen, specific electrical conductivity, and turbidity. Values were logged every fifteen minutes on the YSI 6600 internal data logger. The nephelometric turbidity sensor used with the YSI 6600 measures optical backscatterance at 90^{o} from a light emitting diode source. The output of the turbidity sensor is processed via the YSI 6600's software to provide readings in nephelometric turbidity units (NTUs).

The turbidity monitoring stations consist of four-inch pipe anchored to the riverbank, and extend into the channel. The YSI 6600 is suspended within the pipe using steel cable, and extends a fixed distance into the water. The instrument remains in the pipe for two to four weeks, until it is retrieved by CalDWR staff, and replaced with another calibrated instrument. The YSI 6600's are calibrated at CalDWR's laboratory facility using known calibration standards. Once the retrieved instruments are returned to the laboratory facility, they are placed again in calibration standards to determine calibration drift. The logged data is downloaded, and the instrument is refurbished and calibrated for subsequent deployment to one of the study sites. The data is reviewed for accuracy, and adjusted for calibration drift in accordance with USGS guidelines, described in *Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Site Selection, Field Operation, Calibration, Record Computation, and Reporting, W.R. Investigations Report 00-4252* (USGS, 2000a)

Sediment and "Absolute" Turbidity Sampling

USGS protocol was followed in this project, described in *Field Methods for Measurement of Fluvial Sediment* (Edwards and Glysson, 1986) and in *Interagency Field Manual for the Collection of Water-Quality Data* (USGS, 2000b). There are two collection methods described in Edwards and Glysson (1986): The Equal-Discharge-Increment (EDI) method; and the Equal-Width-Increment (EWI) method. This study used the EWI method, which is the method recommended by the USGS.

In EWI method, a volume of water proportional to the flow is obtained at equally spaced verticals along a cross section. First, the cross-section is subdivided into equal widths. Sampling then occurs along a vertical profile of the water column, located at the centroid of each section (referred to as a vertical). Lowering and raising a sample container through the water column allows for the acquisition of a vertically integrated water sample. The instrument (whether hand-held or cable-and-reel) is lowered and raised at four-tenths of the maximum stream velocity. The rate of lowering and raising is estimated visually. All samples obtained are horizontally and vertically integrated. A hand-held US DH-81 sampler was used at locations that could be waded. When high flows prevented the use of this device, a cable-and-reel type US DH-71 sampler was used.

A minimum of ten vertical passes was used at each cross section. As a result, each cross section required several sample bottles. Following USGS (2000b) protocol, the samples from each bottle were not aggregated in the field; rather, they were analyzed individually in the laboratory for SSC and "absolute" turbidity within 24 hrs of collection.

Timing the collection of samples during storm hydrographs events can be difficult due to the inherent uncertainty in weather forecasts especially for a specific locale. For example, a storm may be forecast for the greater Tahoe area, but due to the spatially spotty nature of storms, it may not end up precipitating in the Truckee basin, even when it is pouring rain over in Tahoe. Additionally, when precipitation does occur somewhere in the Truckee basin, it is difficult to know when the runoff response will occur at Farad. An ideal temporal distribution of sample collections during a thunderstorm event would incorporate the rising limb, peak, and descending limb of the storm hydrograph and would look like that shown in Figure 3.2 for July 23, 2003. However, because of the difficulties in timing collection of samples to the storm pattern described above, the ideal was not always attained. Even with the "ideal" sampling distribution attained on July 23, 2003, the resulting distribution of suspended concentrations sampled was not expected. The peak SSC preceded the peak in the hydrograph, and SSCs dropped to low levels long before the descending limb of the hydrograph occurred. SSC peaking before discharge may be partially due to SSC samples being collected 2.5 miles upstream from where flow is measured, but it may also be due to entrainment of a majority of the sediment during the initial phases of the storm.

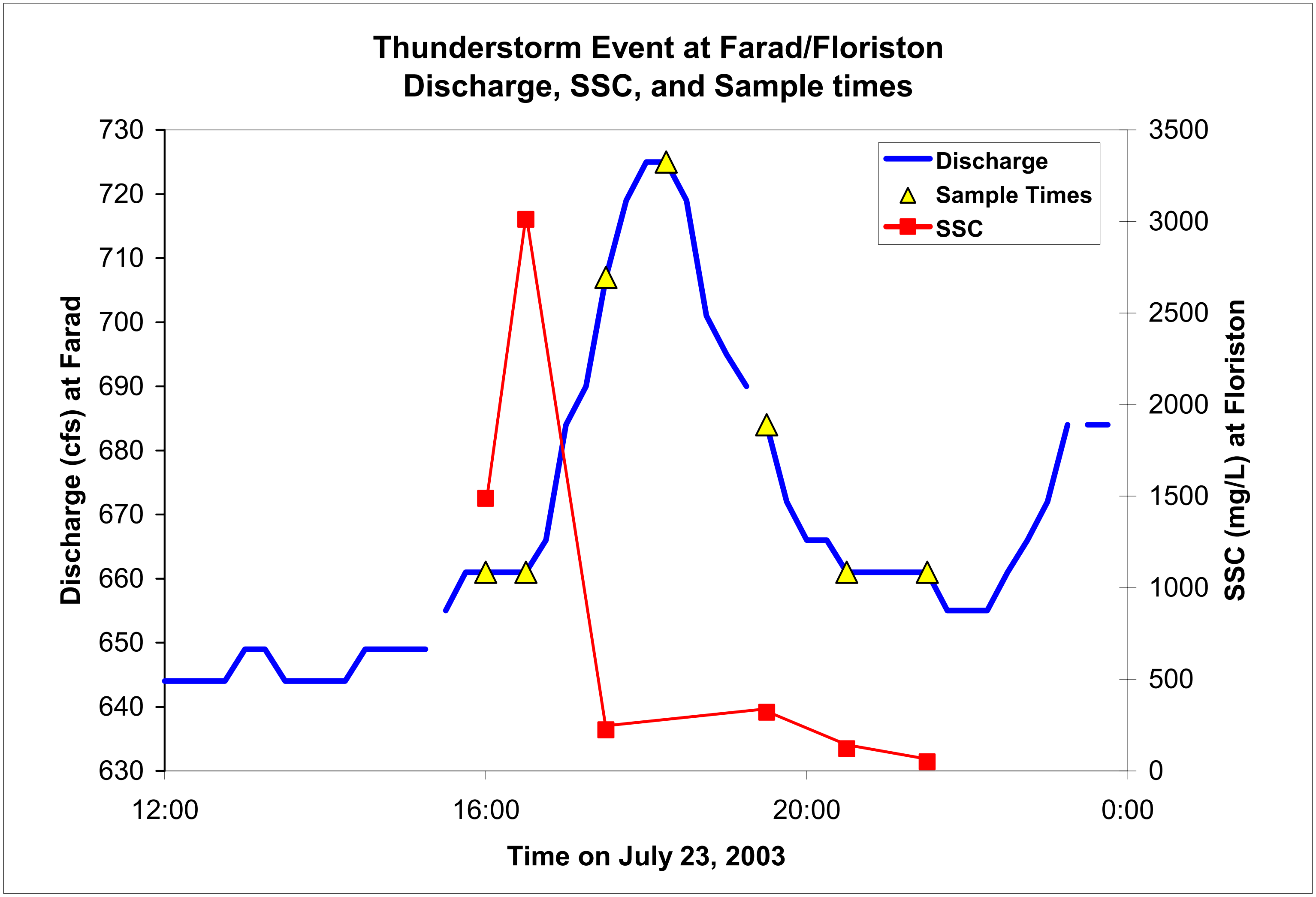


Figure 3.2. Thunderstorm event on July 23, 2003, showing the storm hydrograph, and temporal distribution and concentration of sediment samples collected during the storm.

Laboratory Methods for SSC and Turbidity

The analytical method, ASTM D 3977-97, *Standard Test Method for Determining Sediment Concentration in Water Samples* (ASTM, 2000) was used by DRI's Water Analysis Laboratory to determine SSC for a majority of the samples collected. Most of the samples were analyzed using ASTM (2000) "Method A". For samples with excessive amounts of sediment, ASTM (2000) "Method B" was used. The ASTM (2000) method is the USGS standard for determining concentrations of suspended material in surface water samples. It is used by all USGS sediment analysis laboratories, and by cooperating laboratories certified to provide suspended-sediment data to the USGS. The USGS considers this the most accurate way to measure the total amount of suspended material, since the methods and equipment used by such laboratories are consistent, and are quality assured by the National Sediment Laboratory Quality Assurance Program (USGS, 1998). DRI's Water Analysis Laboratory is EPA-certified and has participated in the USGS Standard Reference Sample Program for more than 20 years.

Another commonly used measurement of suspended material is the total suspended solids (TSS) analytical method. It has been widely used as a measure of suspended material in stream samples because it is mandated, or acceptable for regulatory purposes, and is an inexpensive laboratory procedure. DRI (2001) showed that the relationship between TSS and SSC, for all historic samples that were analyzed for both parameters, is one to one (TSS=0.9779(SSC); r^2,0.9431). That is, for these sites on the Truckee, TSS adequately estimates SSC. Therefore, historic TSS data collected by DRI and Lahontan Regional Water Quality Control Board (LRWQCB) may be used to compare to the data set collected in the present study. TSS samples collected by DRI (2001) were analyzed by the DRI Water Analysis Laboratory using USEPA Method No. 160.1: *Physical Properties: Residue, Filterable Gravimetric, Dried at 180°C* (see USEPA, 1983). TSS samples collected by LRWQCB were analyzed according to USEPA Method 160.2: *Physical Properties: Residue, Non-Filterable Gravimetric, Dried at 103-105°C* (USEPA, 1983).

DRI, USGS and LRWQCB laboratories analyze for turbidity according to USEPA Method No. 180.1: *Determination of Turbidity by Nephelometry – Revision 2.0* (USEPA, 1993). Turbidity is determined using an aliquot of roughly 25-50 mg of the sample to be analyzed for SSC or TSS. The aliquot is removed after vigorously agitating the sample to re-suspend any material that may have settled. The sub-sample is then measured by a nephelometric turbidimeter and subsequently poured back into the original sample to be analyzed for SSC or TSS. It is assumed that turbidity measurements conducted on the aliquot are representative of the entire sample.

Sediment Load Analyses

In order to obtain temporally high-resolution estimates of SSL we chose the approach of developing a surrogate from which to calculate suspended sediment concentrations (SSC), which is described in Chapter 2. A continuous SSC record was estimated using the relationship between variables which are collected continuously (turbidity, discharge, specific conductance, and water temperature), and SSC which was collected monthly during baseflow, weekly during snowmelt, and during storm events. The sediment load was then calculated from the SSC estimates and discharge (see below). The best model for predicting SSC was a multiple linear regression in which SSC is predicted from turbidity, discharge, specific conductivity, and water temperature (Eq. (2.13) in the previous chapter).

The model first finds estimates of the natural log of SSC, or ln(SSC). To find the estimated SSC, or Est(SSC), the exponent of ln(SSC) must be taken:

Est(SSC)=exp(Estln(SSC))

It is typically recommended that estimates backtransformed from natural log should be corrected for "retransformation bias" using the following formula (Duan, 1983):

*Corrected estimated SSC=mean(exp(residuals of the regression))*Est(SSC)*

The *mean(exp(residuals of the regression))*, called "correction factor" is found by computing the residuals and their mean from the regression. Each regression will have its own correction factor. The correction factors for the prediction equations used in this chapter as well as others reported in Chapter 2:

For Eq. 2.13 – 2.15 the correction factor equals 2.103289

For Eq. 2.16 – 2.24 the correction factor equals 2.287144

For Eq. 2.25 – 2.27 the correction factors equals 4.656619

The instantaneous suspended sediment load is the product of estimated concentration *SSC* (in unit of mass per volume) and discharge *Q* (in units of volume per time). Therefore, the total load *L* (mass) past a cross section for any time period is defined by the integral:

$$L = \int_0^T SSC(t)Q(t)dt$$

where concentration and discharge are continuous over time *t*. The equation above can also be approximated by the discrete sum:

$$L = \sum_{i=1}^{T/\delta t} SSC_i Q_i \delta t$$

In calculating daily suspended sediment loads, missing data of up to 20 consecutive data points were found by linear interpolation. Calculation of monthly sediment loads were done if no more than 10% of the data values were missing. The percentage of missing data values are reported as footnotes to the tables presented in the report.

Special treatment of Bridge 8

As mentioned above, flow estimates at Bridge 8 were unavailable due to malfunction of both datalogger and pressure transducer. A regression model using only turbidity, specific conductivity, and water temperature (without flow) was developed to calculate SSC for Bridge 8 (Eq. 2.18 and 2.22). This allowed comparison of SSC among stations over the study period. While SSC could be calculated for Bridge 8 using the regression model, suspended sediment loads cannot be calculated without a flow estimate. SSLs for Bridge 8 were estimated using both the flow at Tahoe City (~6 miles upstream of Bridge 8) and the flow at Near Truckee (~6 miles downstream of Bridge 8), to provide an estimate of SSL. It is difficult to ascertain which scenario provides a more realistic estimate of SSL for Bridge 8, as using Tahoe City flows will undoubtedly result in an underestimate of loads, since it wouldn't account for additional flow added by streams (most noticeably Bear Creek, Squaw Creek, Silver Creek, and Deer Creek) entering the main stem of the Truckee River between

Tahoe City and Bridge 8 (Figure 3.3). Conversely, using Near Truckee flows will undoubtedly result in an overestimate of SSL for Bridge 8, as it adds in flow of streams (most noticeably Pole Creek, Deep Creek, and Cabin Creek) that enter the main stem of the Truckee between Bridge 8 and Near Truckee. Clearly, the true SSL lies somewhere in between these two estimates. For simplicity, Bridge 8 SSLs calculated using Near Truckee flows were used for the purpose of comparing its temporal variability to the other sites.

Results

The Results are broken down into sections: suspended solid concentrations (SSC) for the 2002 to 2003 period, suspended solid loadings (SSL) for 2002 to 2003, and suspended solid loadings for specific sediment "events."

Suspended Solid Concentrations

Monthly average suspended solid concentrations calculated from the regression equations, are shown in Figure 3.4. The data associated with Figure 3.4, along with other statistics (average, st.dev., max., min. and median) can be found in Appendix A2. Throughout 2002 to 2003, SSC monthly averages were generally the lowest at Tahoe City and highest at Farad, with the other two stations intermediate. Suspended sediment concentrations were elevated during snowmelt periods, with SSC at Bridge 8 and Near Truckee three orders of magnitude higher during June 2003 than during June 2002 snowmelt period. Unfortunately, Farad data were missing during much of the 2003 snowmelt period; during 2002 snowmelt, Farad SSCs were four orders of magnitude higher than at the other stations. Other periods of high SSCs occurred during December 2002.

Suspended Sediment Loading 2002 to 2003

Special Treatment of Bridge 8

As detailed in the methods section, because discharge was not available for the Bridge 8 site, suspended sediment loading for this site was estimated using discharge from both Tahoe City and the Near Truckee sites. It can be seen in Figure 3.5 that while the temporal patterns in sediment loading are similar using the two different flow estimates, the loads at Bridge 8 are lower when calculated with Tahoe City discharge compared to using discharge from Near Truckee. Because the scale in Figure 3.5 is logarithmic, these differences don't visually appear to be large. To better evaluate the difference in loading from using the two different flows, monthly loading was calculated. Table 3.1 provides a comparison of monthly sediment loading for Bridge 8 using flows from both Tahoe City and Near Truckee. The percent difference in load estimates was a low as 5 to 11 % during the summer months, but was up to ~600% different in May and June 2003 during the spring snowmelt period.

Average Daily Sediment Loading Estimates for 2002 to *2003*

Average daily suspended sediment loading and discharge are shown in Figure 3.6 for the period of record, a 13 month period from June 2002 to July 2003. In general, SSLs are highest at Farad and lowest at Tahoe City, with Bridge 8 and Near Truckee loads intermediate. The higher SSLs at Farad are to be expected, given that it collects water and sediment from all the upstream subwatersheds within the Truckee River. The low SSLs at Tahoe City are also predictable because it is just below the regulated dam and outflow from Lake Tahoe and does collect water or sediment from any subwatershed. It is not unexpected

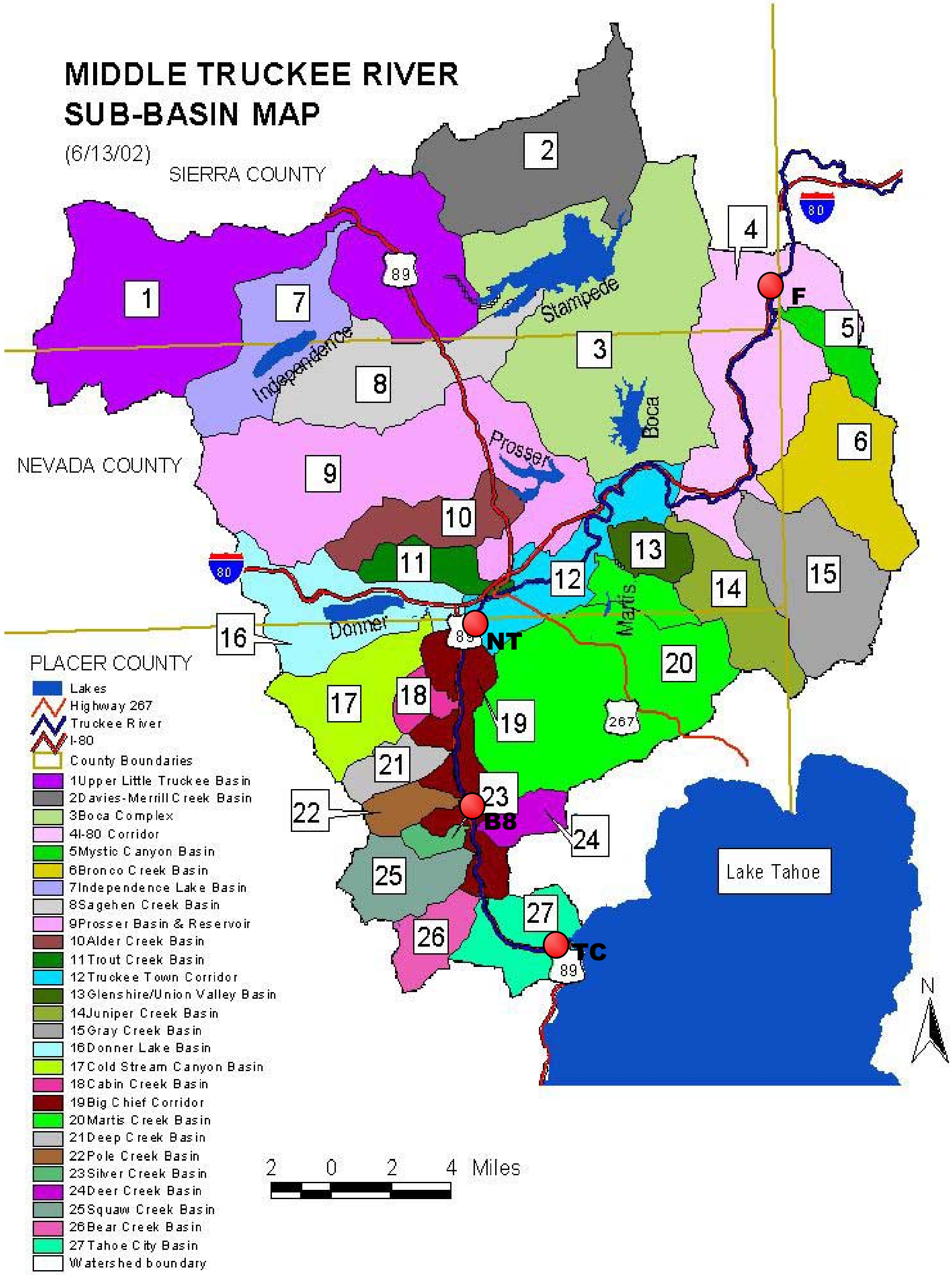


Figure 3.3. Subwatersheds of the main stem Middle Truckee River. Map modified from Truckee River Watershed Council map. Sediment sampling sites for the present project are shown with red markers: TC = Tahoe City, B8 = Bridge 8, NT = Near Truckee and F = Farad.

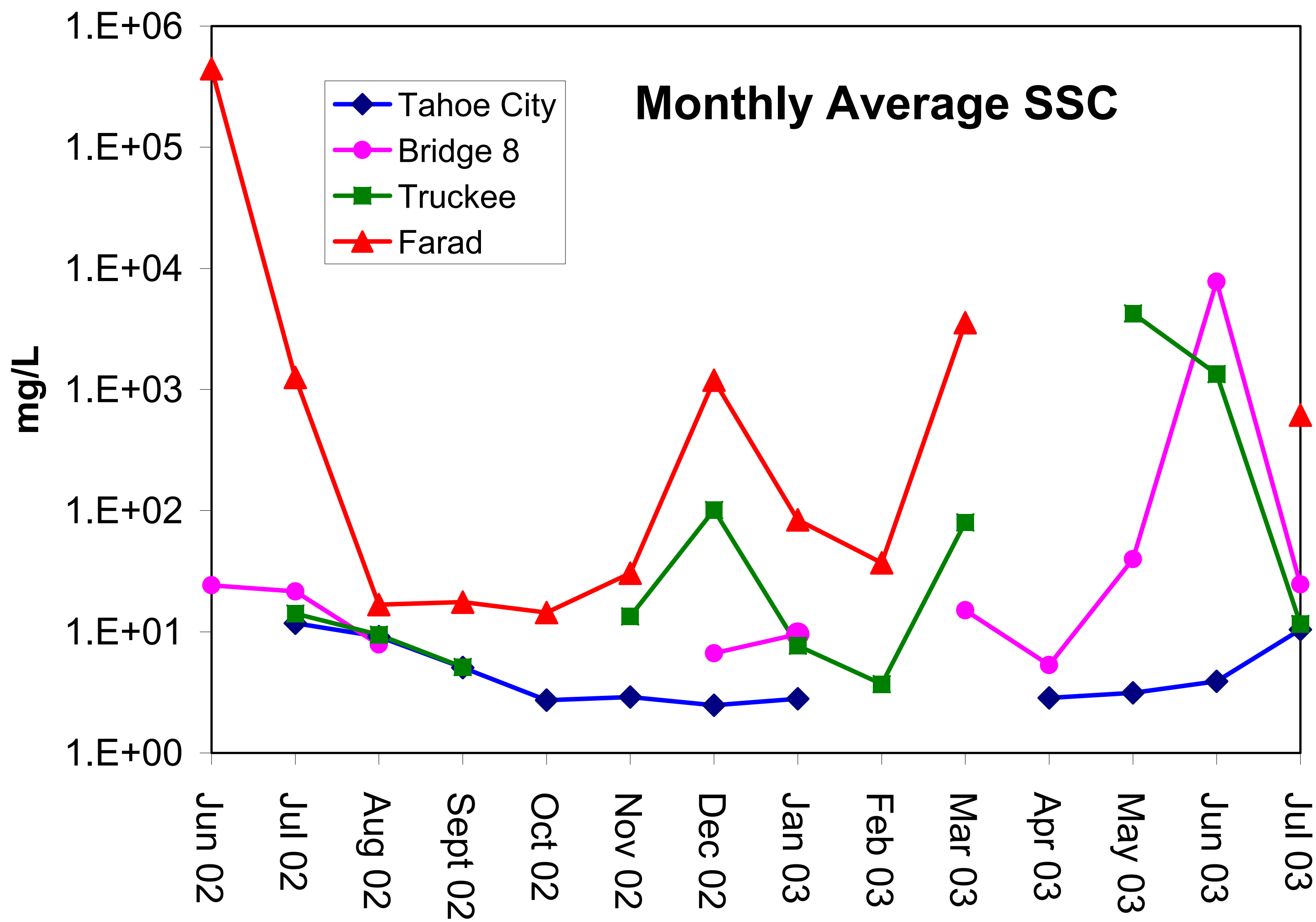


Figure 3.4. Monthly average suspended sediment concentration for stations on the main stem of the Truckee River.

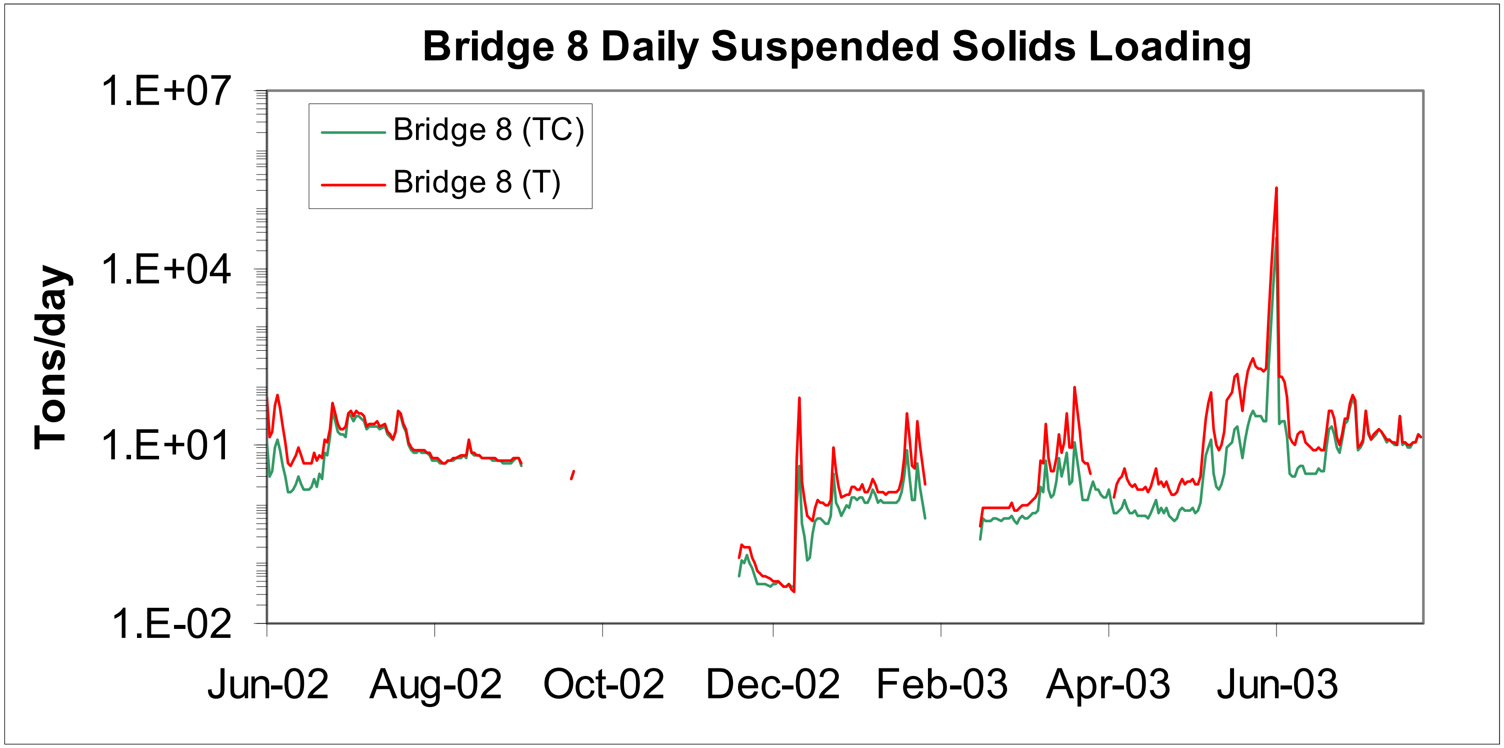


Figure 3.5. Suspended sediment loading at Bridge 8, calculated using discharge from Tahoe City (TC) and Near Truckee (T).

Table 3.1. Bridge 8 total monthly suspended sediment loading (in tons) using Tahoe City discharge (Q) and Near Truckee discharge (Q).

Month	Bridge 8 – Tahoe City Q	Bridge 8 – Near Truckee Q	Difference %
June 2002	243	587	142
July 2002	598	661	11
August 2002	187	196	5
September 2002	n.d.	n.d.	n.d.
October 2002	n.d.	n.d.	n.d.
November 2002	n.d.	n.d.	n.d.
December 2002	18	105.7	481
January 2003*	51	142.3	178
February 2003	n.d.	n.d.	n.d.
March 2003	70	287.1	309
April 2003	30.4	50.7	67
May 2003	269	1,889	602
June 2003	41,965	290,691	593
July 2003	567	624	10

n.d. = not determined due to missing data
*8% of this month's values are missing

that temporal trends in SSL follow discharge patterns over the year. However, there are specific SSL events which do not seem to be associated with high flow. For example, the spikes in SSL at Farad in mid July and early December 2002 and late July 2003 are not coupled with peaks in discharge.

During much of the year, discharge and SSL patterns are temporally similar at all four sites. For example, the SSL events in early November and mid December 2002 are observed at all sites with available data. However, other events, such as the one observed at Farad in mid July 2002, are not seen at the other stations. In addition, there is a long period from mid August to November 2002, in which both flow and SSL at Tahoe City and Near Truckee decline to low levels while flow and SSL remains elevated at Farad. The stable and elevated levels at Farad are likely due to releases from upstream reservoirs through this period.

Other interesting patterns emerge from Figure 3.6 that may bear on mobilization and transport of sediment. In mid March 2003 at the beginning of snowmelt, the discharge at Farad increases and remains relatively stable through mid April. In contrast, SSL exhibits a sharp peak rather than an extended elevated period as does discharge. The initial increase in flow at the beginning of snowmelt likely mobilized sediment until the "source" was depleted. One other period bears remarks. Snowmelt discharge and SSL at Near Truckee increase during May 2003. However as discharge declines in late May and June, the SSL remains elevated. In addition, a large peak in SSL at Bridge 8 occurs during the period that SSL at Near Truckee remains elevated. This indicates a source unrelated to snowmelt may be mobilizing sediment upstream from Near Truckee. These two cases are a good example of why equations to calculate suspended sediment based on flow alone may result in poor predictive capabilities.

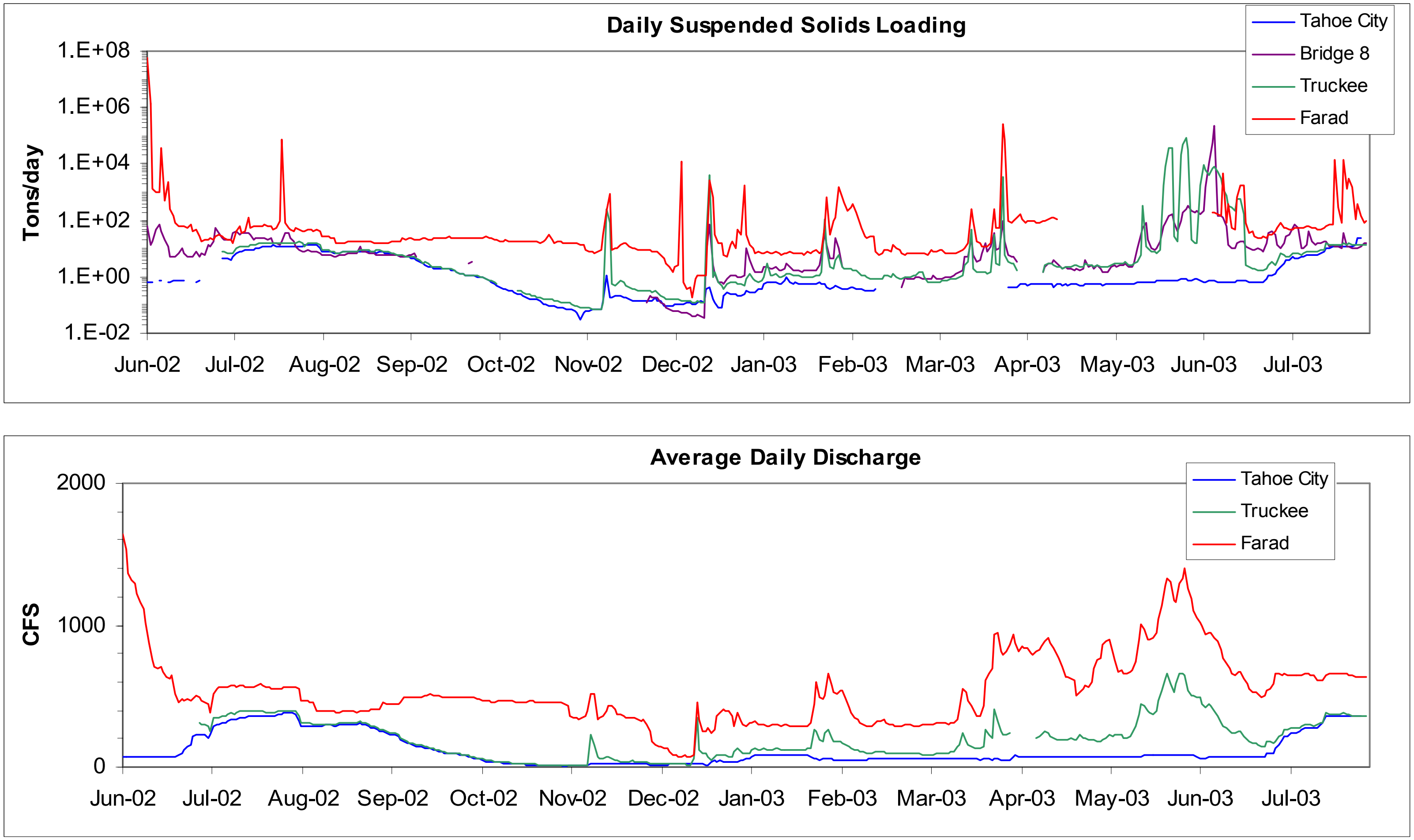


Figure 3.6. Average daily suspended sediment loading (top) and discharge (bottom) for the four sites. Note that flow is not available for the Bridge 8 site. Loads for the Bridge 8 site were calculated using discharge from the (Near) Truckee site.

Monthly Suspended Loading Estimates for 2002 to 2003

Total monthly suspended sediment loading over 2002 to 2003 is shown in Table 3.2 and Figure 3.7. Annual sediment loading could not be calculated due extensive periods of missing turbidity data ("n.d." in Table 3.2.) at various times during the year at all stations. Monthly loadings ranged from ~5 to 6 tons/month (Tahoe City, October through December 2002) up to ~61 million tons/month (Farad, June 2002).

The highest monthly loadings occurred during the snowmelt period, with peaks occurring at different times: peak monthly loading occurred in May 2003 for Near Truckee at ~270,000 tons; it occurred in June 2003 at Bridge 8, at ~290,000 tons; and it occurred in June 2002 at Farad at 61 million tons. The peak monthly loadings at Tahoe City occurred in July 2002/2003 (343, and 264 tons respectively) and are likely related to increased dam releases at that time of year (see Figure 3.6, bottom graph) since the snowmelt season was over by the end of June in both years. In 2003, it appears that there was an initial snowmelt and SSL pulse which did not continue through April (Figure 3.7 and Table 3.2). The main snowmelt pulse and SSL occurred during May through June 2003. Missing turbidity data for the months of April to June precludes evaluation of Farad SSL through the 2003 snowmelt period.

Table 3.2. Total monthly suspended sediment loading (in tons).

Month	Tahoe City	Bridge 8†	Truckee	Farad
June 2002	n.d.	587	n.d.	61,292,909
July 2002	343	661	448	71,489
August 2002	219	196	237	579
September 2002	55.7	n.d.	59.9	694
October 2002	5.3	n.d.	n.d.	553
November 2002	5.1	n.d.	357	1,366
December 2002	5.9	106	4,081	17,816
January 2003	17.2	142***	165	4,087
February 2003	n.d.	n.d.	31.0	1,269
March 2003	n.d.	287	3,535*	338,774
April 2003	16.2	51	n.d.	n.d.
May 2003	20	1,889	270,130	n.d.
June 2003	23.4	290,691	48,387	n.d.
July 2003	364**	624	322	34,778

n.d. = not determined due to missing data
*1% of this month's values are missing
**5% of this month's values are missing
***8% of this month's values are missing
†Loading calculations use discharge from Truckee site

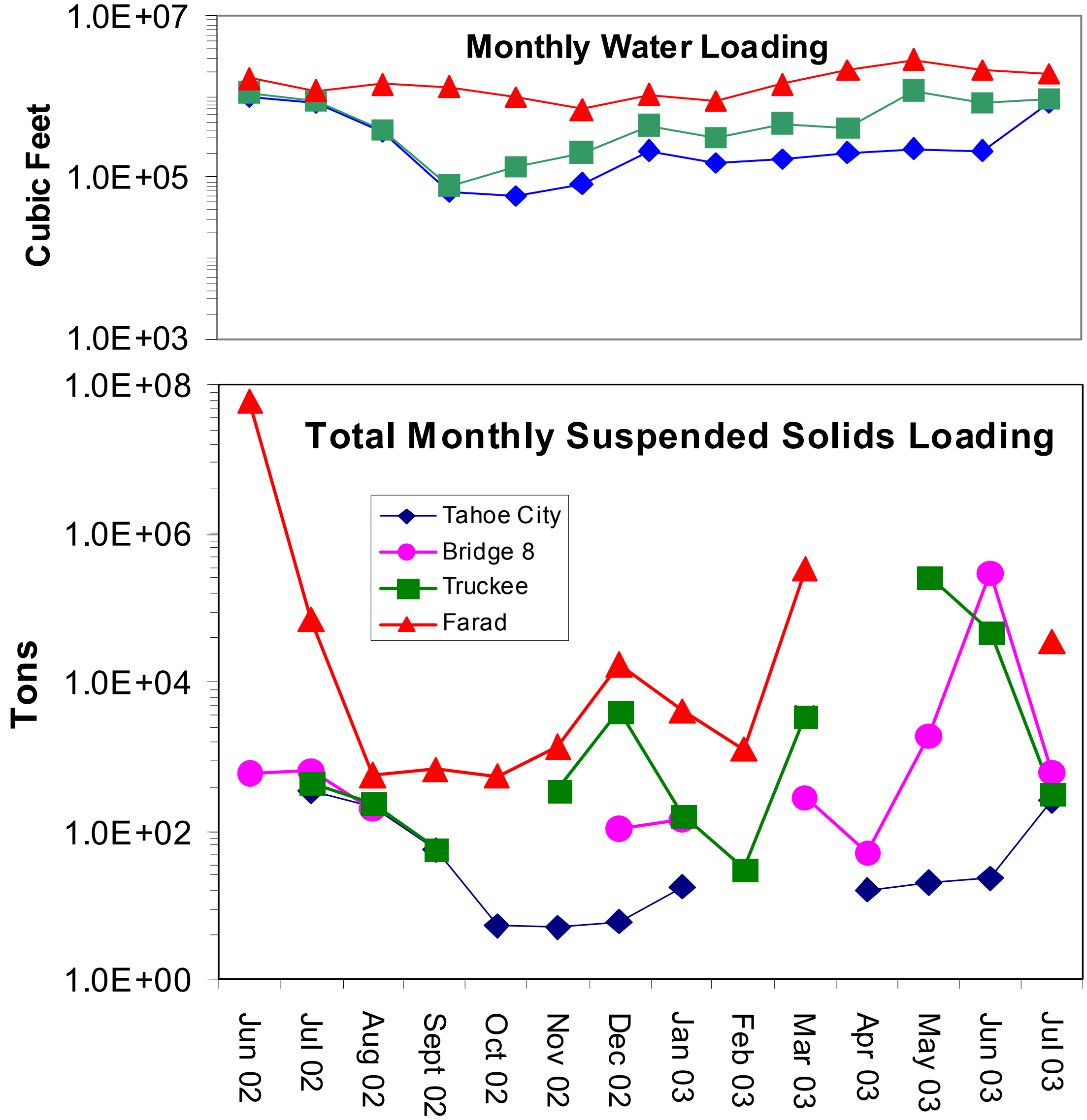


Figure 3.7. Total monthly suspended sediment loading (bottom) and water loading (top) during 2002 to 2003. Water loading estimates not available for Bridge 8. Bridge 8 sediment loads calculated using Near Truckee flow measurements.

The maximum SSL to within a 15 minute period was ~2 million tons, which occurred at Farad in June 2002. 15 minute maxima for other stations were: ~203,000 tons at Bridge 8 in June 2003; ~5,000 tons at Near Truckee in May 2003, and ~6 tons at Tahoe city in July 2003. Statistics (average, standard deviation, maximum, minimum, and median) for monthly SSL data at each station are provided in Appendix A3 (Tahoe City, Near Truckee, and Farad) and Appendix A4 (Bridge 8).

Comparison of Suspended Sediment Loading Estimates to DRI (2001) Report

DRI (2001) estimated suspended sediment loading for tributaries to the Truckee River using a model which predicts loads as a function of discharge. For the purpose of determining how loads calculated in the present report compare to previous estimates using different predictive models. 2002 to 2003 SSL estimates for Farad calculated as a function of turbidity, flow, specific conductivity, and water temperature (equation 2.13 in this report) were compared to 2002 to 2003 SSL estimates for Farad calculated as a function of flow only using the regression equation developed for Farad (R^2, 0.78) on page 163 the 2001 DRI (2001) report:

$$SSL = 10^{(1.59 \times LOG(Q) - 3.44)}$$

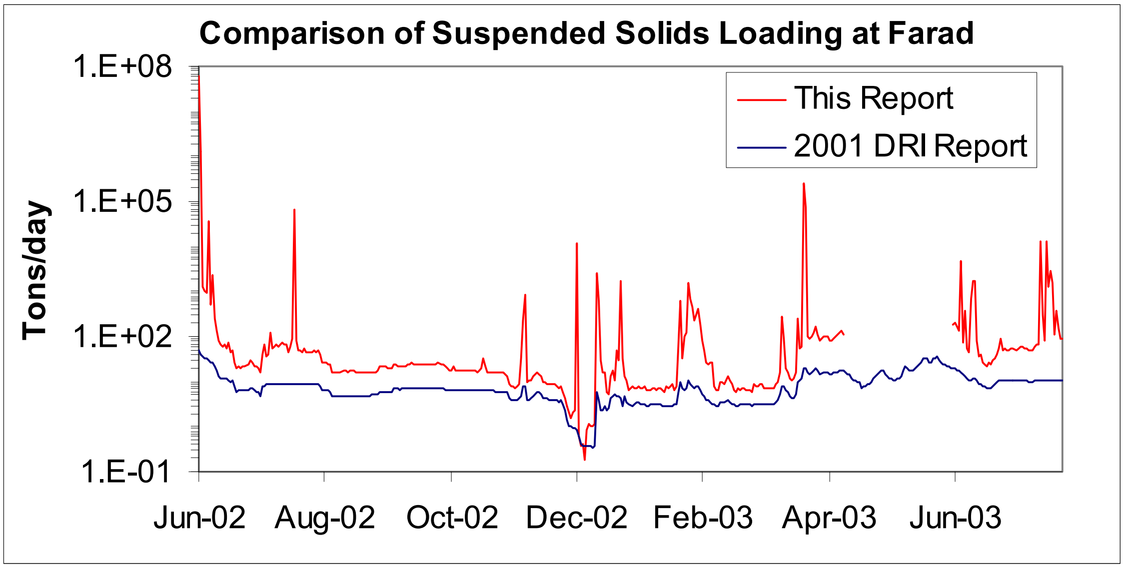
where *SSL* is the suspended sediment loading in tons/day and *Q* is the discharge in cubic feet per second. The loading estimates presented for "This Report" in Figure 3.8 are the same as those presented in Figure 3.6 and Table 3.2. Before discussing the comparison, it should be pointed out that in the present study, a model with only flow used as a predictor resulted in an R^2 of 0.39 as compared to the much better multiple R^2 of 0.73 obtained using turbidity, flow, specific conductivity, and water temperature.

SSLs calculated as a function of flow only (2001 DRI report equation) were consistently less than SSLs calculated as a function of turbidity, flow, specific conductivity and water temperature (Figure 3.8). The difference was less during base flow periods (August to November 2002), but orders of magnitude different during snowmelt. SSL estimated in the present study were 2 to 6 orders of magnitude higher during March, June, and July, as well as December. This comparison underlines the care which must be taking in comparing suspended sediment loads estimated with different methods. In addition, it points to the much better estimates of suspended sediment loading that can be obtained when turbidity data (in addition to flow) is available.

<u>Suspended Sediment Loading of Specific Events During 2002 to 2003</u>

Throughout the year, sediment is entrained and transported down the Truckee River. These processes tend to increase during certain times of the year when discharge increases, during spring snowmelt, as well as during thunderstorm events. We tend to think of the spring snowmelt as one big event. However, upon detailed evaluation of the sediment loading patterns during snowmelt, it is apparent that there is typically a diurnal pulse of sediment that follows the daily melting patterns of the snow. For this reason, these daily pulses of sediment associated with snowmelt are considered as events, along with sediment pulses that occur during thunderstorms. Dam releases produced a third type of sediment releasing event. This was especially apparent at the Tahoe City site which is just downstream of the Tahoe City dam which regulates flow of the Truckee River from Lake Tahoe.

Events were determined by best professional judgment using hourly averaged estimated suspended solids loading for each site. In most instances, events were determined by an obvious change in slope of the data. Events were generally spiky in nature, sharply rising up from and returning back to "baseflow". During the snowmelt season, there could be several spiky events during a given day. In these instances, the entire day was lumped together as one event (generally, it was very obvious). In some snowmelt instances, it was impossible to discern a period of daily snowmelt. In these cases, the snowmelt event included multiple days.



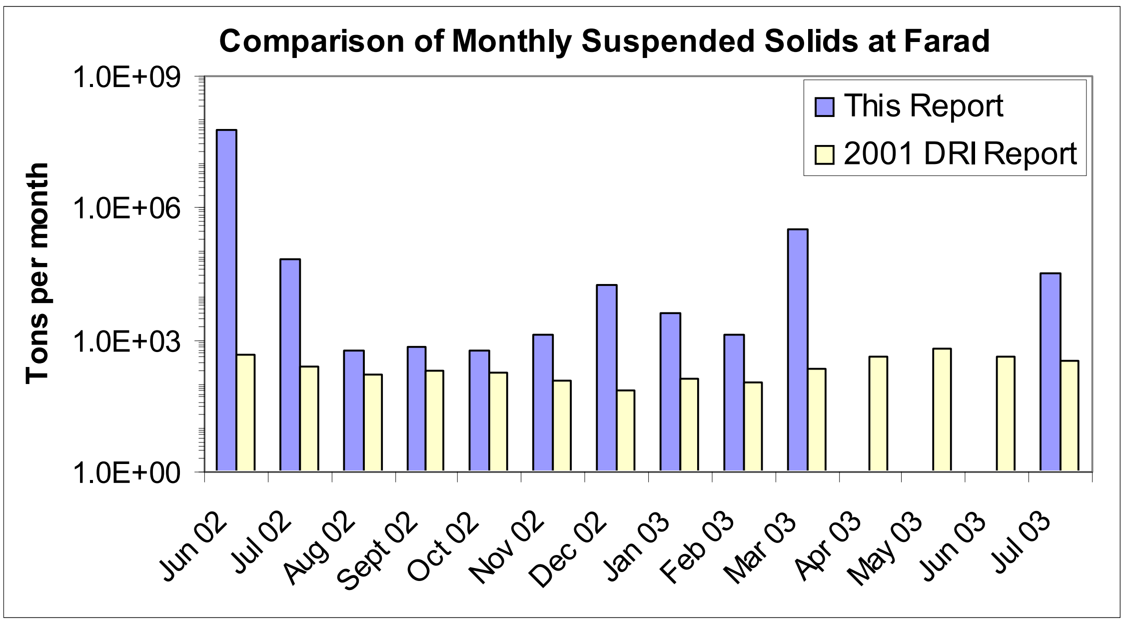


Figure 3.8. Comparison of average daily (top) and total monthly (bottom) suspended solids loading at Farad using two different predictive models. "This Report" estimates were calculated as a function of turbidity, flow, specific conductivity, and water temperature using equation 2.13 developed as a part of the present study. "2001 DRI Report" estimates were calculated as a function of flow only, using the equation, pg 163 DRI (2001).

Characteristics of sediment loading during snowmelt are considered first, followed by sediment loading of selected events (thunderstorm or snowmelt). Finally the frequency, duration, loading, and intensity of all sediment producing events are evaluated.

Suspended Sediment Loading During Snowmelt

During snowmelt, sediment loading exhibits a characteristic diurnal signal at all stations which lasts approximately 24 hours. An example of this can be seen during the time period, June 6-16, 2003 (Figure 3.9 middle graph). The timing of loading follows the daily hydrograph, which lags behind the daily solar/temperature cycle. The lag is a function of the travel time from where the snow melts in the watershed and its entry into the mainstem of the river. The diurnal signal is most regular and pronounced at Near Truckee, with the load varying an order of magnitude between the low (~2 pm) and the peak (~11pm). For example, the sediment load at Near Truckee varied between ~38 tons/hour and ~952 tons/hour during a diurnal cycle on June 7, 2003. While the diurnal sediment load cycle is also regular at Tahoe City, the difference between low and peak is much less (~.008 tons) for this period.

Interestingly, the diurnal signal at Farad, while present, is muted compared to Near Truckee. Daily sediment loading amounts were lower at Farad than at Near Truckee during the June 6-16, 2003 period, (Figure 3.9 top graph) despite greater daily water loading at Farad (Figure 3.9, bottom graph). The loading numbers in the top graph of Figure 3.9 were totaled for each diurnal snowmelt "event" (rather than for a period of a day). Hence the duration of each snowmelt "event" ranged between 18 hours and 3.5 days (and wasn't fixed at 24 hours). There are two suspended sediment loading spikes on June 11 and 13, 2003 at Farad that are probably unrelated to snowmelt.

The diurnal cycle is present at Bridge 8, although again more muted than Near Truckee. Of interest are the large spikes in suspended sediment (up to ~204,000 tons/hr) that appear at Bridge 8 during June 6-9, 2003. While the diurnal signal is still present during this time period, the spiky behavior suggests that other sources other than snowmelt may be contributing to the load during this time period.

Suspended sediment loading of selected events

Sediment producing events were often evident at all four sites, although this was not always the case due to the differential melting of snow at different elevations, spatial variability of thunderstorms, or localized anthropogenic source loading. Figure 3.10 provides a comparison of sediment and water loading of selected significant events that were visible at three or more of the four sites. Except for the event on 12/13/2002 where sediment loading at Near Truckee and Farad were nearly equal, sediment and water loading were always highest at Farad. Loading at Near Truckee exceeded loading at Bridge 8 on three of the events, but the reverse was true of two other events. It is interesting that the sediment and water loads were nearly equal at Tahoe City, Bridge 8 and Near Truckee during the thunderstorm event on 7/23/03, which may indicate a uniformity of the storm distribution over the upper watershed.

Frequency, loading, duration, and intensity of suspended sediment events

Frequency of sediment events

In the course of the 13 month data record, each site had a different number of events (in order of decreasing numbers): Bridge 8 had 94 events; Farad had 74 events; Near Truckee had 33 events; and Tahoe City had 6 "regular" events, and 10 "dam" events. It should be noted that each site had missing data, usually at different time periods, which hampers interpretation of these data (Table 3.3). Even so, it is remarkable that Bridge 8 had nearly twice

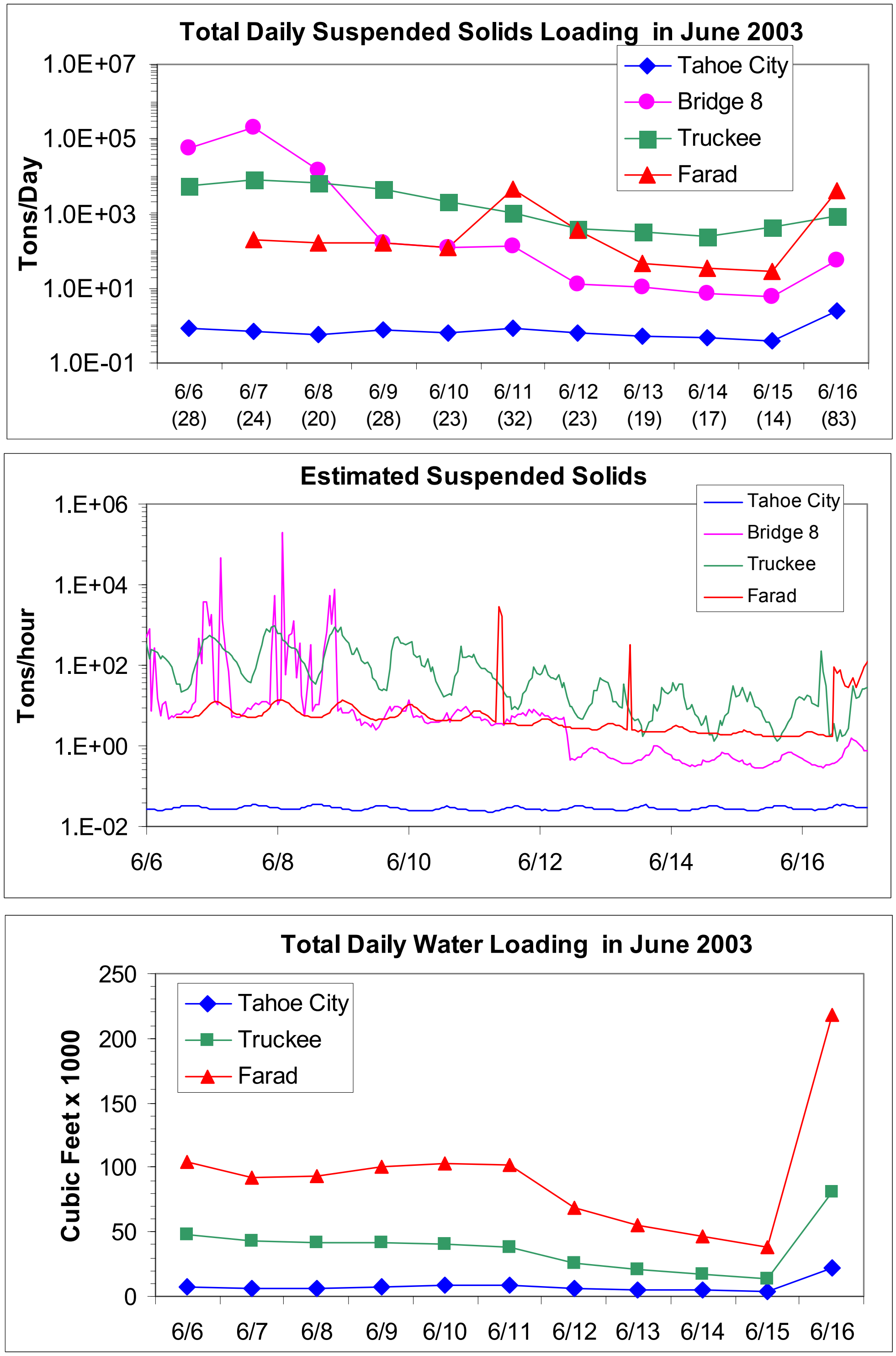
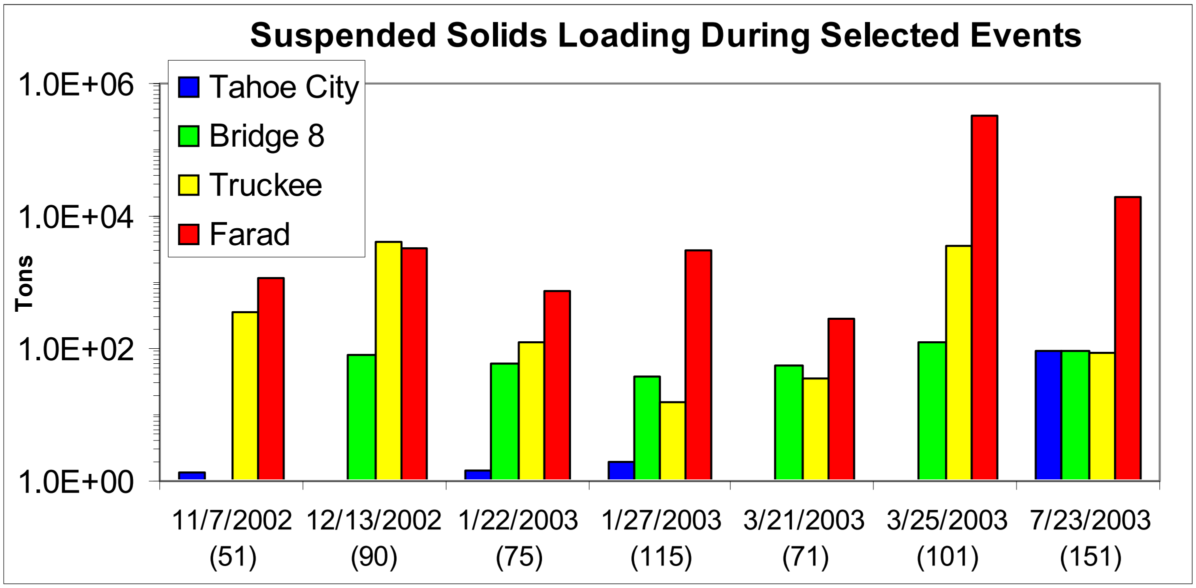


Figure 3.9 Characteristics of suspended sediment and water loading during a selected period (June 6-16) during spring snowmelt 2003. Top graph: total daily suspended sediment loading; middle graph: total hourly suspended sediment loading; lower graph: total daily water loading. The numbers in parentheses in the top graph are the number of hours constituting the "diurnal" cycle each day.



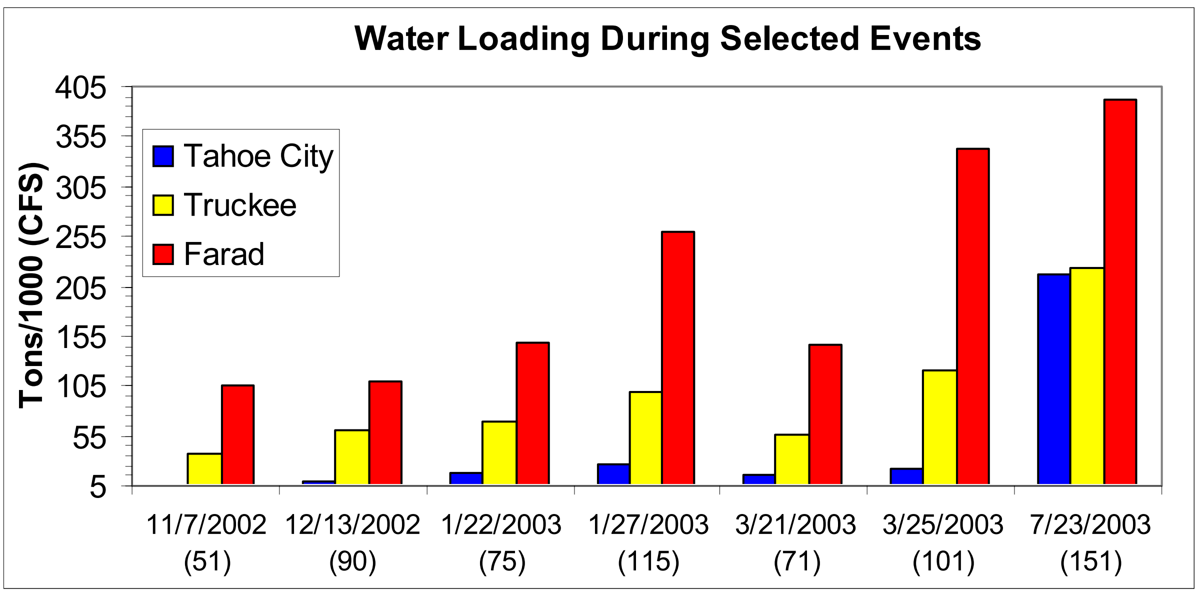


Figure 3.10. Suspended solids (top) and water (bottom) loading during selected events. Dates were selected for this graph using the criteria that the event had to have been evident at three of the four sites. Sediment data were not available for: Bridge 8 on 11/7/2002; and for Tahoe City on 3/21/2003 and 3/25/2003. Numbers in parentheses are the number of hours of event duration. Water loading not available for Bridge 8.

the number of days of missing data as the nearest downstream site, Near Truckee, yet Bridge 8 three times the number of sediment loading events at Near Truckee. This implies frequent loading of sediment from tributaries or other sources above Bridge 8 which settles out before reaching Near Truckee.

Table 3.3 Number of sediment loading events and days with missing data at each sampling location, by month.

	Number of events between June 2002 and July 2003			
	Tahoe City	Bridge 8	Near Truckee	Farad
	6 (+ 10 dam events*)	94	33	74
	Number of days missing data			
Month	Tahoe City	Bridge 8	Near Truckee	Farad
June 2002	10		26	
July 2002				
August 2002				
September 2002		25		
October 2002		31	6	
November 2002		21		
December 2002				
January 2003		2		
February 2003	18	18		
March 2003	27			
April 2003			8	17
May 2003				31
June 2003				6
July 2003				
TOTAL	55	97	40	54

*see text for explanation of “dam” events

Loading of sediment events

The minimum detectable event produced a suspended sediment load of 0.3 tons at Tahoe City and between 1.5 and 2.8 tons at other sites. The maximum sediment loads during a single event were, in order of decreasing loads: 2,762,152 tons at Farad June 1-2, 2002; 227,869 tons at Bridge 8 June 7-9, 2003; 106,812 tons at Near Truckee May 29-30, 2003; and 27 tons at Tahoe City July 29-30, 2003. Appendices A5 through A8 provide statistics (total load, average, minimum, maximum, median, and intensity) for each event at each site. Events at Tahoe City also include different regimes of water release at the dam, determined by obvious breaks in slope of the average daily loading. These “dam” events were typically much longer in duration, ~5 to 39 days, with higher event loads of up to ~1,000 tons, than “regular” (e.g., thunderstorm) events which lasted ~1 day, and less than 28 tons per event. The higher loads of dam events were in part due to the due to the long durations of these events.

The sediment loading of individual events, considering all sites together, show a rather normal distribution, with events producing between 64 and 256 tons of sediment being the most frequently occurring (Figure 3.11). This distribution is similar for Bridge 8 and Farad, although Farad also has almost as many events in the lower 16 to 64 ton range. The distribution of event loading at Near Truckee is shifted toward higher sediment loads per event, with the highest frequencies spread somewhat equally over the range of 1,204 to 65,536 tons/event. Dam events produced the higher loads (>28 tons/event) observed for Tahoe City in the histogram.

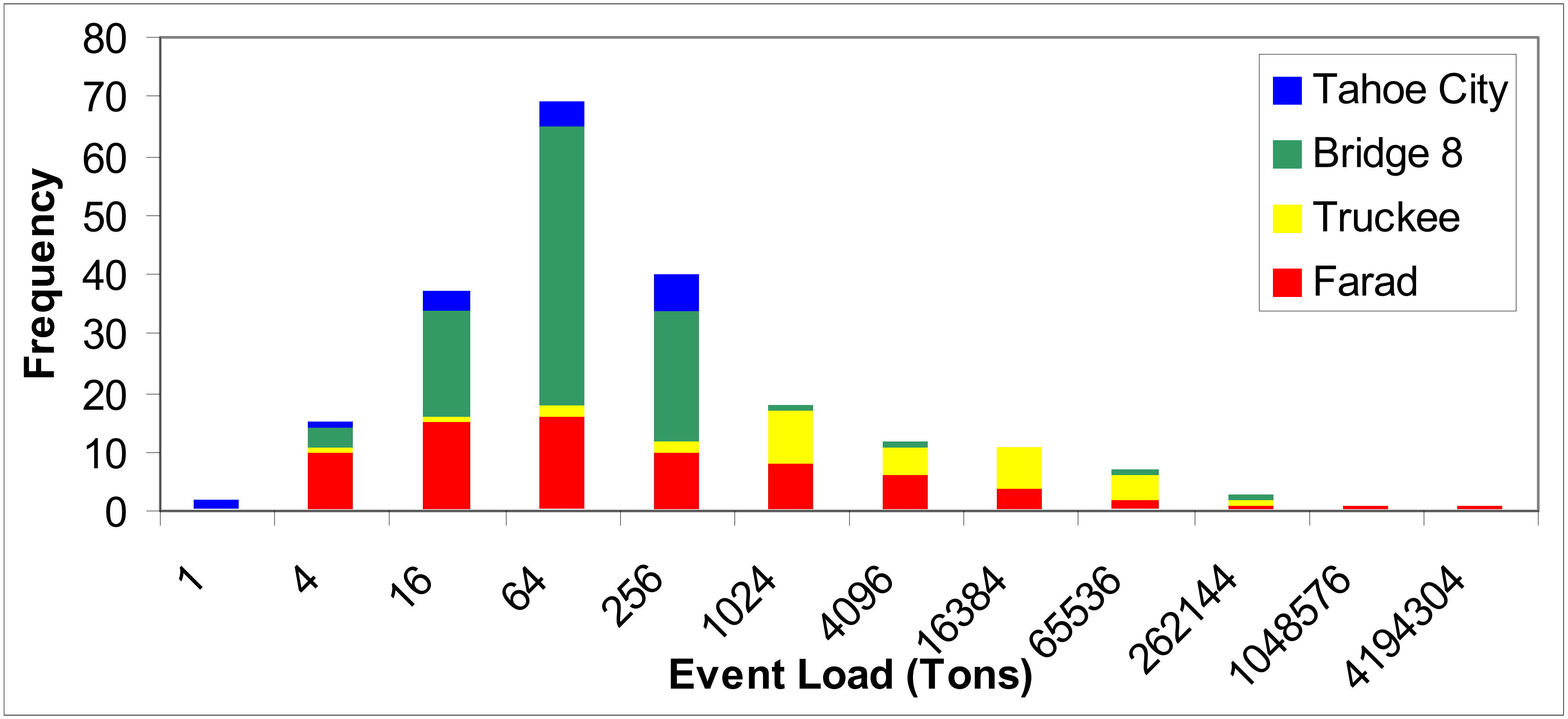


Figure 3.11. Histogram of suspended sediment event loading. Dam events are included in the data for Tahoe City. Bins were determined by starting at 1, then increased by 2^n, where n = 1, 2, 4, 8, 16, 32, 64…..

Duration of sediment events

The highest frequency of sediment event durations, considering all sites together, were in the 25 to 38 hour range, that is about a day to a day and a half (Figure 3.12). The dominance of this temporal signal is in part due to the snowmelt events, which tended to follow a diurnal melting and loading pattern. The distribution of event durations at Bridge 8 was similar to that of all sites considered together. Event durations of 25 to 38 hours were also the most frequent event length at Near Truckee, but unlike other sites, no events above 38 hours were observed at that site. The extremely long events observed at Tahoe City (>200 hours) were due to dam releases. "Regular" event durations at Tahoe City were in the 5 to 8 hour range. In contrast to the other sites, duration of events at Farad were spread more equally among classes from 2 hours in length up to 200 hours in length. This distribution of event durations may be due to the "mixing" of event signals from all upstream sites.

Intensity of sediment events

The intensity of an event is defined here as the sediment event load divided by the event duration (tons/hour). Intensity of events, considering all sites together, occurred most frequently in the 1 to 8 tons/hour range (Figure 3.13). The four sites differed in the event intensity. In order of event intensity, from lowest to highest were Tahoe City in the 0.25 to 2 tons/hour range; Bridge 8 in the 1 to 4 tons/hour range; Farad in the 2 to 16 tons/hour range; and Near Truckee in the 256 to 1,024 tons/hour range. In other words, Near Truckee has more loading in less amount of time than the other sites.

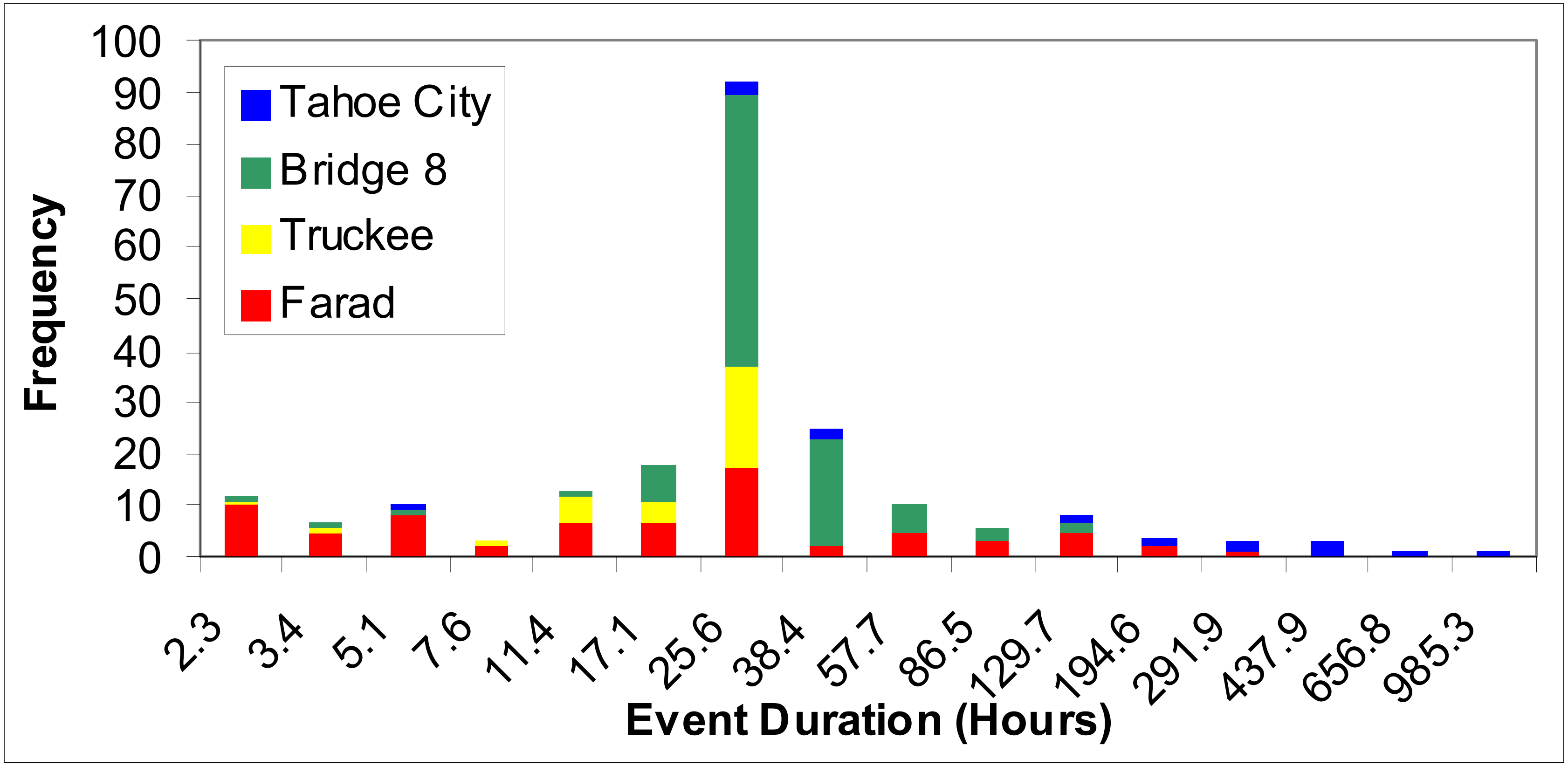


Figure 3.12. Histogram of suspended sediment event duration. Dam events are included in the data for Tahoe City. Bins were determined by starting at 1, then increased by 150%.

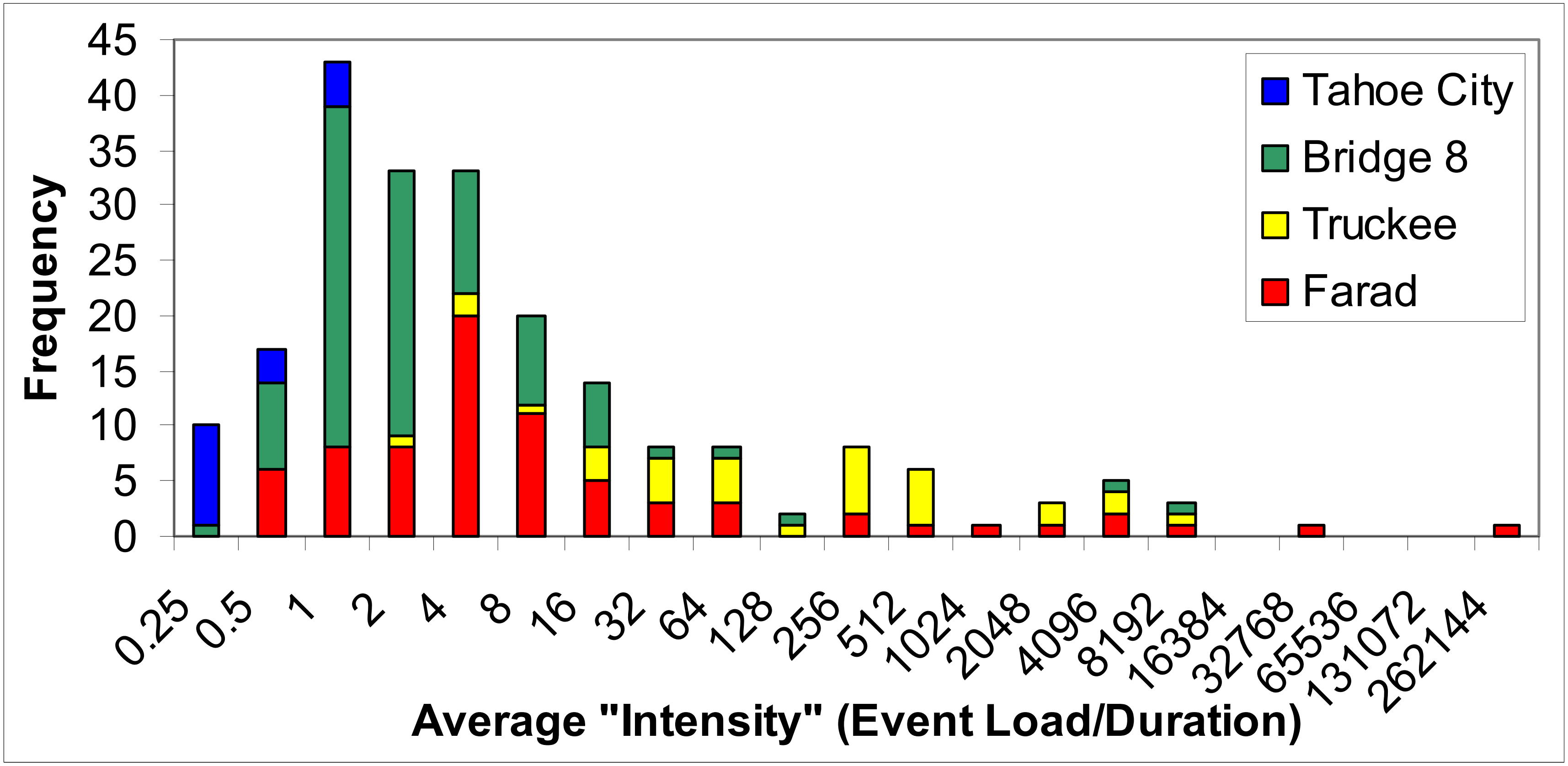


Figure 3.13. Histogram of suspended sediment event intensity (tons/hour). Dam events are included in the data for Tahoe City. Bins were determined as $2^{(n-3)}$, where n = 1, 2, 3, …

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CHAPTER 4: TEMPORAL AND SPATIAL VARIATION OF TURBIDITY

Introduction

The temporal analysis consists of calculating summary statistics including mean, median, maximum and minimum turbidity for all the main portions of the hydrograph during snow melt, summer storms, rain-on-snow events, and base flow. An estimate of the autocorrelation function for turbidity is also included. The autocorrelation function shows persistence and any long-range dependence of turbidity time series. Long-range dependence here means dependence of the current value on the previous values. In addition to examining the temporal characteristics of turbidity, we also explored spatial turbidity patterns for a possible dependence and/or relation between turbidity at different sites. If such a relationship were established, it could be used to predict turbidity at other stations.

Methods

Basic statistical summaries were used to characterize the spatial and temporal patterns of turbidity. In addition, duration (persistence) of high NTU events was determined by autocorrelation analysis. Autocorrelation is the correlation of a time series with itself, but lagged by some time period. If the correlation of a turbidity time series with itself lagged by one time period is large, it indicates that there is a strong relation between the values of series "today" and "tomorrow". If the correlation is positive, it means that a large value of turbidity today will most probably be followed by a large value tomorrow. Therefore, if autocorrelations are large and positive for a few time lags, this indicates that a large (for example) event today will most likely be followed by large events for several days.

All data collected with greater than daily frequency were summarized to daily averages and maximum. In this chapter, all references to NTU refer to continuous field turbidity (as opposed to turbidity determined in the laboratory). Since turbidity patterns seem to follow the same "seasons" as the hydrograph, we divided the data into 4 "seasons" as follows: Winter: December to February; Spring: March to May; Summer: June to August; Fall: September to November.

Results

Temporal and Spatial Variation of Turbidity – Entire Season

Basic statistics cited in this section are found in Appendices A9 through A12. For each pair of consecutive sites along the river, we plotted daily average NTU and daily maximum average NTU (both in logarithmic scale) for the entire available data set and by season. The plots for the entire data sets for both daily average and daily maximum average are presented in Figures 4.1 through 4.6. The plots for seasonal data are presented in Figures 4.7 through 4.21, as part of the section below on "Spatial Variability of Turbidity". In all these plots, two consecutive sampling sites are shown with the upstream site NTU plotted in blue and the site just downstream plotted in red.

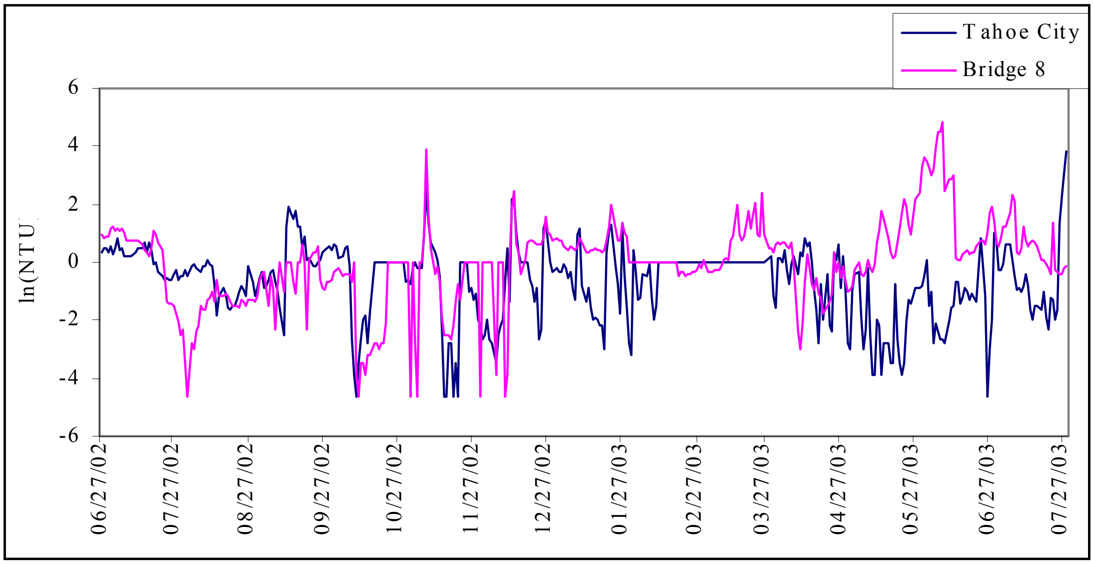

Figure 4.1. Daily average NTU for Tahoe City (TC) and Bridge 8 (B8). All available NTU data included in plots. TC: 9/11/2002 – 6/23/2003; B8: 5/30/2002 – 8/22/2003.

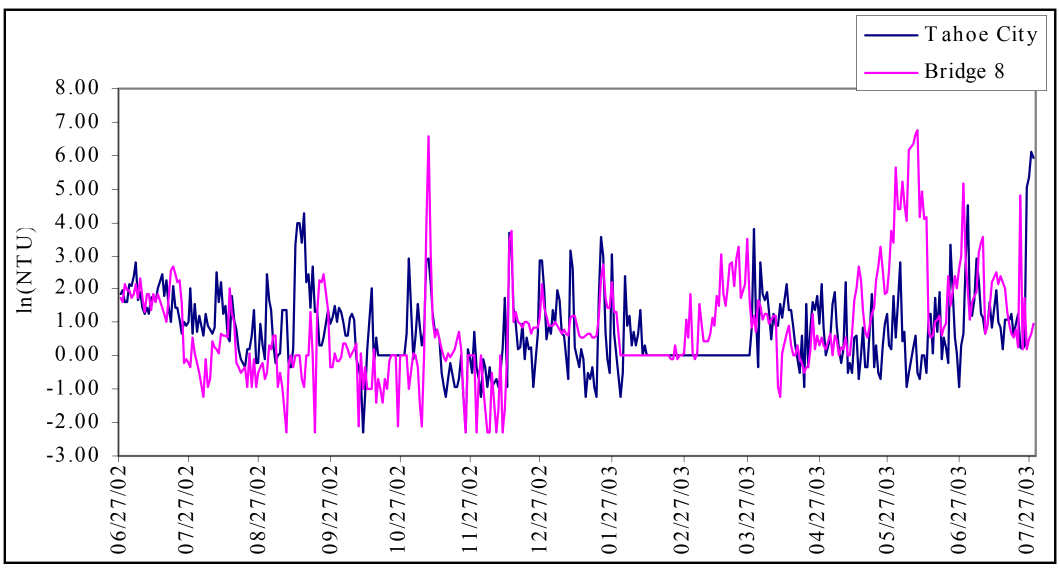

Figure 4.2. Daily maximum average NTU for Tahoe City (TC) and Bridge 8 (B8). All available NTU data included in plots. TC: 9/11/2002 – 6/23/2003; B8: 5/30/2002 – 8/22/2003.

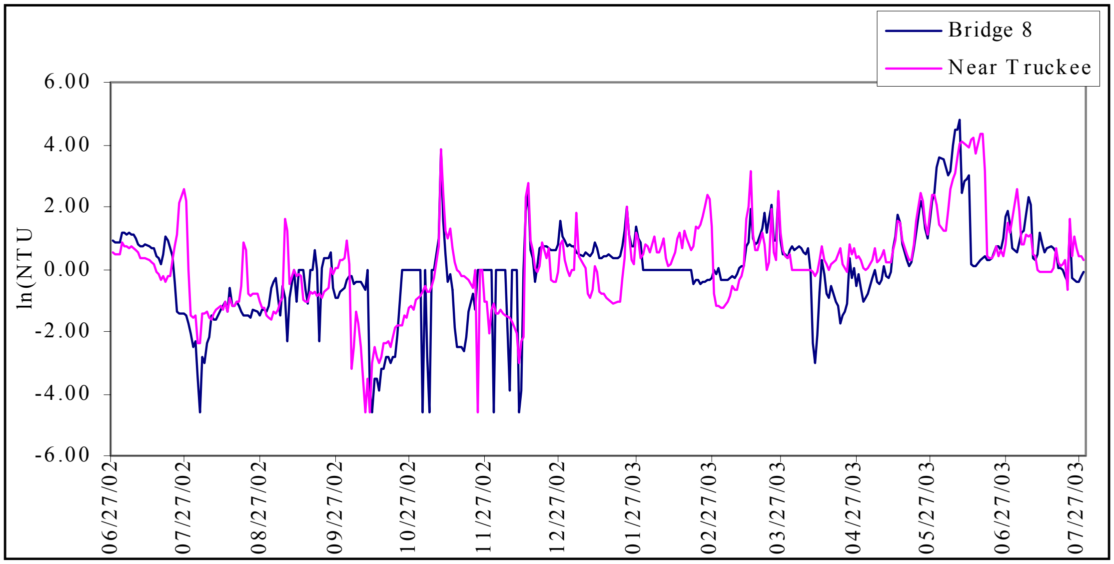

Figure 4.3. Daily average NTU for Bridge 8 (B8) and Near Truckee (NT). All available NTU data included in plots. B8: 5/30/2002 – 8/22/2003; NT: 7/22/2002 – 8/22/2003.

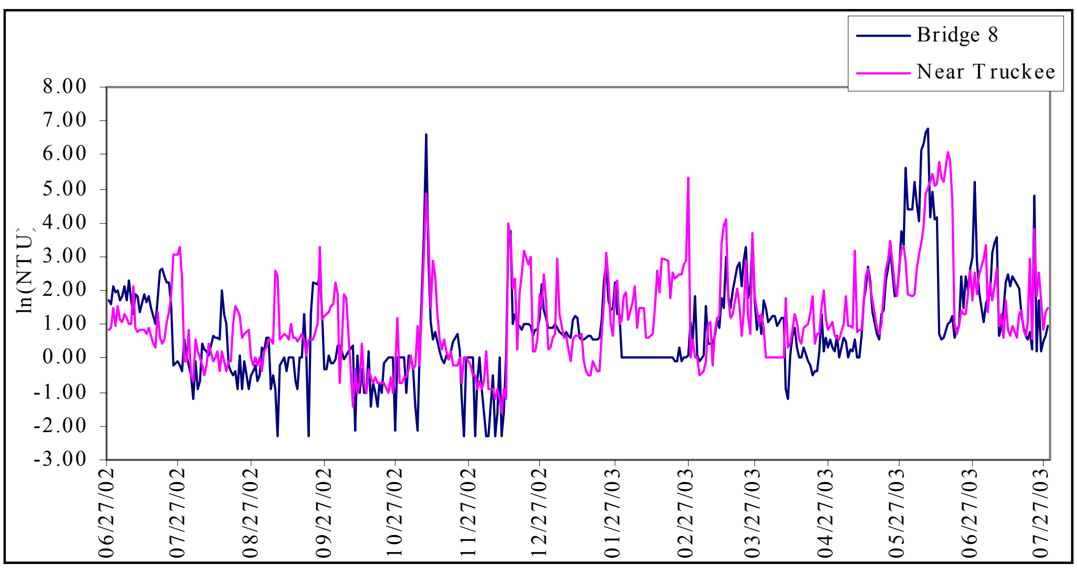

Figure 4.4. Daily maximum average NTU for Bridge 8 (B8) and Near Truckee (NT). All available NTU data included in plots. B8: 5/30/2002 – 8/22/2003; NT: 7/22/2002 – 8/22/2003.

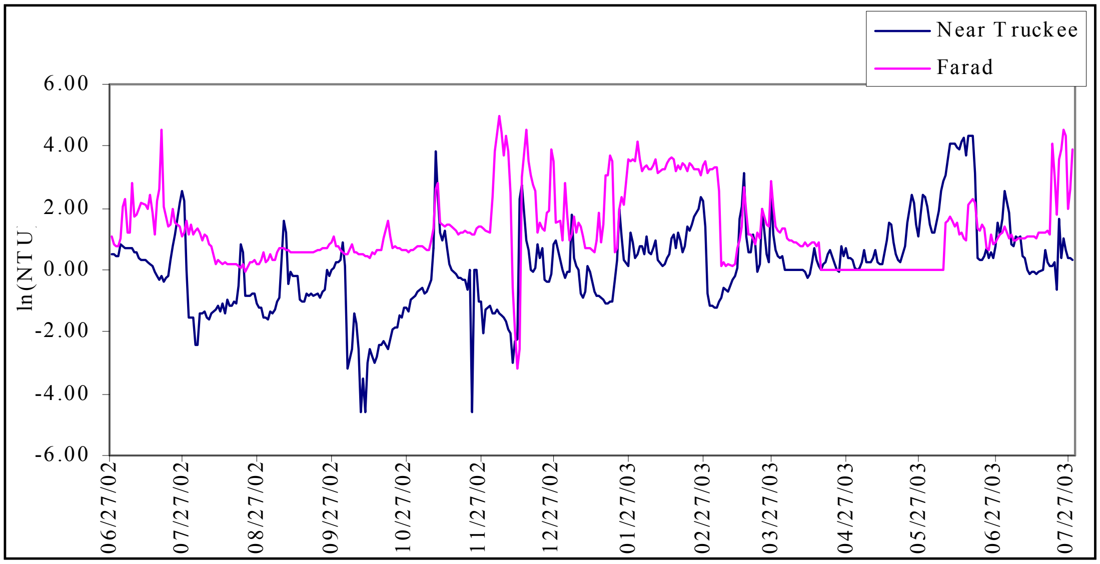

Figure 4.5 Daily average NTU for Near Truckee (NT) and Farad. Available NTU data included in plots NT: 7/22/2002 – 8/22/2003; Farad: 5/16/2002 – 8/01/2003.

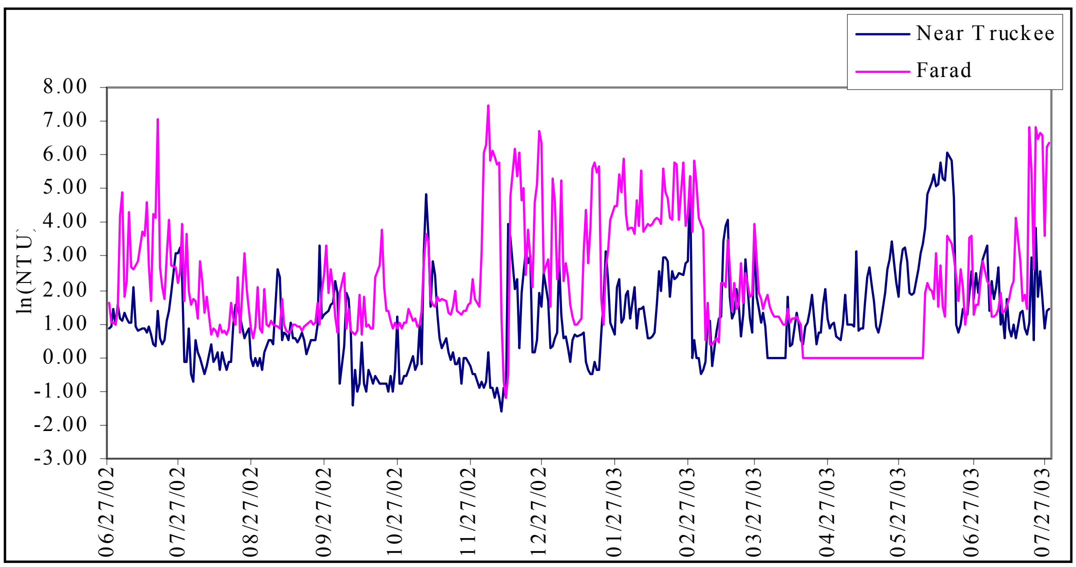

Figure 4.6. Daily maximum average NTU for Near Truckee (NT) and Farad. Available NTU data included in plots NT: 7/22/2002 – 8/22/2003; Farad: 5/16/2002 – 8/01/2003.

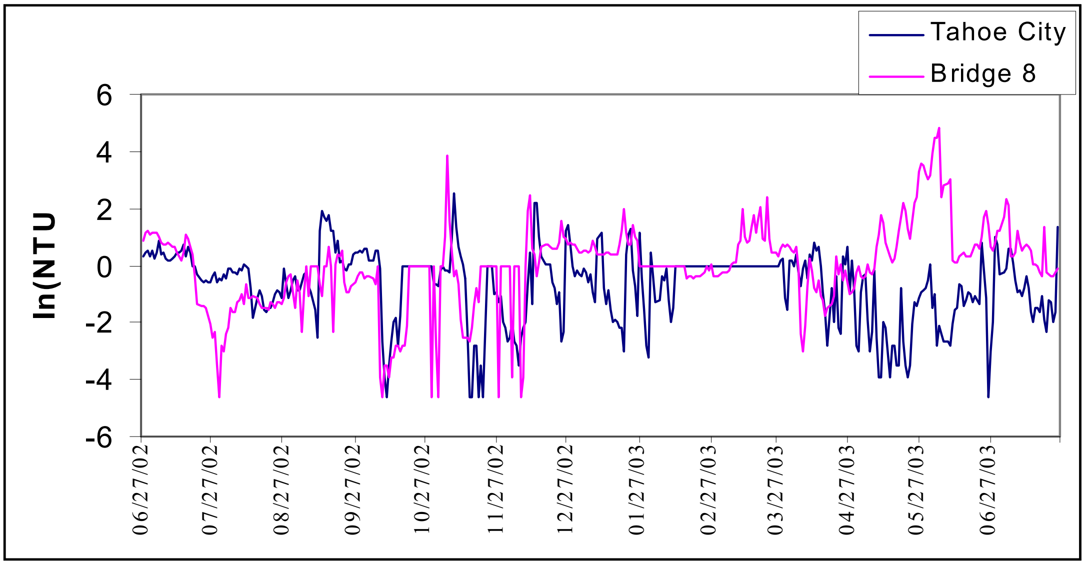

Figure 4.7. NTU at Tahoe City and Bridge 8 for the entire study period – (lag of 3 days).

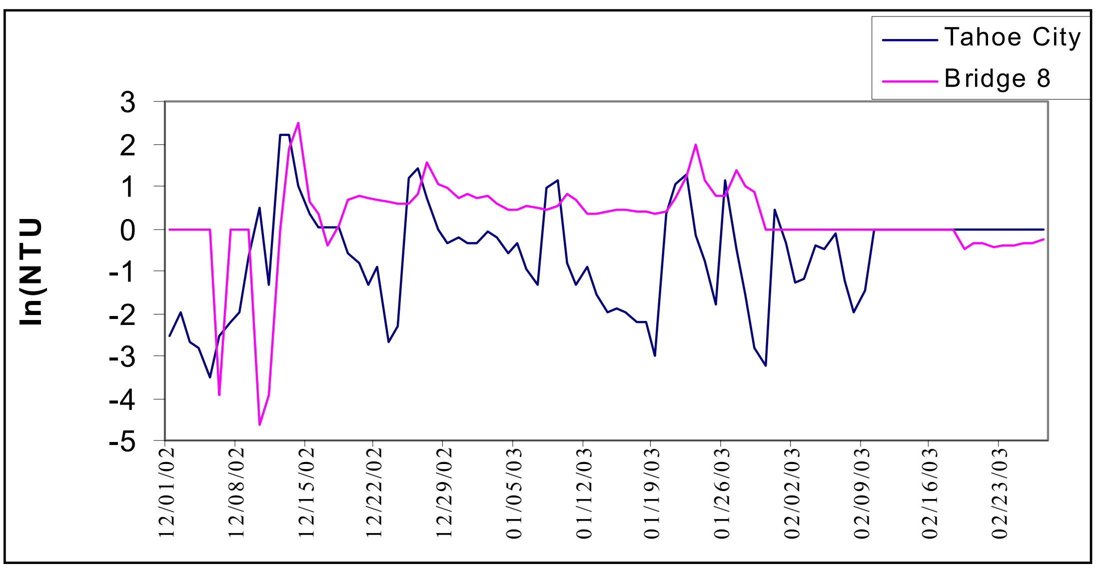

Figure 4.8. NTU at Tahoe City and Bridge 8 – Winter (no lag).

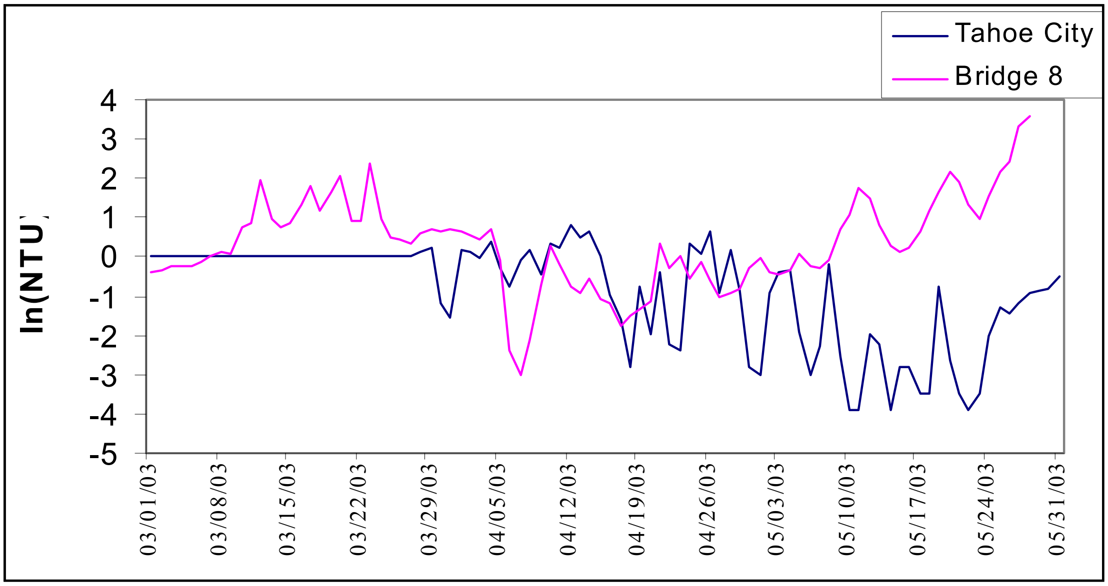

Figure 4.9. NTU at Tahoe City and Bridge 8 – Spring (lag of 3 days).

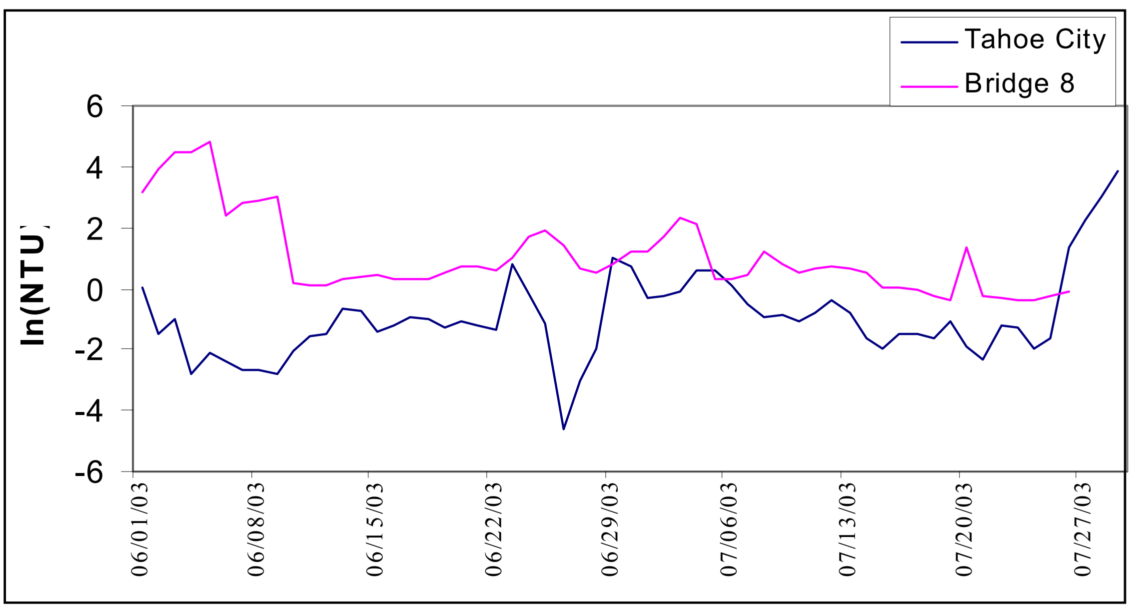

Figure 4.10. NTU at Tahoe City and Bridge 8 – Summer (lag of 3 days).

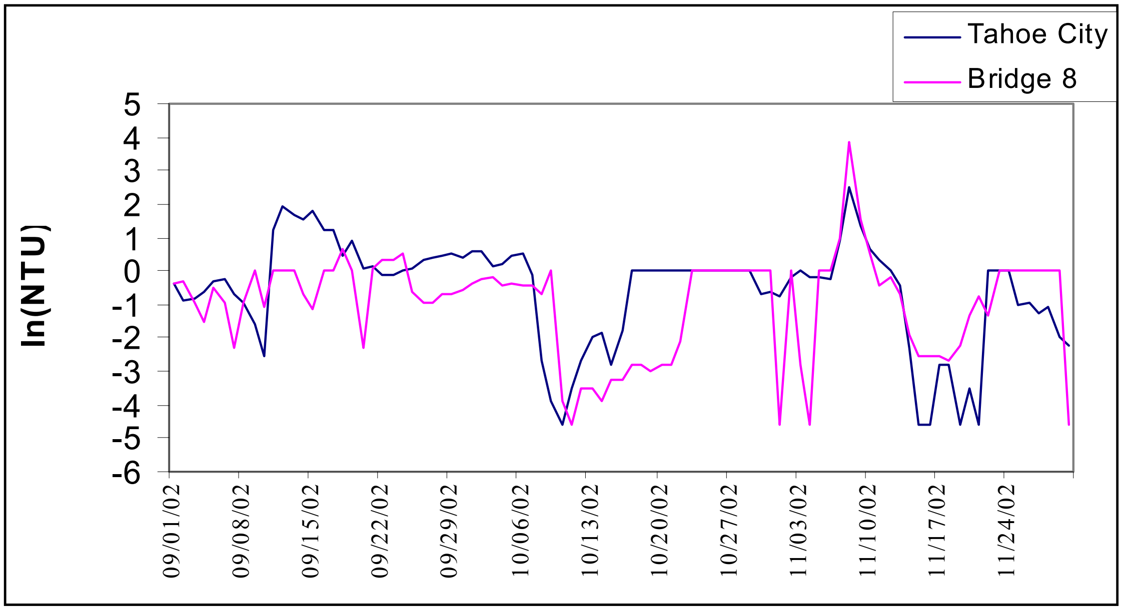

Figure 4.11. NTU at Tahoe City and Bridge 8 – Fall (no lag).

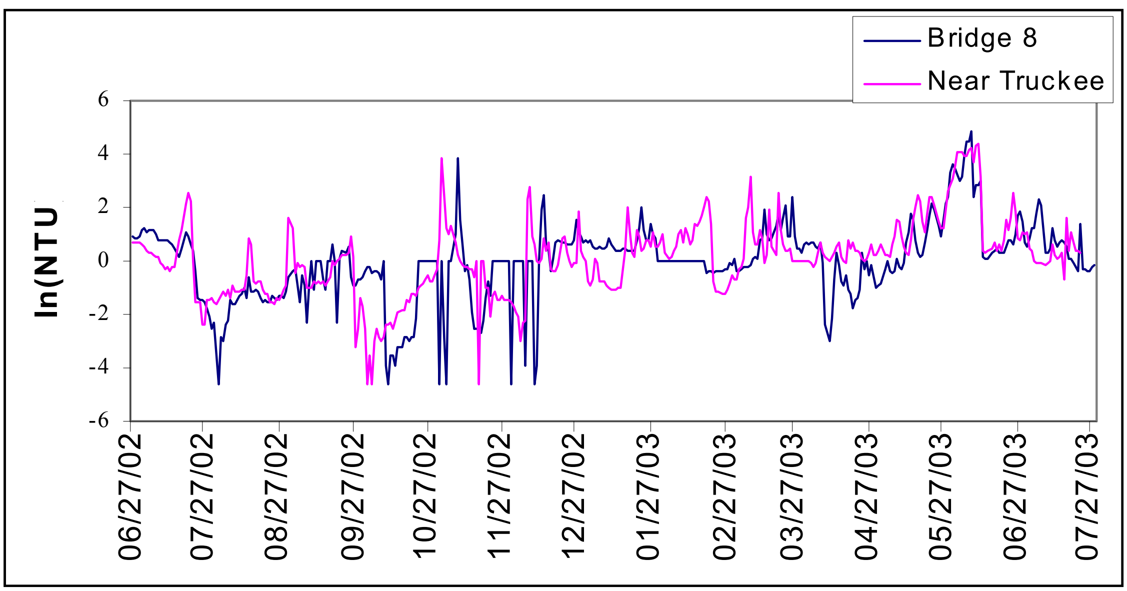

Figure 4.12. NTU at Bridge 8 and Near Truckee 8 for the entire study period – (lag of 6 days).

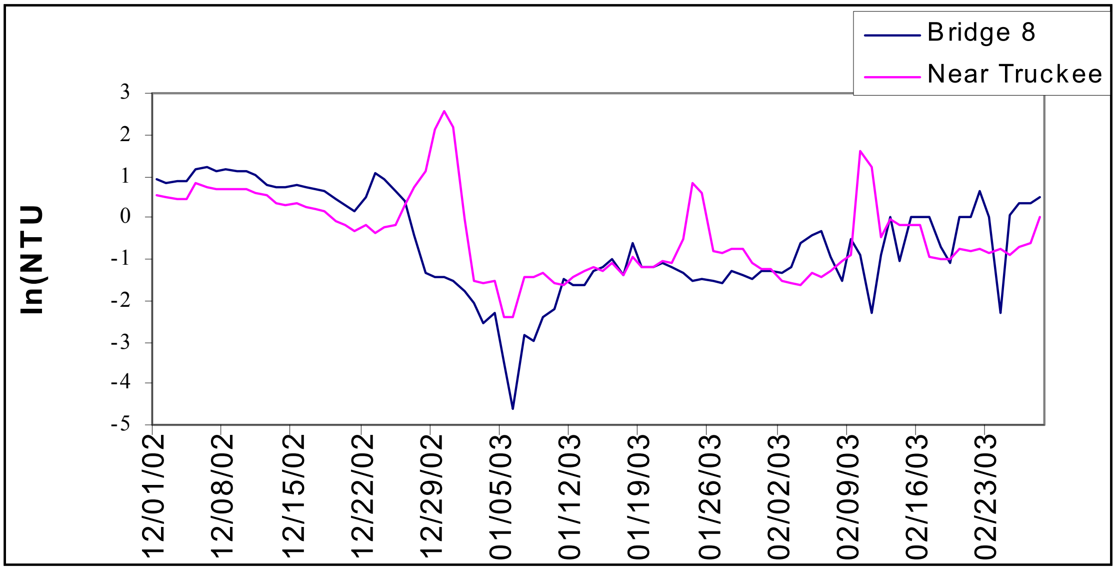

Figure 4.13. NTU at Bridge 8 and Near Truckee – Winter (no lag).

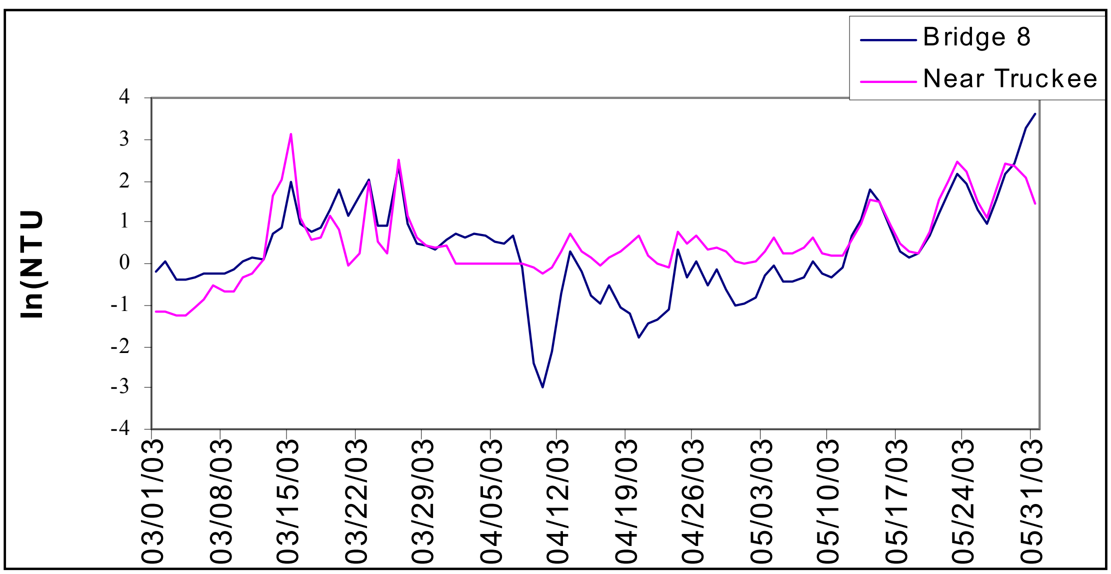

Figure 4.14. NTU at Bridge 8 and Near Truckee – Spring (no lag).

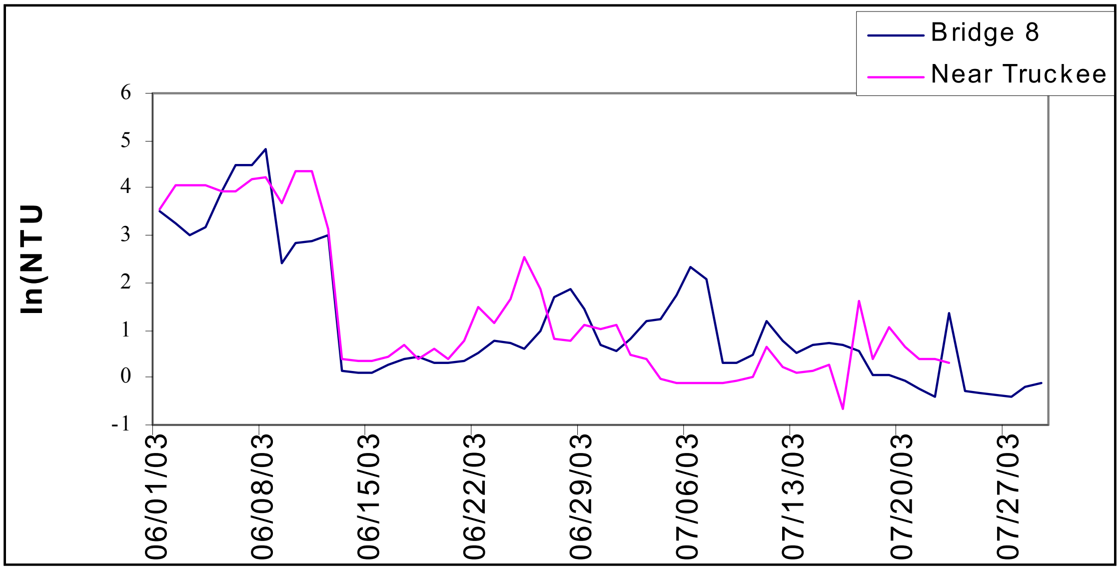

Figure 4.15. NTU at Bridge 8 and Near Truckee – Summer (lag of 6 days).

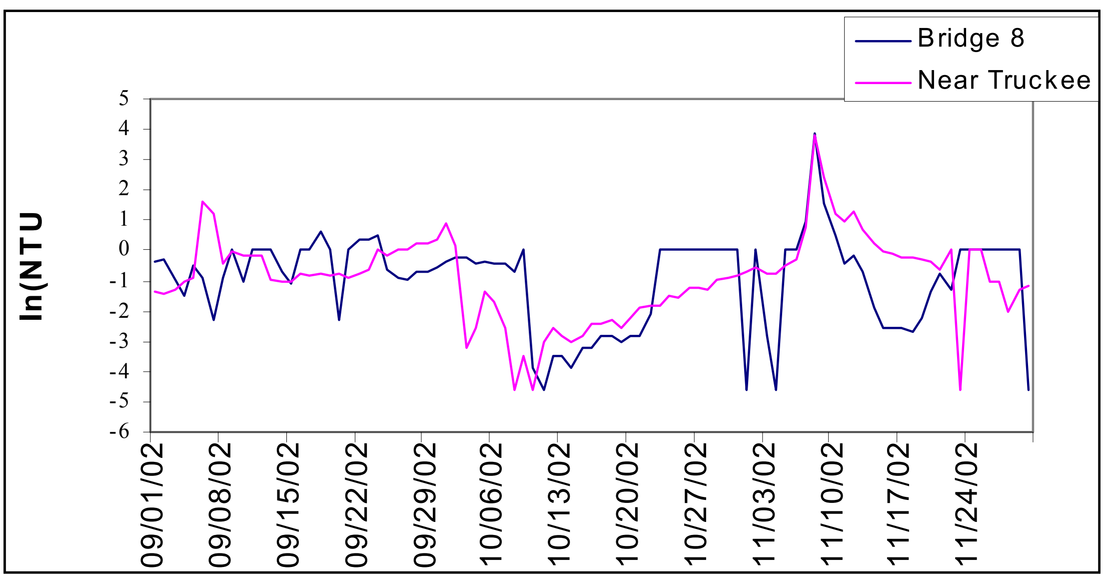

Figure 4.16. NTU at Bridge 8 and Near Truckee – Fall (no lag).

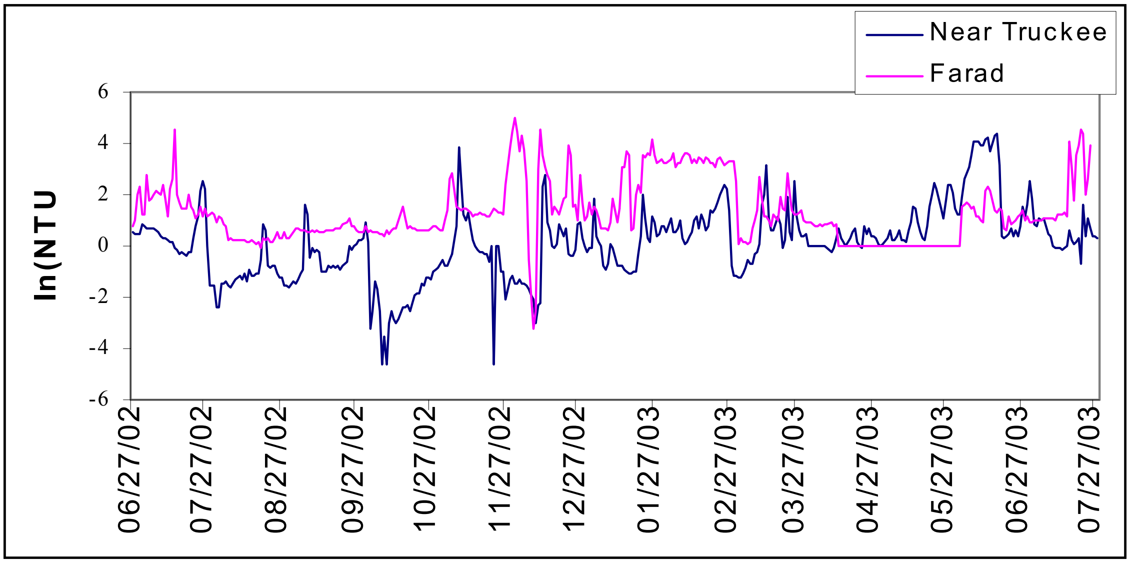

Figure 4.17. NTU at Near Truckee and Farad for the entire study period (lag of 3 days)

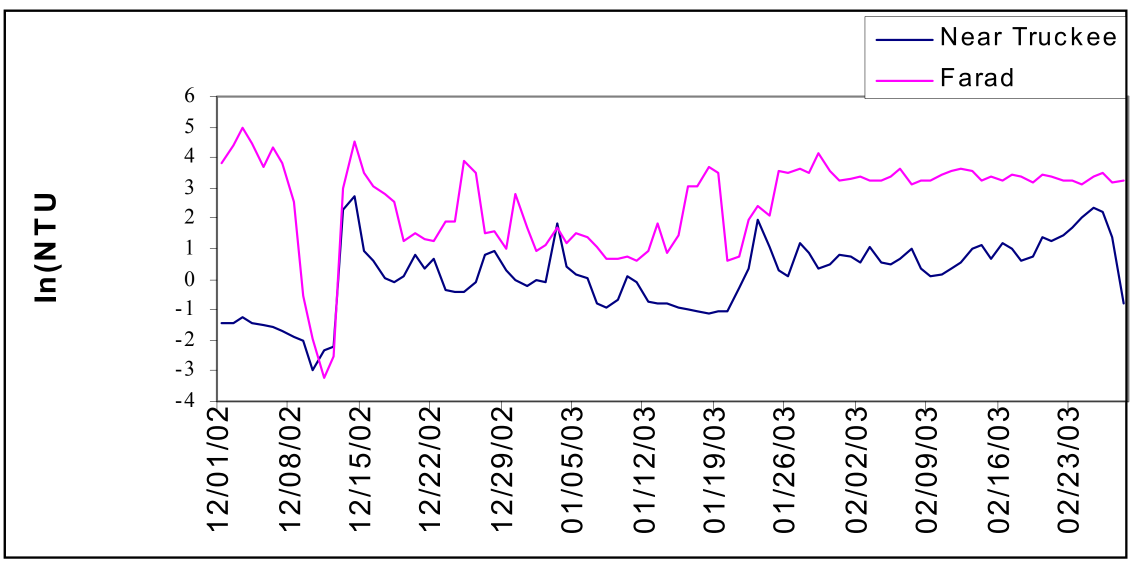

Figure 4.18. NTU at Near Truckee and Farad – Winter (lag of 1 day).

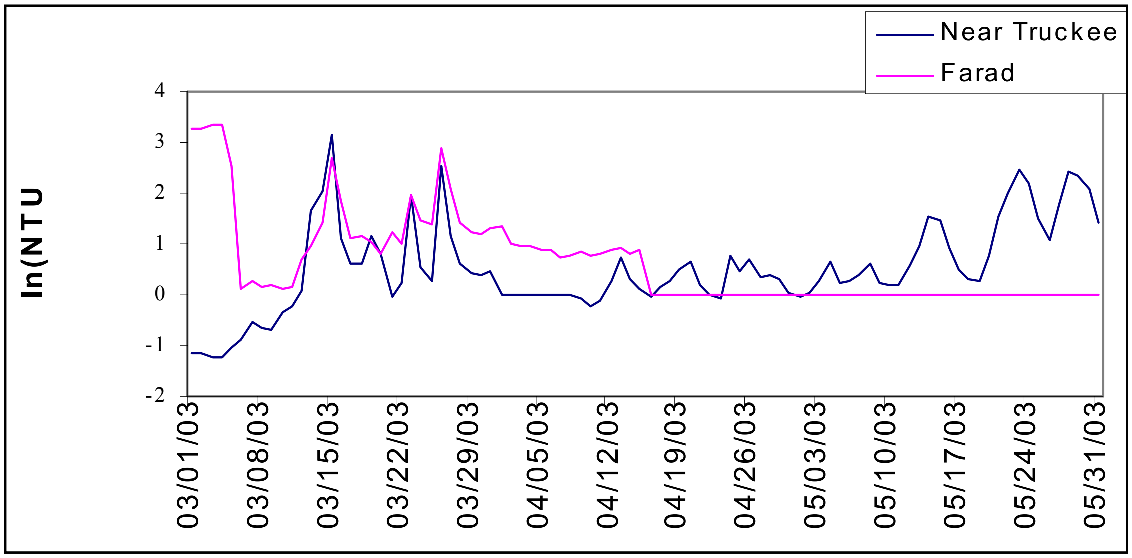

Figure 4.19. NTU at Near Truckee and Farad – Spring (No lag).

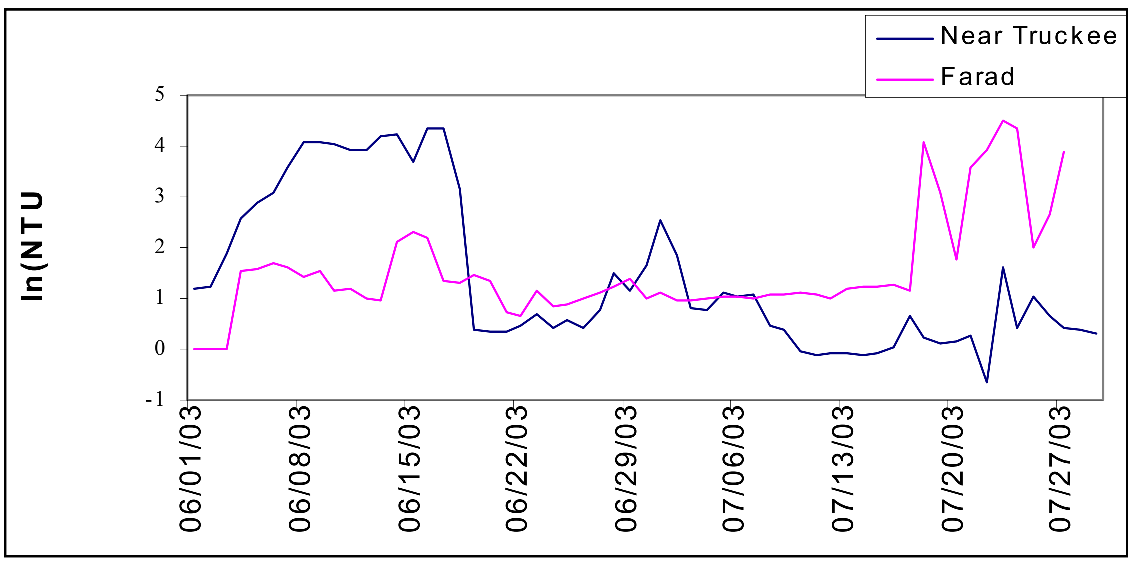

Figure 4.20. NTU at Near Truckee and Farad – Summer (lag of 2 days).

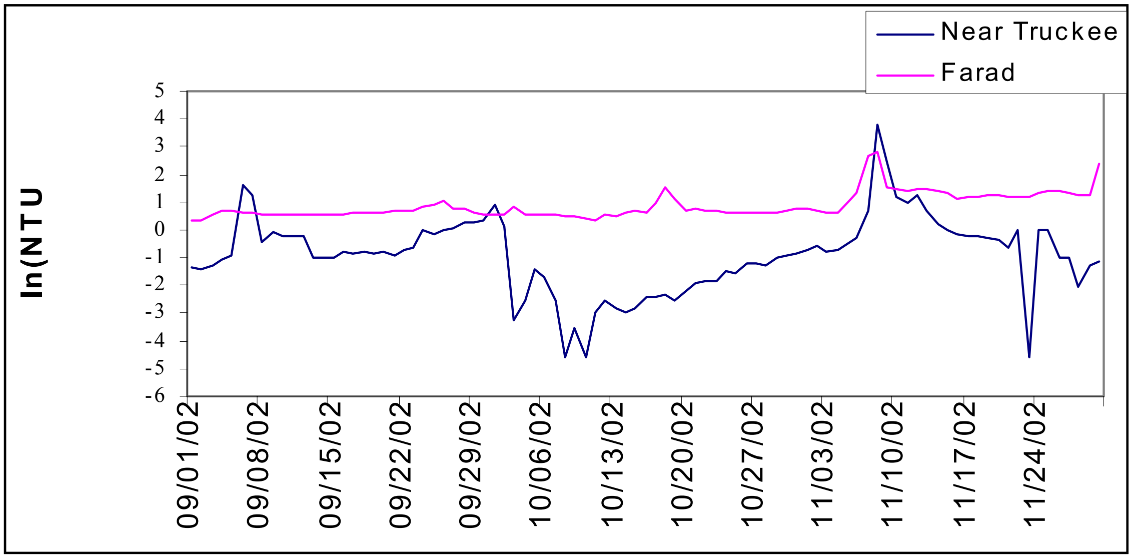

Figure 4.21. NTU at Near Truckee and Farad – Fall (lag of 1 day).

Temporal and Spatial Variation of Turbidity – By Season

Spatial variation of turbidity was assessed by calculating correlations of NTU at pairs of sites with and without lag periods. We analyzed daily average NTU in pairs of stations: an upstream station was paired with the immediate downstream station. We computed the correlation and statistics of NTU at the paired stations, for the entire data set, and for different seasons. The database for this report include data from summer of 2002 through early fall of 2003. Our findings are reported below, by location. All NTU graphs are done on logarithmic scale. The upstream site NTU is plotted in black and the downstream site is plotted in red. Basic statistics cited in the following sections are found in Appendices A13 through A16.

Tahoe City and Bridge 8

NTU at Tahoe City (TC) and Bridge 8 (B8) are highly correlated in winter and fall with no lag periods (Figures 4.7 through 4.11 and Table 4.1) Over the entire study period daily average NTU at TC had lower median (0.52 TC/1.03 B8), maximum (46 TC/122 B8) and lower standard deviation (3.00 TC/10.37 B8) than at B8.

Table 4.1 Correlations between NTU at TC and B8 for the entire study period and for each season. Only the best lag correlations are reported. Lag units are in days.

	No Lag	Best lag
Entire study period	0.017	-0.076 (lag 3)
Winter	0.831	Best with no lag
Spring	-0.099	-0.186 (lag 3)
Summer	-0.066	-0.169 (lag 3)
Fall	0.823	Best with no lag

Bridge 8 and Near Truckee

These two sites have very similar overall features and statistics for daily average NTU. Over the entire study period daily average NTU at B8 had a slightly lower median (1.029 B8/1.185 NT), higher maximum (122 B8/77 NT) and a slightly higher standard deviation (10.37 B8/10.29 NT) than at NT (Figures 4.12 – 4.16). NTU at B8 and NT are highly correlated over the entire study period with a lag of six days; in summer (lag of six days) (Figure 4.15) and in fall (Table 4.2). These correlations are highest in fall with no lag period (Figure. 4.16).

Table 4.2 Correlations between NTU at B8 and NT for the entire study period and for each season. Only the best lag correlations are reported. Lag units are in days.

	No Lag	Best lag
Entire study period	0.441	0.079 (lag 6)
Winter	0.594	Best with no lag
Spring	0.492	Best with no lag
Summer	0.379	0.741 (lag 6)
Fall	0.976	Best with no lag

Near Truckee and Farad

NTU at NT had lower median (1.19 NT/3.28 F), maximum (77 NT/143 F), and standard deviation (10.29 NT/17.53 F) than at F. There is no significant correlation between NTU at NT and at F during the entire study period (Table 4.3). However, there is a high correlation between NTU at NT and at Farad during the fall season (lag of 1 day). NTU followed different patterns for these two sites (Figures 4.17 through 4.21)

Table 4.3 Correlations between NTU at NT and F for the entire study period and for each season. Only the best lag correlations are reported. Lag units are in days.

	No Lag	Best lag
Entire study period	-0.031	-0.046 (lag 3)
Winter	-0.041	0.171 (lag1)
Spring	0.156	Best with no lag
Summer	-0.044	-0.057 (lag 2)
Fall	0.725	0.728 (lag 1)

Temporal and Spatial Variation of High Turbidity Periods

Spatial Correlation of High Turbidity Periods

To determine if there is a significant correlation between high turbidity events upstream and downstream, we evaluated NTU data restricted to: (1) only those observations with maximum daily NTU at upstream site greater than certain a value, and vice-versa, (2) only those observations with maximum daily NTU at downstream site greater than certain a value. The cutpoint values chosen for this analysis were: mean, median and mean plus one standard deviation of NTU at each site. No correlation was found between turbidity extremes at TC and B8 (Table 4.4). High values of NTU at B8 and NT, and at NT and F correlate significantly and quite strongly for some cutpoint values, but not all (Tables 4.5 and 4.6).

Table 4.4. TC and B8 – Correlation between high values of NTU at both sites with p-values.

Restrictions on NTU	Correlation between NTU at TC and B8	p-value
NTU TC > 8.27	-0.078	0.641
NTU TC > 2.25	0.001	0.989
NTU TC > 43.73	-0.195	0.675
NTU B8 > 17	-0.147	0.447
NTU B8 > 2	-0.032	0.685
NTU B8 > 100.6	0.343	0.332

Table 4.5. B8 and NT – Correlation between high values of NTU at both sites with p-values.

Restrictions on NTU	Correlation between NTU at TC and B8	p-value
NTU B8 > 17	0.369	0.034
NTU B8 > 2	0.275	0.0003
NTU B8 > 100.6	0.337	0.341
NTU NT > 13.1	0.107	0.433
NTU NT > 2.6	0.238	0.0016
NTU NT > 56.3	-0.362	0.185

Table 4.6. NT and F – Correlation between high values of NTU at both sites with p-values.

Restrictions on NTU	Correlation between NTU at TC and B8	p-value
NTU NT > 13.1	-0.088	0.562
NTU NT > 2.6	-0.082	0.311
NTU NT > 56.3	0.065	0.817
NTU Farad > 68	0.192	0.181
NTU Farad > 6.8	0.29	0.0003
NTU Farad > 247	0.91	0

Duration (Persistence) of turbidity periods

Autocorrelation analysis of the NTU time series shows that the persistence patterns of high turbidity are different in all locations and also differ by season (Table 4.7). In general (apart from summer at B8), NTU conditions persist longer at TC during the winter and spring seasons than at NT, F or B8. The autocorrelation at B8 in summer is significantly greater than zero for very long time periods. This is because in summer at B8 is an essentially monotonic function (first increasing and then decreasing) (Figure 4.15).

Table 4.7 Length of time (in days) with autocorrelation of the NTU series significantly different from zero at 5% significant level for all seasons and locations.

	TC	B8	NT	F
Winter	1 and 13	1	1	3
Spring	4 and 12	3	2	2
Summer	2	63	9	6
Fall	3	0	1	3
Entire data	3	9	11	14

Maximum of high turbidity periods

Daily maxima of NTU were computed for all sites and all seasons. Both means and maxima of daily maximum NTU are largest in summer in all locations except Farad, where the largest mean and maximum daily maximum occurred in winter. That means that the largest NTU events occur in summer and in essentially all locations. The smallest values of the means of daily maxima occur in fall except TC and B8 where they occur in spring and winter respectively. Also smallest values of the maximum of daily maximum occur in winter except NT and Farad where they occur in spring and fall respectively. NTU is most volatile in the summer. The largest daily maximum was observed in F (NTU=1767.5), the second largest at B8 (NTU=875.6), then at TC (NTU=450.8), and finally at NT (NTU=445.1). Daily maxima have the largest standard deviation in F (179.1) followed by B8 (83.6), NT (43.2) and TC (35.5). Table 4.8 reports seasons with the largest and smallest means and maximums for daily averages and daily maximum NTU by site. Summary statistics for daily maxima are included in Appendices A13 through A16.

Table 4.8. Seasons with largest and smallest mean and maximum daily average and daily maximum NTU. L – Largest NTU, S – Smallest NTU, Sp – Spring, Su – Summer, F – Fall, W – Winter.

	Tahoe City				Bridge 8				Near Truckee				Farad			
	Daily Average		Daily Maximum		Daily Average		Daily Maximum		Daily Average		Daily Maximum		Daily Average		Daily Maximum	
	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S
Mean	Su	Sp	Su	Sp	Su	F	Su	W	Su	F	Su	F	W	F	W	F
Max	Su	Sp	Su	W	F	W	Su	W	Su	W	Su	Sp	W	F	W	F

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APPENDICES

Appendix A1. Data set used for development of predictive models. Contains SSC data and corresponding information on explanatory variables. The values of the other variables were time matched to the time the SSC samples were collected. The first four columns contain the information on date and time (in minutes from midnight) of SSC sampling; temp – water temperature (^oC), NTU - continuous field turbidity (nephelometric turbidity units), flow – stream discharge (cfs), SSC – suspended sediment concentration (mg/L), spcond – specific conductivity (mS/cm), NTU lab – field collected turbidity measured in laboratory (nephelometric turbidity units); site: TC – Tahoe City, B8 – Bridge 8, NT – Near Truckee, F – Farad.

year	month	day	min	temp	NTU	flow	ssc	spcond	NTUulab	site
2002	6	5	661	16.36	0.4	71	7.83	0.096	0.25	TC
2002	6	10	976	16.21	0.6	71	1.17	0.094	0.34	TC
2002	6	18	1051	16.17	0.6	71	0.7	0.093	0.17	TC
2002	6	24	1006	17.99	1.8	178	6.6	0.093	0.6	TC
2002	7	5	811	19.74	3.9	312	2.36	0.094	0.32	TC
2002	9	18	646	16.78	1.5	111	4.77	0.094	1.42	TC
2002	9	18	661	17.07	1.7	111	4.69	0.094	1.66	TC
2002	10	17	900		0	18	0.47		3	TC
2003	1	7	750	5.25	0.5	82	1	0.095	0.76	TC
2003	2	25	610			56	0.8		0.5	TC
2003	4	2	685	4.26	1	78	2.43	0.098	1.76	TC
2003	4	17	545	6.67	0	69	1	0.097	0.51	TC
2003	4	24	610	6.41	3.1	71	6.4	0.099	1.73	TC
2003	5	1	590	7.19	0.1	68	2	0.098	0.9	TC
2003	5	10	660	9.22	0.8	74	2.4	0.096	0.58	TC
2003	5	17	615	9.51	0	79	0.5	0.094	0.34	TC
2003	5	22	585	11.72	0	81	3	0.094	0.42	TC
2003	5	29	640	14.56	0.4	79	0.7	0.094	0.44	TC
2003	6	5	560	16.92	0.1	65	1.1	0.096	0.58	TC
2003	6	19	705	19.12	0.9	69	1.4	0.093	0.36	TC
2003	6	26	690	18.68	0	69	1.2	0.093	0.5	TC
2003	7	17	720	19.8	0.2	361	5	0.093	0.76	TC
2003	8	14	635			329	1.2		0.44	TC
2002	6	5	616	10.59	0.5	-9.9	10.4	0.069	0.85	B8
2002	6	10	901	14.83	0.6	-9.9	3.55	0.079	0.62	B8
2002	6	18	976	17.5	0.2	-9.9	4.6	0.071	0.61	B8
2002	6	18	1006	17.24	0.8	-9.9	2.4	0.07	0.52	B8
2002	6	24	946	19.3	0.4	-9.9	3.4	0.086	0.64	B8
2002	7	5	721	18.55	1.7	-9.9	6.34	0.093	0.86	B8
2002	9	18	676	14.87		-9.9	0.74	0.095	0.25	B8
2002	10	17	856	11.94	0	0.03	2.1		0.39	B8
2003	1	7	796	3.12	1.7	-9.9	0.6	0.104	0.46	B8
2003	1	7	795	3.12	1.7		0.6	0.104	0.46	B8
2003	2	25	640	3.8	0.7		0.9	0.105	0.7	B8
2003	4	2	790	2.85	1.7		1.42	0.089	0.8	B8
2003	4	10	611	5.83	0		0.5	0.093	0.72	B8

Appendix A1. Data set used for development of predictive models (continued).

year	month	day	min	temp	NTU	flow	ssc	spcond	NTUulab	site
2003	4	17	585	4.82	0.4		7.1	0.098	0.94	B8
2003	4	24	655	4.87	3.1		9.5	0.097	1.55	B8
2003	5	1	630	5.69	1		0.92	0.11	1.76	B8
2003	5	10	685	7.38	0.6		0.5	0.105	0.54	B8
2003	5	17	655	7.38	1		4.8	0.085	1.07	B8
2003	5	22	630	8.1	1.8		9.3	0.079	1.71	B8
2003	5	29	680	9.21	4.8		28.8	0.069	1.89	B8
2003	6	5	600	8.93	7.3		20.1	0.067	0.81	B8
2003	6	19	670	12.7	1.5		119	0.07	0.88	B8
2003	6	26	615	12.56	1.8		2.54	0.08	0.77	B8
2003	7	17	680	18.65	0.7		32.3	0.092	1.46	B8
2003	8	14	585	17.33	0		9.5	0.094	0.51	B8
2002	6	24	901			224	3.4		0.7	NT
2002	7	5	676	17.39	1.5	361	5.43	0.096	0.53	NT
2002	8	8	631	16.62	0.1	295	2.9	0.096	1.36	NT
2002	9	18	736	15.73	0.1	112	0.97	0.102	0.49	NT
2002	11	8	661	3.69	85.91	128	56.4	0.106	30.7	NT
2002	11	8	751	4.01	46.93	192	59.1	0.101	13.1	NT
2002	11	8	781	4.05	42.19	228	62.3	0.103	10.5	NT
2002	11	8	916	4.01	47.99	305	80.2	0.099	14.4	NT
2002	11	8	961	4.02	50.01	295	69	0.094	10.5	NT
2002	11	8	1021	4.08	44.08	305	63.4	0.09	13	NT
2002	11	9	661	3.84	6.75	115	7.61	0.108	3.12	NT
2002	10	17	946	12.56	0	22	0.6	0.115	0.24	NT
2003	1	7	825	3.18	0.3	121	1.1	0.105	0.58	NT
2003	2	25	670	3.51	9.1	94	0.4	0.11	0.6	NT
2003	4	2	810			245	1.48		0.76	NT
2003	4	10	630	6.19	0.5	212	3.3	0.09	1.08	NT
2003	4	17	630	5.27	0.7	185	1.7	0.096	0.58	NT
2003	4	24	705	5.44	2.8	224	6.6	0.095	1.96	NT
2003	5	1	695	6.96	0.7	181	1.61	0.101	1.27	NT
2003	5	10	715	7.93	1.1	196	0.7	0.096	1.29	NT
2003	5	17	705	7.82	0.9	371	2.5	0.074	1.1	NT
2003	5	22	685	8.78	2	456	5.3	0.068	2.13	NT
2003	5	29	720	9.66	3.4	564	8	0.06	2.52	NT
2003	6	5	620	8.47	8	398	2.83	0.057	1.87	NT
2003	6	19	635	10.66	1.2	204	3.2	0.064	1.1	NT
2003	6	26	585	11.48	2.1	143	2.5	0.081	1	NT
2003	7	17	575	16.51	1.5	387	7.6	0.103	2.85	NT
2003	8	14	545	16.45	3.6	340	2.4	0.099	0.58	NT
2002	5	9	796	9.98	2.5	1012.56	50.6	0.078	1.7	F
2002	5	9	991	10.96	2.6	990.58	18.2	0.079	1.5	F
2002	5	11	646	8.66	2	940.45	168.4	0.081	1.4	F
2002	5	11	826	10.67	2	926.41	13.6	0.081	1.4	F
2002	5	17	856	12.1	4.2	1080.27	14	0.073	1.6	F
2002	5	27	751	10.74	3.1	1034.83	6.39	0.074	1.24	F
2002	6	5	496	10.96	5.1	1308.32	56.3	0.07	1.95	F
2002	6	10	751	12.92	3.7	864.85	330	0.077	1.24	F
2002	6	18	826	16.47	2.9	649.47	45.2	0.081	1.31	F
2002	6	24	811	17.18	3.2	470.5	4.2	0.092	1.2	F
2002	6	30	781	18.67	1.8	448	4.1	0.098	1	F

Appendix A1. Data set used for development of predictive models (continued).

year	month	day	min	temp	NTU	flow	ssc	spcond	NTUulab	site
2002	7	5	586	15.47	3.4	574	32.9	0.096	1	F
2002	7	12	1066	19.72	8.6	579	23.9	0.1	1.23	F
2002	7	12	1186	19	3.7	579	7.85	0.1	1.51	F
2002	7	17	1066	17.75	4.7	574	4.6	0.1	1.44	F
2002	7	17	1126	17.54	5.5	568	108	0.1	1.26	F
2002	8	8	556	14.61	1.7	392	2.2	0.112	1.2	F
2002	10	17	976	13.42	1.7	448	8.2	0.093	1.56	F
2002	11	7	871	7.6	2.6	368	4.7	0.099	1.35	F
2003	1	8	824	1.83	1.7	290	17.8	0.132	1.47	F
2003	2	16	645	3.78	31.4	337	3.2	0.132	1.13	F
2003	2	16	705	4.19	17.5	340	3.2	0.136	1.35	F
2003	2	16	840	4.66	26.5	333	4.4	0.131	1.08	F
2003	2	25	730	4.05	12.3	297	3.8	0.132	1.1	F
2003	3	23	660	6.59	9	713	6.04	0.112	2.3	F
2003	3	23	865	6.83	11.4	690	462	0.106	3.97	F
2003	3	23	1095	6.94	7.5	655	12.9	0.1	3.54	F
2003	3	24	930	8.63	3.2	638	29.83	0.101	2.53	F
2003	3	27	580	4.79	6.9	955	16.62	0.088	3.7	F
2003	4	2	870	5.94	2.3	865	6.7	0.093	1.9	F
2003	4	10	673	8.08	2	838	23.03	0.094	2.14	F
2003	4	17	675	6.87		756	3.04	0.101	1.38	F
2003	4	24	1005	8.32		508	24.04	0.114	0.76	F
2003	4	24	790	8.37		499	46.3	0.115	1.12	F
2003	5	1	765	9.1		762	3.18	0.1	2.65	F
2003	5	10	760	9.5		661	1.9	0.102	1.25	F
2003	5	17	755	9.61		885	65.9	0.086	1.55	F
2003	5	22	745	10.57		1060	23.9	0.079	3.48	F
2003	5	29	775	11.29		1210	60.1	0.069	6.79	F
2003	6	5	800	12.24		926	41.5	0.068	2.53	F
2003	6	19	540	11.6	3.7	644	6.37	0.074	1.79	F
2003	6	26	525	11.56	1.7	499	3.3	0.093	1.71	F
2003	7	17	530	15.14	3.3	666	8.2	0.096	2.22	F
2003	7	22	990	19.82	3.9	649	9	0.097	2.74	F
2003	7	23	960	19.24	5.1	666	1488	0.096	1083	F
2003	7	23	990	19	391.4	672	3011	0.095	2599	F
2003	7	23	1050	18.57	170.1	725	223.9	0.094	66.1	F
2003	7	23	1170	17.95	51.1	678	319.7	0.097	42.6	F
2003	7	23	1230	17.75	58.9	666	120.2	0.101	45.7	F
2003	7	23	1290	17.81	34.7	661	49.2	0.098	14.4	F
2003	8	14	510	15	2	508	6.6	0.103	2.32	F

Appendix A-2. Statistics for monthly estimated suspended solids concentration

Month	Average	Std	Max	Min	Median	Month	Average	Std	Max	Min	Median
		mg L^{-1}						mg L^{-1}			
		Tahoe City						**Bridge 8**			
Jun 02	n.d.	n.d.	n.d.	n.d.	n.d.	Jun 02	24.2	33.8	381.3	5.4	13.7
Jul 02	11.8	1.7	21.1	3.7	12.1	Jul 02	21.5	22.4	260.5	6.3	14.8
Aug 02	9.1	0.9	15.4	3.8	9.1	Aug 02	7.9	4.0	149.5	5.5	7.4
Sept 02	5.1	1.1	9.4	1.7	4.9	Sept 02	n.d.	n.d.	n.d.	n.d.	n.d.
Oct 02	2.7	0.5	4.7	2.1	2.5	Oct 02	n.d.	n.d.	n.d.	n.d.	n.d.
Nov 02	2.9	2.7	27.3	0.1	2.4	Nov 02	n.d.	n.d.	n.d.	n.d.	n.d.
Dec 02	2.5	1.5	19.0	1.9	2.2	Dec 02	6.7	14.2	178.2	0.7	4.2
Jan 03	2.8	0.7	12.4	0.4	2.7	Jan 03***	9.6	13.1	134.6	4.4	5.6
Feb 03	n.d.	n.d.	n.d.	n.d.	n.d.	Feb 03	n.d.	n.d.	n.d.	n.d.	n.d.
Mar 03	n.d.	n.d.	n.d.	n.d.	n.d.	Mar 03	15.1	20.7	187.2	3.0	7.4
Apr 03	2.9	0.4	18.0	2.2	2.8	Apr 03	5.3	2.8	41.0	2.6	4.3
May 03	3.1	0.4	5.7	2.6	3.1	May 03	39.8	95.1	4397	2.5	11.2
Jun 03	3.9	0.5	7.3	1.8	3.8	Jun 03	7786	299450	15625342	10.6	33.4
Jul 03**	10.4	13.7	590.1	4.6	9.1	Jul 03	24.6	31.0	558.3	7.7	13.3
		Truckee						**Farad**			
Jun 02	n.d.	n.d.	n.d.	n.d.	n.d.	Jun 02	444344	3646906	41839332	14.5	29.4
Jul 02	14.1	2.9	28.7	3.7	14.3	Jul 02	1258	33493	1179883	10.5	30.1
Aug 02	9.5	1.1	12.7	7.1	9.5	Aug 02	16.7	2.2	34.3	4.0	16.1
Sept 02	5.1	1.2	10.1	2.8	4.9	Sept 02	17.6	3.6	112.2	14.2	17.4
Oct 02	n.d.	n.d.	n.d.	n.d.	n.d.	Oct 02	14.4	8.8	196.2	9.7	13.8
Nov 02	13.4	90.9	1539	0.8	3.1	Nov 02	30.4	143.9	2345.7	4.8	9.3
Dec 02	101.1	938.7	15266	1.5	2.7	Dec 02	1195	57658	3141868	0.0	7.6
Jan 03	7.7	49.9	844.0	2.6	3.4	Jan 03	83.8	236.4	4724	4.3	8.7
Feb 03	3.7	1.6	51.4	2.5	3.4	Feb 03	37.1	66.8	378.8	4.9	10.4
Mar 03*	80.1	705.5	10446	0.7	3.9	Mar 03	3571	26598	298927	5.8	12.9
Apr 03	n.d.	n.d.	n.d.	n.d.	n.d.	Apr 03	n.d.	n.d.	n.d.	n.d.	n.d.
May 03	4247	19410	206830	4.0	7.4	May 03	n.d.	n.d.	n.d.	n.d.	n.d.
Jun 03	1342	3014	29415	3.4	13.7	Jun 03	n.d.	n.d.	n.d.	n.d.	n.d.
Jul 03	11.6	2.9	23.9	4.8	12.2	Jul 03	614	12782	594038	22.7	33.7

n.d. = Not determined due to missing data

*1% of this month's values are missing

** 5% of this month's values are missing

*** 8% of this months values were missing

Appendix A-3. Statistics for estimated monthly loadings based on 15 minute data.

Month	Average	Std	Max	Min	Median
		tons			
		Tahoe City			
Jun 02	n.d.	n.d.	n.d.	n.d.	n.d.
Jul 02	0.115	0.025	0.216	0.007	0.122
Aug 02	0.073	0.011	0.126	0.026	0.076
Sept 02	0.019	0.011	0.060	0.005	0.017
Oct 02	0.002	0.001	0.007	0.000	0.001
Nov 02	0.002	0.002	0.024	0.000	0.001
Dec 02	0.002	0.001	0.014	0.001	0.001
Jan 03	0.006	0.002	0.030	0.001	0.006
Feb 03	n.d.	n.d.	n.d.	n.d.	n.d.
Mar 03	n.d.	n.d.	n.d.	n.d.	n.d.
Apr 03	0.006	0.001	0.042	0.004	0.006
May 03	0.007	0.001	0.013	0.005	0.007
Jun 03	0.008	0.003	0.031	0.005	0.007
Jul 03**	0.093	0.142	5.954	0.020	0.072
		Truckee			
Jun 02	n.d.	n.d.	n.d.	n.d.	n.d.
Jul 02	0.15	0.04	0.32	0.02	0.16
Aug 02	0.08	0.01	0.11	0.05	0.08
Sept 02	0.02	0.01	0.06	0.01	0.02
Oct 02	n.d.	n.d.	n.d.	n.d.	n.d.
Nov 02	0.12	1.2	21.6	0.00	0.00
Dec 02	1.4	14.1	247.4	0.00	0.01
Jan 03	0.06	0.51	8.68	0.01	0.01
Feb 03	0.01	0.01	0.14	0.01	0.01
Mar 03*	1.19	11.24	171.33	0.00	0.02
Apr 03	n.d.	n.d.	n.d.	n.d.	n.d.
May 03	90.8	429.7	4804.8	0.02	0.08
Jun 03	16.8	42.8	422.5	0.01	0.20
Jul 03	0.11	0.04	0.26	0.03	0.10
		Farad			
Jun 02	21282	176027	2060304	0.18	0.55
Jul 02	24.0	647	23440	0.08	0.48
Aug 02	0.19	0.04	0.44	0.04	0.18
Sept 02	0.24	0.05	1.6	0.17	0.24
Oct 02	0.19	0.11	2.6	0.10	0.18
Nov 02	0.47	2.9	50.3	0.02	0.09
Dec 02	6.0	230	12432	0.00	0.05
Jan 03	1.4	4.3	85.5	0.04	0.07
Feb 03	0.47	1.0	6.1	0.04	0.09
Mar 03	114	862	9785	0.05	0.14
Apr 03	n.d.	n.d.	n.d.	n.d.	n.d.
May 03	n.d.	n.d.	n.d.	n.d.	n.d.
Jun 03	n.d.	n.d.	n.d.	n.d.	n.d.
Jul 03	11.7	247	11519	0.41	0.62

n.d. = Not determined due to missing data
* 1% of this month's values are missing
** 5% of this months values were missing

Appendix A4. Bridge 8 statistics for estimated monthly suspended sediment loadings.

	Average	Std	Max	Min	Median
	tons				
Bridge 8 (using Tahoe City flow)					
Jun 02	0.084	0.133	1.603	0.011	0.032
Jul 02	0.201	0.204	2.646	0.017	0.143
Aug 02	0.063	0.034	1.265	0.044	0.059
Sept 02	n.d.	n.d.	n.d.	n.d.	n.d.
Oct 02	n.d.	n.d.	n.d.	n.d.	n.d.
Nov 02	n.d.	n.d.	n.d.	n.d.	n.d.
Dec 02	0.006	0.012	0.128	0.000	0.003
Jan 03*	0.019	0.023	0.224	0.007	0.012
Feb 03	n.d.	n.d.	n.d.	n.d.	n.d.
Mar 03	0.024	0.033	0.302	0.004	0.011
Apr 03	0.011	0.006	0.098	0.005	0.008
May 03	0.090	0.215	9.883	0.005	0.024
Jun 03	14.571	561.350	29313.505	0.020	0.081
Jul 03	0.191	0.234	5.670	0.050	0.115
Bridge 8 (using Near Truckee flow)					
Jun 02	0.204	0.356	4.267	0.031	0.096
Jul 02	0.222	0.224	2.835	0.025	0.159
Aug 02	0.066	0.036	1.322	0.046	0.062
Sept 02	n.d.	n.d.	n.d.	n.d.	n.d.
Oct 02	n.d.	n.d.	n.d.	n.d.	n.d.
Nov 02	n.d.	n.d.	n.d.	n.d.	n.d.
Dec 02	0.036	0.154	1.748	0.000	0.008
Jan 03*	0.052	0.112	1.344	0.012	0.019
Feb 03	n.d.	n.d.	n.d.	n.d.	n.d.
Mar 03	0.098	0.224	2.589	0.007	0.035
Apr 03	0.024	0.010	0.129	0.013	0.022
May 03	0.635	1.561	68.783	0.013	0.118
Jun 03	100.935	3878.090	202708.053	0.049	0.205
Jul 03	0.210	0.261	6.076	0.071	0.121

n.d. = Not determined due to missing data

* 8% of this months values were missing

Appendix A5. Suspended Solids loading at Tahoe City, by event.

Index event #	Start date	End date	Duration (hrs)	Load (tons)	Average (tons)	Std (tons)	Max (tons)	Min (tons)	Median (tons)	Intensity load/hr
TC 01	11/8/2002	11/8/2002	21	1.1	0.013	0.007	0.024	0.001	0.015	0.053
TC 02	12/13/2002	12/14/2002	22	0.6	0.007	0.004	0.014	0.002	0.006	0.028
TC 03	1/10/2003	1/10/2003	4	0.3	0.020	0.010	0.030	0.006	0.027	0.084
TC 04	7/27/2003	7/28/2003	23	13.5	0.145	0.076	0.590	0.115	0.127	0.586
TC 05	7/28/2003	7/29/2003	27	24.3	0.223	0.587	5.954	0.070	0.135	0.899
TC 06	7/29/2003	7/30/2003	28	27.3	0.244	0.311	2.005	0.066	0.133	0.974
"Dam" Events										
TCE1	6/20/2002	6/26/2002	135	12.0	0.022	0.013	0.068	0.008	0.020	0.089
TCE2	6/26/2002	6/30/2002	110	20.4	0.046	0.005	0.078	0.036	0.045	0.185
TCE3	6/30/2002	7/14/2002	340	129.3	0.095	0.026	0.190	0.007	0.097	0.380
TCE4	7/14/2002	7/30/2002	382	201.1	0.132	0.011	0.216	0.110	0.130	0.527
TCE5	7/30/2002	8/22/2002	550	177.5	0.081	0.012	0.152	0.048	0.079	0.323
TCE6	8/22/2002	9/7/2002	390	79.0	0.051	0.016	0.098	0.022	0.051	0.203
TCE7	9/7/2002	10/17/2002	946	36.6	0.010	0.007	0.035	0.001	0.008	0.039
TCE8	6/26/2003	7/4/2003	181	15.1	0.021	0.010	0.050	0.005	0.020	0.084
TCE9	7/4/2003	7/16/2003	288	66.0	0.057	0.010	0.096	0.033	0.057	0.229
TCE10	7/16/2003	7/26/2003	241	112.9	0.117	0.012	0.152	0.066	0.118	0.468

Appendix A6. Suspended solids loading at Bridge 8, by event.

Index event#	Start date	End date	Duration (hrs)	Load (tons)	Average (tons)	Std (tons)	Max (tons)	Min (tons)	Median (tons)	Intensity load/hr
B8 01	6/1/2002	6/2/2002	20	31.3	0.387	0.327	1.423	0.070	0.227	1.565
B8 02	6/2/2002	6/3/2002	25	12.7	0.125	0.075	0.513	0.048	0.102	0.506
B8 03	6/3/2002	6/4/2002	25	17.9	0.177	0.175	1.125	0.050	0.097	0.716
B8 04	6/4/2002	6/5/2002	23	47.9	0.515	0.751	3.879	0.060	0.188	2.081
B8 05	6/5/2002	6/6/2002	25	71.7	0.709	1.005	4.267	0.069	0.197	2.866
B8 06	6/6/2002	6/7/2002	16	38.9	0.598	0.594	2.125	0.074	0.307	2.430
B8 07	6/7/2002	6/8/2002	31	23.8	0.190	0.157	1.051	0.056	0.135	0.768
B8 08	6/8/2002	6/9/2002	22	8.9	0.100	0.123	1.187	0.041	0.079	0.405
B8 09	6/12/2002	6/13/2002	23	7.0	0.076	0.040	0.224	0.036	0.066	0.306
B8 10	6/13/2002	6/14/2002	24	10.1	0.104	0.070	0.367	0.041	0.074	0.420
B8 11	6/14/2002	6/15/2002	26	6.6	0.063	0.026	0.140	0.034	0.055	0.255
B8 12	6/22/2002	6/24/2002	47	26.1	0.138	0.083	0.618	0.037	0.114	0.555
B8 13	6/24/2002	6/25/2002	17	24.0	0.347	0.282	1.485	0.068	0.253	1.409
B8 14	6/25/2002	6/26/2002	25	62.9	0.622	0.404	2.061	0.112	0.505	2.514
B8 15	6/26/2002	6/27/2002	22	25.4	0.285	0.150	1.131	0.102	0.251	1.155
B8 16	6/27/2002	6/28/2002	27	24.6	0.226	0.141	1.172	0.100	0.188	0.913
B8 17	6/28/2002	6/29/2002	22	17.8	0.200	0.092	0.634	0.073	0.181	0.810
B8 18	6/29/2002	6/30/2002	25	19.6	0.194	0.082	0.577	0.080	0.183	0.785
B8 19	6/30/2002	7/1/2002	20	15.2	0.188	0.148	0.809	0.025	0.157	0.762
B8 20	7/1/2002	7/2/2002	26	48.8	0.465	0.262	1.357	0.025	0.408	1.878
B8 21	7/2/2002	7/3/2002	24	36.9	0.380	0.200	1.450	0.152	0.337	1.536
B8 22	7/3/2002	7/4/2002	26	30.7	0.292	0.183	1.804	0.116	0.253	1.180
B8 23	7/4/2002	7/5/2002	23	42.0	0.451	0.361	1.952	0.113	0.314	1.825
B8 24	7/5/2002	7/6/2002	24	32.4	0.334	0.186	0.956	0.108	0.283	1.348
B8 25	7/6/2002	7/7/2002	23	33.8	0.364	0.216	1.059	0.128	0.290	1.471
B8 26	7/7/2002	7/8/2002	26	30.4	0.290	0.176	1.525	0.120	0.250	1.170
B8 27	7/8/2002	7/9/2002	22	21.6	0.243	0.207	1.850	0.123	0.203	0.983
B8 28	7/9/2002	7/10/2002	25	20.8	0.206	0.082	0.735	0.107	0.189	0.831
B8 29	7/10/2002	7/11/2002	24	25.8	0.266	0.215	2.131	0.114	0.229	1.073
B8 30	7/11/2002	7/12/2002	23	25.4	0.274	0.213	2.064	0.124	0.232	1.106
B8 31	7/12/2002	7/13/2002	25	22.4	0.222	0.135	0.987	0.109	0.192	0.897

Appendix A6. Suspended Solids loading at Bridge 8, by event (continued).

Index event #	Start date	End date	Duration (hrs)	Load (tons)	Average (tons)	Std (tons)	Max (tons)	Min (tons)	Median (tons)	Intensity load/hr
B8 32	7/13/2002	7/14/2002	27	24.3	0.223	0.191	1.923	0.098	0.179	0.900
B8 33	7/14/2002	7/15/2002	21	19.4	0.228	0.141	0.886	0.105	0.180	0.923
B8 34	7/15/2002	7/16/2002	24	15.9	0.164	0.063	0.480	0.091	0.150	0.662
B8 35	7/16/2002	7/17/2002	25	14.8	0.147	0.051	0.399	0.084	0.135	0.592
B8 36	7/18/2002	7/23/2002	119	132.3	0.277	0.332	2.835	0.068	0.157	1.111
B8 37	7/24/2002	7/24/2002	3	1.9	0.150	0.244	0.961	0.078	0.081	0.648
B8 38	8/14/2002	8/15/2002	26	13.2	0.126	0.170	1.322	0.052	0.072	0.509
B8 39	9/21/2002	9/22/2002	30	4.8	0.040	0.047	0.410	0.013	0.027	0.161
B8 40	12/13/2002	12/15/2002	36	73.9	0.510	0.491	1.748	0.002	0.401	2.054
B8 41	12/27/2002	12/28/2002	32	11.8	0.091	0.073	0.356	0.024	0.057	0.368
B8 42	1/22/2003	1/25/2003	63	56.4	0.223	0.209	1.232	0.023	0.150	0.896
B8 43	1/27/2003	1/28/2003	41	33.7	0.204	0.242	1.344	0.036	0.098	0.821
B8 44	3/13/2003	3/15/2003	35	9.3	0.066	0.048	0.349	0.021	0.053	0.265
B8 45	3/15/2003	3/16/2003	34	27.1	0.198	0.144	0.738	0.029	0.144	0.796
B8 46	3/19/2003	3/21/2003	50	23.6	0.117	0.084	0.414	0.016	0.093	0.472
B8 47	3/21/2003	3/25/2003	89	61.5	0.172	0.177	1.221	0.018	0.108	0.691
B8 48	3/25/2003	3/28/2003	76	123.3	0.404	0.539	2.589	0.037	0.118	1.622
B8 49	4/24/2003	4/24/2003	8	2.2	0.066	0.026	0.129	0.022	0.068	0.272
B8 50	5/12/2003	5/13/2003	18	10.3	0.141	0.113	0.563	0.035	0.087	0.571
B8 51	5/13/2003	5/14/2003	23	39.0	0.419	0.337	1.472	0.046	0.334	1.696
B8 52	5/14/2003	5/15/2003	26	74.9	0.714	0.463	2.034	0.100	0.775	2.882
B8 53	5/15/2003	5/16/2003	15	49.0	0.803	0.650	2.626	0.150	0.572	3.266
B8 54	5/16/2003	5/17/2003	32	19.3	0.150	0.050	0.322	0.074	0.146	0.603
B8 55	5/19/2003	5/20/2003	22	12.5	0.141	0.069	0.393	0.062	0.121	0.570
B8 56	5/20/2003	5/21/2003	23	16.7	0.180	0.093	0.439	0.067	0.147	0.727
B8 57	5/21/2003	5/22/2003	25	75.9	0.752	0.751	3.583	0.090	0.390	3.036
B8 58	5/22/2003	5/23/2003	23	112.1	1.205	0.739	3.486	0.190	1.364	4.872
B8 59	5/23/2003	5/24/2003	23	168.7	1.814	0.793	3.770	0.391	1.842	7.333
B8 60	5/24/2003	5/25/2003	26	146.5	1.395	0.862	3.842	0.294	1.167	5.633
B8 61	5/25/2003	5/26/2003	23	48.7	0.524	0.412	3.275	0.183	0.406	2.119
B8 62	5/26/2003	5/27/2003	23	35.6	0.383	0.203	0.888	0.173	0.310	1.550

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Appendix A6. Suspended Solids loading at Bridge 8, by event (continued).

Index event #	Start date	End date	Duration (hrs)	Load (tons)	Average (tons)	Std (tons)	Max (tons)	Min (tons)	Median (tons)	Intensity load/hr
B8 63	5/27/2003	5/28/2003	24	146.8	1.513	1.044	4.857	0.180	1.562	6.117
B8 64	5/28/2003	5/29/2003	25	226.8	2.245	1.065	4.563	0.434	2.376	9.072
B8 65	5/29/2003	5/30/2003	20	201.8	2.492	0.754	4.619	0.956	2.437	10.092
B8 66	5/30/2003	5/30/2003	2	86.4	9.598	22.195	68.783	1.886	2.251	43.191
B8 67	5/30/2003	5/31/2003	21	220.8	2.597	0.776	4.568	1.485	2.502	10.513
B8 68	5/31/2003	6/1/2003	23	198.9	2.139	0.633	4.607	1.252	2.027	8.648
B8 69	6/1/2003	6/2/2003	25	216.8	2.146	1.509	15.349	1.156	1.881	8.671
B8 70	6/2/2003	6/3/2003	23	187.2	2.013	1.369	13.718	1.194	1.695	8.140
B8 71	6/3/2003	6/4/2003	24	179.4	1.849	0.402	2.837	1.217	1.795	7.474
B8 72	6/4/2003	6/5/2003	27	482.8	4.430	16.435	131.964	1.147	2.001	17.883
B8 73	6/5/2003	6/6/2003	22	2806.4	31.533	133.448	869.580	1.068	1.920	127.564
B8 74	6/6/2003	6/7/2003	24	58195.1	599.950	4664.034	45842.508	1.102	2.103	2424.796
B8 75	6/7/2003	6/9/2003	48	227869.0	1180.668	14601.360	202708.053	0.471	2.191	4747.271
B8 76	6/9/2003	6/10/2003	23	141.0	1.517	0.901	7.353	0.438	1.395	6.132
B8 77	6/10/2003	6/11/2003	23	124.5	1.338	0.519	3.858	0.540	1.149	5.412
B8 78	6/11/2003	6/12/2003	27	139.6	1.281	0.480	2.716	0.103	1.212	5.172
B8 79	6/26/2003	6/27/2003	26	29.8	0.284	0.236	1.378	0.073	0.181	1.147
B8 80	6/27/2003	6/28/2003	23	42.1	0.453	0.549	4.995	0.131	0.257	1.832
B8 81	6/28/2003	6/29/2003	32	45.9	0.356	0.255	1.952	0.081	0.293	1.435
B8 82	6/29/2003	6/30/2003	12	8.1	0.165	0.248	1.219	0.049	0.075	0.673
B8 83	6/30/2003	7/1/2003	17	9.0	0.130	0.068	0.473	0.049	0.115	0.528
B8 84	7/2/2003	7/3/2003	19	20.5	0.266	0.105	0.606	0.102	0.258	1.080
B8 85	7/3/2003	7/4/2003	23	26.6	0.286	0.162	1.131	0.141	0.249	1.158
B8 86	7/4/2003	7/5/2003	24	39.5	0.407	0.273	1.574	0.139	0.307	1.646
B8 87	7/5/2003	7/7/2003	61	162.3	0.662	0.318	2.057	0.101	0.673	2.661
B8 88	7/11/2003	7/12/2003	26	48.0	0.457	0.406	2.028	0.089	0.321	1.846
B8 89	7/14/2003	7/16/2003	44	30.9	0.175	0.100	0.811	0.092	0.146	0.702
B8 90	7/16/2003	7/17/2003	21	21.3	0.251	0.142	0.870	0.109	0.209	1.014
B8 91	7/23/2003	7/24/2003	15	30.0	0.492	0.932	6.076	0.086	0.140	2.000
B8 92	7/25/2003	7/25/2003	4	2.9	0.168	0.273	1.229	0.092	0.100	0.715
B8 93	7/30/2003	7/31/2003	18	11.6	0.158	0.129	1.152	0.086	0.136	0.642
B8 94	7/31/2003	7/31/2003	15	10.7	0.176	0.354	2.837	0.083	0.116	0.716

Appendix A7. Suspended Solids loading at Near Truckee, by event

Index event #	Start date	End date	Duration (hrs)	Load (tons)	Average (tons)	Std (tons)	Max (tons)	Min (tons)	Median (tons)	Intensity load/hr
T 01	11/8/2002	11/9/2002	23	346.8	3.729	5.572	21.555	0.021	1.334	15.078
T 02	12/13/2002	12/14/2002	20	4066.1	50.199	69.724	247.448	0.021	20.885	203.306
T 03	1/23/2003	1/24/2003	8	113.2	3.430	3.430	8.676	0.041	2.198	14.148
T 04	1/28/2003	1/28/2003	2	2.8	0.313	0.780	2.392	0.048	0.053	1.408
T 05	3/15/2003	3/15/2003	16	46.0	0.708	0.533	1.686	0.036	0.596	2.877
T 06	3/23/2003	3/23/2003	10	29.2	0.713	0.791	2.394	0.023	0.274	2.922
T 07	3/26/2003	3/26/2003	14	3404.9	59.735	56.095	171.329	0.035	62.231	243.205
T 08	5/14/2003	5/14/2003	6	335.9	13.438	12.529	33.437	0.117	11.851	55.991
T 10	5/22/2003	5/23/2003	20	9913.3	122.386	183.480	516.769	0.131	0.327	495.664
T 11	5/23/2003	5/24/2003	22	45235.1	508.259	648.044	1835.939	0.178	0.507	2056.139
T 12	5/24/2003	5/25/2003	21	26889.1	316.343	546.178	1568.002	0.192	0.404	1280.434
T 13	5/27/2003	5/28/2003	19	22450.5	291.565	478.803	1363.721	0.178	0.417	1181.604
T 14	5/28/2003	5/29/2003	24	56012.6	577.449	856.991	2508.368	0.214	71.234	2333.857
T 15	5/29/2003	5/30/2003	22	106812.2	1200.137	1584.599	4804.799	0.230	0.522	4855.100
T 16	5/30/2003	5/31/2003	9	569.7	15.397	90.883	553.277	0.265	0.467	63.301
T 17	6/3/2003	6/3/2003	3	15.3	1.173	3.719	13.551	0.123	0.148	5.083
T 18	6/3/2003	6/4/2003	10	2661.0	64.902	85.273	225.622	0.193	0.311	266.098
T 19	6/4/2003	6/4/2003	10	1313.6	32.038	27.930	90.905	0.129	25.651	131.356
T 20	6/4/2003	6/5/2003	24	10513.3	108.385	98.441	322.487	0.110	70.336	438.055
T 21	6/5/2003	6/6/2003	24	4240.9	43.721	32.775	112.459	0.103	39.697	176.706
T 22	6/6/2003	6/7/2003	24	5159.3	53.189	42.156	151.689	5.500	42.972	214.973
T 23	6/7/2003	6/8/2003	24	8136.4	83.880	76.497	422.462	0.245	62.497	339.016
T 24	6/8/2003	6/9/2003	25	6858.2	67.903	74.246	367.268	0.125	37.704	274.327
T 25	6/9/2003	6/10/2003	23	4213.1	45.303	42.260	188.716	0.105	28.696	183.180
T 26	6/10/2003	6/11/2003	25	2070.5	20.500	21.614	142.300	1.641	15.034	82.820
T 27	6/11/2003	6/12/2003	25	911.3	9.022	7.530	44.713	0.050	7.415	36.451
T 28	6/12/2003	6/13/2003	23	383.2	4.120	4.386	24.877	0.076	2.542	16.660
T 29	6/13/2003	6/14/2003	19	313.5	4.071	3.197	13.787	0.380	2.902	16.498
T 30	6/14/2003	6/15/2003	17	235.3	3.410	2.423	11.908	0.579	2.884	13.839
T 31	6/15/2003	6/16/2003	14	454.1	7.967	16.225	75.673	0.035	3.212	32.435
T 32	6/16/2003	6/17/2003	21	448.3	5.274	6.403	44.693	0.074	4.003	21.347
T 33	6/17/2003	6/18/2003	18	381.4	5.225	6.077	50.566	0.029	4.141	21.189

Appendix A8. Suspended Solids loading at Farad, by event.

Index event #	Start date	End date	Duration (hrs)	Load (tons)	Average (tons)	Std (tons)	Max (tons)	Min (tons)	Median (tons)	Intensity load/hr
F 01	6/1/2002	6/2/2002	12	2762152.5	56370.458	161321.365	689289.915	30.016	37.729	230179.372
F 02	6/6/2002	6/6/2002	2	34484.3	3831.590	11470.190	34418.764	7.402	8.210	17242.156
F 03	6/8/2002	6/8/2002	2	2013.3	223.696	662.243	1989.677	2.863	2.938	1006.630
F 04	6/16/2002	6/16/2002	2	36.0	4.002	10.545	32.121	0.478	0.487	18.008
F 05	7/2/2002	7/3/2002	24	72.2	0.744	0.652	4.085	0.337	0.441	3.008
F 06	7/5/2002	7/6/2002	19	104.5	1.357	0.885	3.294	0.422	1.195	5.500
F 07	7/18/2002	7/19/2002	22	69864.3	784.993	3682.741	23439.990	0.483	1.697	3175.652
F 08	7/6/2002	7/14/2002	184	494.9	0.672	0.308	2.362	0.422	0.561	2.690
F 09	7/16/2002	7/17/2002	40	132.9	0.826	0.366	1.508	0.406	0.655	3.323
F 10	10/19/2002	10/20/2002	25	36.7	0.363	0.536	2.560	0.172	0.198	1.467
F 11	11/7/2002	11/9/2002	50	1119.9	5.572	9.758	50.287	0.101	2.506	22.398
F 12	12/4/2002	12/4/2002	2	12432.0	1381.333	4143.953	12431.873	0.004	0.015	6215.998
F 13	12/14/2002	12/17/2002	77	3341.1	10.813	27.261	182.602	0.000	0.387	43.391
F 14	12/17/2002	12/18/2002	18	19.9	0.272	0.248	1.741	0.046	0.262	1.104
F 15	12/18/2002	12/19/2002	15	8.8	0.144	0.061	0.322	0.042	0.151	0.587
F 16	12/19/2002	12/19/2002	10	3.2	0.078	0.063	0.305	0.037	0.049	0.321
F 17	12/20/2002	12/22/2002	25	13.9	0.138	0.177	1.013	0.085	0.093	0.557
F 18	12/22/2002	12/22/2002	7	11.4	0.392	0.622	2.171	0.080	0.118	1.622
F 19	12/24/2002	12/24/2002	4	24.0	1.410	3.230	10.655	0.084	0.107	5.994
F 20	12/24/2002	12/24/2002	3	9.8	0.754	2.384	8.689	0.082	0.091	3.266
F 21	12/24/2002	12/25/2002	3	8.6	0.658	1.372	4.394	0.105	0.108	2.852
F 22	12/25/2002	12/27/2002	43	1851.4	10.701	123.728	1627.885	0.050	0.118	43.055
F 23	12/28/2002	12/28/2002	4	2.5	0.149	0.115	0.473	0.098	0.107	0.632
F 24	12/29/2002	12/30/2002	24	10.2	0.105	0.098	0.549	0.064	0.076	0.424
F 25	12/31/2002	1/1/2003	12	5.6	0.114	0.099	0.607	0.053	0.078	0.466
F 26	1/17/2003	1/18/2003	25	8.9	0.088	0.092	0.740	0.049	0.062	0.356
F 27	1/18/2003	1/19/2003	28	9.5	0.084	0.047	0.360	0.047	0.069	0.340
F 28	1/20/2003	1/20/2003	2	1.6	0.178	0.205	0.661	0.063	0.066	0.799
F 29	1/20/2003	1/21/2003	6	3.2	0.127	0.123	0.546	0.063	0.075	0.530
F 30	1/23/2003	1/25/2003	64	727.9	2.832	5.804	20.899	0.101	0.303	11.373

Appendix A8. Suspended Solids loading at Farad, by event (continued).

Index event #	Start date	End date	Duration (hrs)	Load (tons)	Average (tons)	Std (tons)	Max (tons)	Min (tons)	Median (tons)	Intensity load/hr
F 31	1/25/2003	1/31/2003	147	3186.8	5.411	7.345	85.485	0.224	2.652	21.679
F 32	1/31/2003	2/4/2003	94	973.6	2.582	1.446	6.057	0.289	2.455	10.357
F 33	2/7/2003	2/7/2003	4	7.6	0.447	0.367	1.115	0.104	0.236	1.899
F 34	2/8/2003	2/8/2003	8	17.5	0.531	0.308	0.980	0.108	0.659	2.191
F 35	2/9/2003	2/9/2003	5	16.8	0.800	0.699	1.798	0.077	0.793	3.360
F 36	2/16/2003	2/16/2003	2	2.9	0.325	0.389	1.194	0.114	0.138	1.461
F 37	2/21/2003	2/21/2003	2	1.5	0.162	0.284	0.919	0.058	0.067	0.729
F 38	2/21/2003	2/22/2003	9	3.0	0.082	0.085	0.552	0.048	0.060	0.339
F 39	2/24/2003	2/24/2003	3	1.8	0.138	0.227	0.892	0.061	0.072	0.597
F 40	3/1/2003	3/1/2003	3	2.3	0.179	0.313	1.219	0.080	0.093	0.774
F 41	3/13/2003	3/18/2003	109	401.7	0.919	1.770	7.955	0.109	0.193	3.685
F 42	3/22/2003	3/24/2003	47	279.0	1.476	3.642	16.383	0.146	0.471	5.936
F 43	3/25/2003	3/29/2003	95	337610.4	886.116	2266.460	9785.013	0.500	0.981	3553.793
F 44	3/29/2003	4/3/2003	128	621.5	1.212	0.378	2.587	0.686	1.095	4.856
F 45	4/3/2003	4/15/2003	279	1209.0	1.082	0.166	1.563	0.690	1.061	4.333
F 46	6/6/2003	6/7/2003	24	185.1	1.909	0.634	3.128	1.212	1.683	7.714
F 47	6/7/2003	6/8/2003	24	199.0	2.051	0.797	3.632	1.211	1.744	8.291
F 48	6/8/2003	6/9/2003	23	177.8	1.911	0.748	3.345	1.055	1.602	7.728
F 49	6/9/2003	6/10/2003	25	156.3	1.548	0.535	2.715	1.012	1.271	6.253
F 50	6/10/2003	6/11/2003	18	98.1	1.343	0.298	1.916	1.026	1.208	5.448
F 51	6/11/2003	6/11/2003	4	4616.3	271.548	339.347	804.758	0.897	1.035	1154.080
F 52	6/11/2003	6/12/2003	15	57.2	0.938	0.143	1.198	0.736	0.900	3.814
F 53	6/12/2003	6/13/2003	11	34.7	0.772	0.096	0.908	0.618	0.761	3.157
F 54	6/13/2003	6/13/2003	2	315.0	35.003	68.205	157.279	0.624	0.634	157.515
F 55	6/13/2003	6/14/2003	14	36.7	0.644	0.088	0.826	0.522	0.631	2.622
F 56	6/14/2003	6/15/2003	10	21.9	0.533	0.044	0.608	0.455	0.531	2.185
F 57	6/15/2003	6/16/2003	14	27.5	0.483	0.049	0.579	0.422	0.474	1.966
F 58	6/16/2003	6/19/2003	83	4262.3	12.800	20.409	69.569	0.345	0.684	51.353
F 59	6/21/2003	6/21/2003	2	11.8	1.307	2.955	9.188	0.302	0.329	5.882
F 60	6/25/2003	6/25/2003	10	15.0	0.367	0.353	1.705	0.215	0.263	1.504

Appendix A8. Suspended Solids loading at Farad, by event (continued).

Index event #	Start date	End date	Duration (hrs)	Load (tons)	Average (tons)	Std (tons)	Max (tons)	Min (tons)	Median (tons)	Intensity load/hr
F 61	6/26/2003	6/26/2003	2	3.6	0.405	0.453	1.612	0.243	0.254	1.821
F 62	6/29/2003	6/30/2003	22	51.8	0.583	0.072	0.832	0.341	0.594	2.357
F 63	6/30/2003	7/1/2003	16	39.4	0.606	0.073	0.749	0.473	0.611	2.462
F 64	7/1/2003	7/2/2003	4	38.8	2.283	2.793	7.343	0.465	0.618	9.703
F 65	7/3/2003	7/3/2003	11	27.4	0.609	0.096	0.903	0.515	0.590	2.493
F 66	7/14/2003	7/15/2003	4	11.9	0.702	0.961	4.424	0.430	0.452	2.983
F 67	7/16/2003	7/16/2003	5	14.5	0.691	0.441	2.063	0.505	0.541	2.902
F 68	7/17/2003	7/17/2003	20	53.5	0.660	0.082	0.772	0.474	0.689	2.673
F 69	7/20/2003	7/20/2003	3	13.7	1.055	1.310	5.413	0.684	0.694	4.570
F 70	7/20/2003	7/22/2003	38	13887.8	90.770	536.637	5239.518	0.723	0.937	365.467
F 71	7/22/2003	7/23/2003	20	69.9	0.863	0.367	2.794	0.716	0.782	3.495
F 72	7/23/2003	7/27/2003	99	18924.4	47.789	587.131	11518.665	0.672	3.227	191.156
F 73	7/27/2003	7/29/2003	48	546.3	2.830	7.692	60.652	0.442	0.867	11.380
F 74	7/29/2003	7/30/2003	25	77.7	0.770	0.253	1.180	0.407	0.780	3.109

APPENDICES A9 THROUGH A16:
TURBIDITY AND FLOW SUMMARY STATISTICS

Summary statistics for water temperature, average and maximum daily turbidity, flow, and specific conductivity were computed for all stations for the entire study periods and for individual seasons. The study periods for different stations are different:

Tahoe City: May 30, 2002 – September 3, 2003

Bridge 8: May 30, 2002 – September 3, 2003

Near Truckee: June 26, 2002 - September 3, 2003

Farad: May 2, 2002 – August 14, 2003

The statistics were computed on daily data: Daily average/maximum water temperature (^{o}C), continuous NTU (nephelometric turbidity units), flow (cfs) and specific conductivity (ms/cm). The statistics are reported in the following tables. For example, Min of Daily average NTU was computed as the smallest value of the daily average NTUs, Mean Daily Maximum NTU was computed as the largest of the daily NTU maximums, etc. The 1st quantile is the 25th percentile of the data, that is the value that separates the lower 25% of the data from the top 75%. The 3rd quantile is the 75th percentile of the data. Median is the 50th percentile, that is it separates the lower 50% from the upper 50% of the data. Total N is the total number of data rows in the data sets. NA's is the total number of missing values for each variable, location and season.

Appendix A9. Summary statistics for NTU at TC – entire study period (May 30, 2002 to September 3, 2003).

	Daily average water temp	Daily average NTU	Daily Maximum NTU	Daily average flow	Daily maximum flow	Daily average Spcond
Min	0.124	0	0	1.426	1.9	0.09
1stQ	5.595	0.190	1	49.815	51	0.094
Mean	11.864	1.107	8.27	117.063	121.58	0.097
Median	12.985	0.518	2.25	69.104	71	0.095
3rdQ	17.734	1.151	4.7	168.026	183.25	0.099
Max	21.398	45.956	450.8	378.927	383	0.141
Total N	398	398	398	398	398	398
NA's	58	58	58	0	0	58
StDev	6.303	3.003	35.464	113.478	115.5	0.005

Appendix A10. Summary statistics for NTU at B8 - entire study period (May 30, 2002 to September 3, 2003).						
	Daily average water temp	Daily average NTU	Daily Maximum NTU	Daily average flow	Daily maximum flow	Daily average Spcond
Min	0.050	0	0	n/a	n/a	0.061
1stQ	3.883	0.267	0.9	n/a	n/a	0.092
Mean	9.605	3.117	16.987	n/a	n/a	0.096
Median	7.295	1.029	2	n/a	n/a	0.095
3rdQ	16.833	2.116	5.5	n/a	n/a	0.104
Max	21.505	122.447	875.6	n/a	n/a	0.145
Total N	398	398	398	n/a	n/a	398
NA's	22	27	27	n/a	n/a	80
StDev	6.678	10.372	83.6	n/a	n/a	0.015

Appendix A11. Summary statistics for NTU at NT - entire study period (June 26, 2002 - September 3, 2003).						
	Daily average water temp	Daily average NTU	Daily Maximum NTU	Daily average flow	Daily Maximum flow	Daily average Spcond
Min	-0.012	0	0	7.835	8.8	0.053
1stQ	3.741	0.424	1.3	92.693	97	0.095
Mean	9.320	3.713	13.108	200.289	220.582	0.101
Median	7.251	1.185	2.6	182.432	196	0.102
3rdQ	16.329	2.116	6.6	302.806	315	0.109
Max	21.479	77.438	445.1	664.031	827	0.152
Total N	398	398	398	398	398	398
NA's	8	8	8	0	0	12
StDev	6.602	10.293	43.210	139.85	159.803	0.018

Appendix A12. Summary statistics for NTU at Farad - entire study period (May 2, 2002 – August 14, 2003).						
	Daily average water temp	Daily average NTU	Daily Maximum NTU	Daily average flow	Daily Maximum flow	Daily average Spcond
Min	0.653	0.04	0.3	72.656	76	0.064
1stQ	4.883	1.997	3.3	351.031	365	0.095
Mean	9.957	10.242	67.948	518.621	550.396	0.107
Median	9.543	3.277	6.8	473.328	494	0.102
3rdQ	14.997	7.755	42.3	642.820	661	0.118
Max	20.079	143.415	1767.5	1405.313	1600	0.182
Total N	398	398	398	398	398	398
NA's	0	51	51	0	0	0
StDev	5.577	17.353	179.137	235.09	270.132	0.02

Appendix A13. Seasonal summary statistics for NTU at TC.

	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
	Average Daily NTU				Maximum Daily NTU				Average Daily Flow			
Min	0.02	0.01	0	0.03	0.4	0.4	0	0.3	49.65	65.06	1.43	3.89
1stQ	0.09	0.27	0.14	0.14	1	1.7	0.73	0.7	54.67	184.69	11.53	31.91
Mean	0.56	1.34	1.25	1.03	3.68	14.27	5.90	4.56	66.70	250.10	52.97	48.58
Median	0.40	0.56	0.75	0.46	2.3	2.9	1.8	1.4	69.05	289.44	20.07	52.24
3rdQ	0.97	1.10	1.53	0.99	4.7	5.5	3.98	3.53	73.49	350.95	89.80	57.67
Max	2.20	45.96	12.23	9.04	45.8	450.8	73.3	38.8	85.57	378.93	228.43	91.63
Total N	92	125	91	90	92	125	91	90	92	125	91	90
NA's	27	0	13	18	27	0	13	18	0	0	0	0
StDev	0.56	4.53	1.88	1.67	5.97	56.83	12.39	7.90	10.91	109.23	59.69	25.89

Appendix A14. Seasonal summary statistics for NTU at B8.

	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
	Average Daily NTU				Maximum Daily NTU				Average Daily Flow			
Min	0.05	0.01	0	0	0.3	0.3	0	0	NA	NA	NA	NA
1stQ	0.70	0.31	0.01	0.69	1.4	1.4	0.24	1	NA	NA	NA	NA
Mean	2.77	5.58	0.96	1.76	9.49	34.31	10.67	3.48	NA	NA	NA	NA
Median	1.28	1.45	0.11	1.55	2.75	3.7	0.73	2.2	NA	NA	NA	NA
3rdQ	2.54	2.56	0.57	2.11	6.33	9.1	1.22	3.1	NA	NA	NA	NA
Max	36.29	122.45	47.17	11.84	279.1	875.6	738.95	42.4	NA	NA	NA	NA
Total N	92	125	91	90	92	125	91	90	NA	NA	NA	NA
NA's	0	0	7	20	0	0	7	20	NA	NA	NA	NA
StDev	4.98	16.52	5.15	1.82	30.46	123.81	80.60	6.34	NA	NA	NA	NA

Appendix A15. Seasonal summary statistics for NTU at NT.

	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
	Average Daily NTU				Maximum Daily NTU				Average Daily Flow			
Min	0.29	0.09	0	0.05	0.6	0.5	0	0.2	83.63	147.35	7.84	17.07
1stQ	1.08	0.52	0.16	0.47	2.2	1.8	0.59	1.23	180.73	280.82	22.74	90.17
Mean	2.80	7.29	1.29	2.05	7.59	26.26	4.48	8.72	253.25	321.32	68.02	111.79
Median	1.48	1.47	0.41	1.34	3.2	3	1.4	2.8	208.04	311.67	41.58	107.57
3rdQ	2.68	2.81	0.83	2.41	6.7	8.2	2.65	10.25	251.82	378.88	95.65	128.34
Max	23.01	77.44	46.30	15.44	59.3	445.1	126.56	209.4	664.03	506.78	239.52	357.2
Total N	92	125	91	90	92	125	91	90	92	125	91	90
NA's	8	0	0	0	8	0	0	0	0	0	0	0
StDev	3.51	16.78	4.98	2.56	10.76	70.65	14.21	22.96	149.06	75.23	61.06	59.90

Appendix A16. Seasonal summary statistics for NTU at Farad.

	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
	Average Daily NTU				Maximum Daily NTU				Average Daily Flow			
Min	1.12	0.94	1.38	0.04	1.5	1.8	2	0.3	293.97	383.91	153.97	72.66
1stQ	2.25	2.35	1.80	4.58	3.15	4.08	2.5	18.75	529.76	465.46	375.04	283.23
Mean	5.84	7.66	2.70	23.56	20.87	68.45	5.87	154.11	730.81	582.92	425.90	306.17
Median	2.74	3.23	1.98	22.93	4.95	7.65	3.6	59.85	758.58	565.70	443.99	296.33
3rdQ	4.12	5.44	3.23	32.77	9.08	18.13	5.6	226.68	896.69	647.78	490.28	342.13
Max	28.09	92.58	16.74	143.41	332.6	1200.2	44.6	1767.5	1405.31	1192.71	510.10	648.74
Total N	92	125	91	90	92	125	91	90	92	125	91	90
NA's	46	5	0	0	46	5	0	0	0	0	0	0
StDev	7.45	15.55	2.12	23.62	54.38	202.97	7.30	235.65	287.05	161.55	71.95	117.87