Characterization of Turbidity and Total Suspended Solids in the Upper Carson River, Nevada

Richard B. Susfalk
Brian Fitzgerald
Anna M. Knust

January 2008

DHS Publication No. 41242

prepared by

Desert Research Institute, Nevada System of Higher Education

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Nevada Division of Environmental Protection in fulfillment of Contract Award #DEP 04-039

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ABSTRACT

The Upper Carson River in Nevada has been listed as an impaired water body for turbidity and total suspended solids (TSS). Existing data have been useful in identifying turbidity levels and TSS concentrations that exceed Nevada state standards, but additional data are needed to adequately characterize changes in TSS and turbidity that occur seasonally and in response to specific hydrologic events. A greater understanding of suspended solids processes can benefit basin managers in the creation of science-based standards, as well as researchers and managers concerned with the impact that elevated suspended solids may have on water quality and the aquatic ecosystem.

The level of suspended solids in rivers changes rapidly and unpredictably with changing water depths and velocities, requiring a large number of water quality samples to adequately characterize the inherent temporal variability. An alternative approach is the use of turbidity measurements as a surrogate for TSS concentrations. Both techniques provide a measure of suspended solids levels in the river, but turbidity measurements having the benefit of automated sampling. Once turbidity levels have been calibrated with manually collected TSS measurements, TSS concentrations and loads can be estimated on a near-continuous basis.

Turbidity was measured at 15-minute intervals from March 2004 through October 2006 at four sites along the Upper Carson River: Diamond Valley on the west fork, Riverview on the east fork, Genoa Lakes on the main stem, and downstream of the New Empire Bridge in the Carson Canyon. Site-specific relationships were developed between in-stream turbidity and discrete water samples collected for TSS analysis, achieving correlation coefficients of greater than 0.86 at all sites except for Diamond Valley. Additional relationships were developed using water discharge as a TSS surrogate to estimate historic turbidity levels and TSS concentrations from water year (WY) 1995 through WY2006. Using turbidity as a surrogate is preferred, as discharge-based estimates had lower correlation coefficients, and typically under-predicted turbidity-based estimates during the period of observation. This was due to the inability of discharge-based surrogates to account for the highly dynamic changes and hysteresis observed in TSS and turbidity during hydrologic events.

Nevada's current turbidity and TSS thresholds are not linked: the turbidity thresholds were found to be more restrictive at all sites. Turbidity thresholds were exceeded from 14 to 68 percent of the time, compared to TSS thresholds that were exceeded from 7 to 13 percent of the time during the period of observation. When the Nevada TSS standard was exceeded during the period of observation, the maximum duration of the event ranged from 12 days at Diamond Valley up to 30 days at Brunswick Canyon Road in the Carson Canyon. In comparison, the maximum duration of historic exceedance events was about 80 days at both sites, but there were fewer exceedance events per year during the historic period.

Estimated historical TSS loads were highly variable. The highest loads were estimated for WY1997 due to the 1997 New Year's Flood, ranging from $1{,}137 \pm 987 \times 10^5$ kg/yr at Riverview to $1{,}617 \pm 499 \times 10^5$ kg/yr at Brunswick Canyon Road. The lowest estimated loads were during the drought year of 2001, ranging from $61 \pm 207 \times 10^5$ kg/yr to $60 \pm 75 \times 10^5$ kg/yr at Riverview and Brunswick Canyon, respectively.

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1.0 INTRODUCTION

The State of Nevada has listed the east fork, west fork, and the main stem Carson River from the state line to New Empire Bridge as an impaired water body (Nevada Division of Environmental Protection (NDEP), 2002) due to exceedances of turbidity and total suspended solids (TSS) standards. Under NDEP's current ambient monitoring program for the Carson River basin, grab samples are collected every two to six months at various locations throughout the watershed. While these data have been useful to identify the existence of high turbidity and TSS levels, they do little to describe the duration and frequency of these exceedances due to their low collection frequency. An improved knowledge of the duration and frequency of suspended solids levels in the Carson River can be used to help evaluate the impacts that elevated suspended solids levels have on aquatic organisms. Sediment suspended in the water column can irritate fish gills and suffocate organisms if significant concentrations and durations occur (Bash *et al*., 2001), necessitating the need for a better understanding of both the *length of time* and *how often* they may be exposed to a specific level of suspended solids.

The characterization of suspended solids transport in rivers is difficult due to the rapid and unpredictable fluctuations of suspended solids concentrations related to anthropogenic causes or during natural hydrologic events. To capture these rapid changes in suspended solids, sampling must be conducted at a high temporal frequency that is usually impractical and expensive. A more practical method is to monitor a surrogate, some parameter that is closely related to the concentration of suspended sediment and that can be continuously monitored (Leopold and Maddock, 1953). Historically, water discharge was used as a surrogate for suspended sediment concentration, as there appeared to be a causal relationship between the two factors. However, discharge-based estimates have typically been shown to underestimate actual suspended sediment loading (Lewis, 1996). With recent developments in submersible light-scattering sensors, in-stream turbidity measurements have become the preferred surrogate for suspended sediment concentration (Gippel, 1995; Lewis, 1996). Discharge-based estimates of suspended sediment loading on the California portion of the Truckee River were found to be two to six orders of magnitude lower during hydrologic events than that predicted using the turbidity-based estimates (Dana *et al.,* 2004). The use of turbidity as a surrogate for suspended sediment concentrations has become more common, such as in several studies in the smaller streams of Lake Tahoe, including Incline and Third creeks (Dana *et al*., in preparation), Rosewood Creek (Susfalk, 2006), and Trout Creek (Smolen *et al*., 2004).

The objectives of this project were to establish a continuous turbidity record at four sites on the Carson River between March 2004 and October 2006, estimate TSS concentrations during the period of record using the turbidity surrogate method, and estimate historic turbidity and TSS concentrations from WY1995 through WY2006 using water discharge as a surrogate. The four sites were: 1) the east fork at Dresslerville (commonly referred to as Riverview); 2) the west fork near Paynesville at Diamond Valley Road; 3) the main stem at the Genoa Lakes Golf Course; and 4) the main stem downstream at New Empire Bridge in Carson Canyon on Brunswick Canyon Road. The river reaches bracketed by these sites have been designated as a coldwater fishery in the Nevada water quality regulations. The Nevada Division of Wildlife (NDOW) currently manages these systems as a coldwater, put-and-take fishery; however, this management concept was adopted when there was less natural opportunity for fish to reproduce. High turbidity may be one of the environmental conditions negatively influencing trout survival and the historically poor populations of wild salmonid.

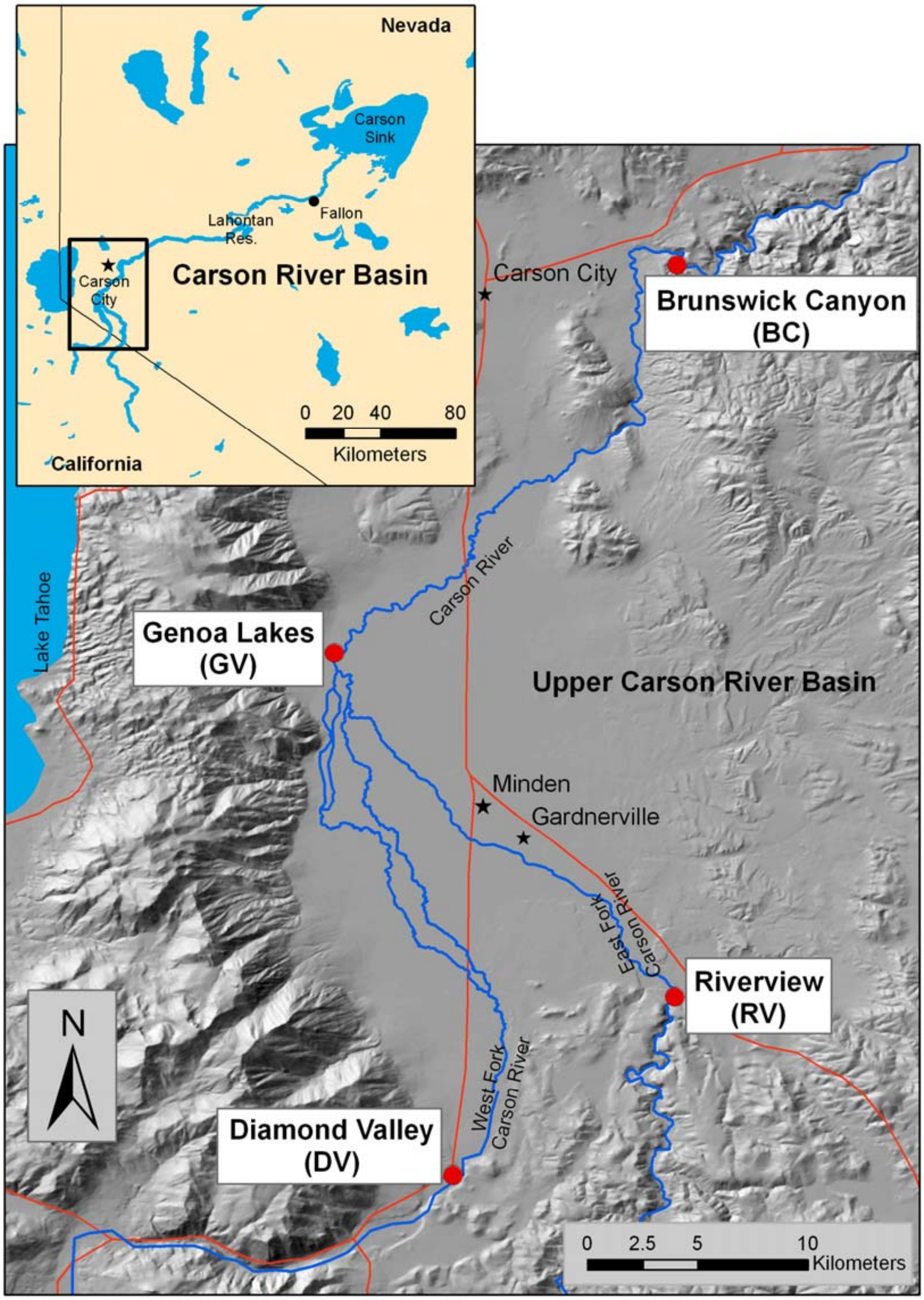

Figure 1-1. Four sampling sites along the Upper Carson River in Nevada.

2.0 SITES AND METHODS

2.1. Monitoring Equipment

To estimate continuous TSS levels in the Carson River, turbidimeters were installed at four sites. Turbidity is a specific class of scattering measurements expressed in nephelometric turbidity units (NTU). The NTU is based on an empirical relationship to standard concentrations of formazin in water. These formazin standards are homogeneous and repeatable for a given concentration. However, natural water samples are typically comprised of particles having many different shapes and sizes, particles of both organic and inorganic composition, and contain other compounds that may absorb light. Turbidity sensors can employ a variety of different techniques, each with a different sensitivity to the aforementioned factors, resulting in the same water sample having two different turbidities on two different instruments that have been correctly calibrated with formazin. For these reasons, relationships between turbidity and TSS are both site and sensor specific. A further discussion of turbidity and other measurements of optical properties can be found in Taylor *et al*. (2004).

Each of the four sites was equipped with an in-stream turbidimeter (DTS-12, FTS Inc., Victoria, BC, Canada) and a conductivity/water temperature sensor (CS547A, Campbell Scientific, Logan, UT). Data from these sensors were collected every 15-minutes by a datalogger (CR10X, Campbell Scientific) that was powered by a 10-watt solar panel.

Sensors were suspended within a four-inch-diameter PVC tube with staggered holes cut in it to allow water to pass. This PVC housing boom was secured to the bridge with a two-dimensional gimble mount. The mount allowed the sensor end of the PVC boom to "swim" in the river currents. The design also allowed the boom to float up and out of the way, or self-clean, in the case of large river debris. Smaller river debris that was caught in the openings of the PVC required manual cleaning either by wading into the water, or raising the lower end of the boom up to the bridge so it can be accessed.

2.2 Sites

The two upstream sites were located near the California-Nevada border, at Diamond Valley on the west fork and at Riverview on the east fork (Table 2-1, Figure 2-1). The Genoa Lakes site was on the main stem of the river just below the confluence of the two forks. The fourth site was near the lower end of the Upper Carson River, on Brunswick Canyon Road near the entrance to Carson Canyon.

Table 2-1. Latitude and longitude of the four DRI sampling sites. Coordinates are in WGS84.

DRI Sampling Sites	Sampling Start	Sampling End	Latitude	Longitude
Diamond Valley (DV)	3/5/2004	9/30/2006	38.80869000	-119.77719600
Riverview (RV)	5/6/2004	9/30/2006	38.87601900	-119.68985000
Genoa Lakes (GL)	3/25/2004	9/30/2006	39.01108000	-119.82860300
Brunswick Canyon (BC)	3/8/2004	9/30/2006	39.17574200	-119.68899800

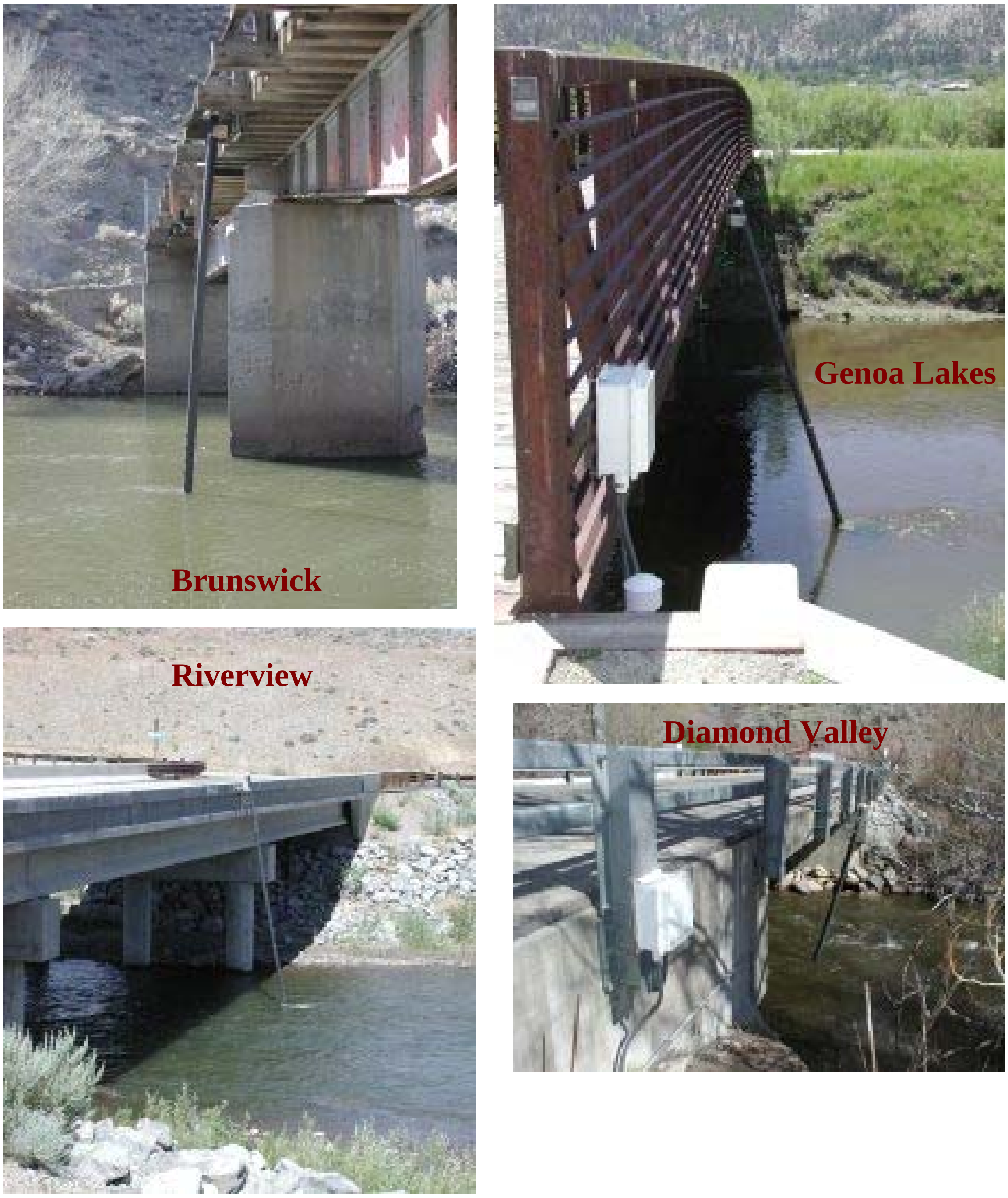

Figure 2-1. Turbidity monitoring installations.

2.2.1 Diamond Valley

The Diamond Valley site was located on the Alpine County Bridge at Diamond Valley Road, 0.45 miles downstream of U.S. Geological Survey (USGS) gaging station number 10310000. The bridge railing was approximately 15 feet above seasonal water levels, on average. The width of the west fork at this location was approximately 40 feet. The bridge stanchions constrict the river at higher flows.

Due to obstructions on the downstream side of the bridge, the monitoring boom was installed on the upstream side of the bridge. The ability of the boom to move upward was constricted by the bridge deck during flows close to flood stage. This resulted in the sensors being submerged deeper in the water column and prevented the boom from self-cleaning under these conditions. Turbidity readings we not affected as the turbidity sensor remained in the top 20% of the water column.

The higher water velocities characteristic of this site tended to produce turbulence and cavitation that introduced noise into the turbidity measurements. This noise produced high, random turbidity values that were filtered out during the data workup process. The excessive turbulence also loosened the detachable vacuum-sealed connector socket on the turbidity sensor that occasionally broke the electrical communication to the datalogger and resulted in the intermittent failure of the turbidimeter under high water conditions. After several attempts to address the issue spanning multiple years, the issue was finally resolved by immobilizing the cable above the socket within a small, protective tube.

2.2.2 Riverview

The Riverview site was located on the Dresslerville Bridge that spanned the east fork of the Carson River. The bridge was approximately 3.3 miles downstream of USGS gaging station number 10309000. Strong water velocities at this wide and shallow river section caused the lower end of the boom to float further downstream than at the other sites, resulting in the sensor being too near the water surface to take consistent measurements. The high water velocities also caused turbulence within the boom to a greater extent than at Diamond Valley. Both issues were somewhat mitigated by the addition of a 15-pound brass weight that was added to the lower end of the boom. As with Diamond Valley, the vibration and turbulence of the water caused the socket part of the electrical connection to enlarge and loosen the electrical contact between the cable and sensor. The other downstream sites were not susceptible to this due to their considerably lower water velocities.

2.2.3 Genoa Lakes

The Genoa Lakes site was located on the main stem of the Carson River just below the confluence of the east and west forks on the Genoa Lakes golf course. This site was approximately 23 miles downstream of Diamond Valley and 14 miles downstream of Riverview. It was co-located with the USGS gaging station number 10310407. The river was as little as 20 feet wide and several inches deep during the summer agriculture season or as much as 100 feet wide and a few feet deep at high flow. Flows were generally too low in the late summer to support measurements, requiring the removal of the sensors to prevent damage. The height from the water surface to the top of the bridge railing, where the cable and reel sampler were placed, ranged from 25 to 40 feet. As discharge data were available at this site beginning in 2002, data from a downstream USGS gaging station (10311000) were used for historical estimates prior to 2002.

2.2.4 Brunswick Canyon

The lower-most site was approximately 20 river miles downstream of Genoa Lakes and was the lower endpoint of the Upper Carson River in Nevada. The USGS gaging station number 10311400 was located at Deer Run Road, while the DRI sampling site was 0.83 miles further downstream off of Brunswick Canyon Road. The width of the river here was approximately 120 feet, with consistently laminar flow with low water velocities. The height of the bridge ranged from 20 to 26 feet above the water surface. Uniform depth-width sampling across the river could not be safely done off this decrepit bridge, requiring the establishment of only four sampling sites across approximately 65 percent of the river. Due to potential vandalism at this site, a stainless steel shroud was placed at the top of the monitoring boom to prevent access to the boom. The datalogger was hidden below the bridge and covered by a 1/4-inch-thick steel plate. During the project, the boom was commonly hit by paintballs and was also shot by a rifle that cleanly broke off the bottom 6 feet of the boom. The sensors were not damaged, and the missing section of boom was replaced within 10 days of being broken off. The solar panel was stolen once, and the four custom-built bridge board/safety railings were destroyed, requiring that water quality sampling was conducted from the bridge surface thereafter.

2.3 Turbidity Monitoring.

Continuous turbidity measurements were taken *in situ* every 15 minutes by the turbidity meter and stored on the datalogger. These data were collected on regular trips to each site for maintenance and sample collection. Despite having wipers that cleaned the face of the sensor before each measurement, the turbidimeters also required routine, manual cleaning. This was accomplished by pulling the instrument cluster out the top of the boom and by raising the boom to the bridge to remove debris stuck to the boom.

Turbidity sensors were calibrated prior to their installation, and checked for calibration drift several times while deployed and when they were removed from the field either for maintenance or at the end of the project. The DTS-12 turbidity sensors were chosen for this project due to their history of producing low-noise measurements that are not susceptible to sensor drift, which was confirmed by our calibration checks. At the outset of the project, a smaller, portable boom termed the ‘mini-boom’ was constructed and placed next to the sensor boom sequentially at each site. This method of quality assurance was abandoned after several months as the mini-boom was difficult to control and did not exactly reproduce the interior conditions within the sensor booms due to the higher water velocities at Diamond Valley and Riverview. In higher water velocities, the presence of the mini-boom immediately adjacent to the main sensor boom affected the readings of both sensors. In addition, the mini-boom tended to swim around and have greater water turbulence within the boom as it was not moored directly to the bridge as the standard booms were. As a result, composite samples were collected and analyzed for turbidity in the laboratory with a Hach 2100 turbidimeter to check for the possibility for sensor drift or biofouling.

2.4 Sample Collection

Water samples for TSS analysis were collected at each site following equal-width integrated sampling techniques (Edwards and Glysson, 1998, Shelton, 1994). Water samples were collected using a US D-76 sampler (Rickly Hydrological Co.) and a bridgeboard outfitted with a hand winch (Model 4200 bridgeboard and A-55 winch, Rickly Hydrological

Co.). Depth-integrated samples were taken at between 4 and 12 stations across the channel depending on the width of the river. All samples for a given site were combined in a churn splitter to produce a single representative sample.

During the first year of sampling, TSS samples were collected during every visit to each site, resulting in an average of 35 samples per site. Sites were visited approximately every two to three weeks, with more frequent visits during the snowmelt season. As the hydrograph and seasonal suspended solids loads were thought to be dominated by snowmelt-derived flows, resources were not consistently devoted to sampling during rain events. Following the first year of monitoring, the data were evaluated to determine the appropriate number and turbidity range of samples needed to establish adequate TSS versus turbidity relationships. This was done to minimize costs, and reduce the number of samples collected that were below the TSS reporting limit. After collection, samples were delivered to the Nevada State Health Laboratory for TSS analysis (EPA Method 160.2), generally within 24 hours. The Nevada State Health Laboratory had a TSS reporting limit of 10 mg/L.

2.5 Data Analysis

Fifteen-minute turbidity and specific conductance (SC) data were assessed utilizing the Turbidity Threshold Sampling Adjuster (TTS Adjuster) program (Redwood Sciences Laboratory, U.S. Forest Service, Arcata, CA). The TTS Adjuster provided an efficient means to compile and manipulate raw data files. The program created yearly files of corrected stage, discharge, turbidity, and SC data, and allowed the user to graphically view and adjust obvious problems in the data. Obvious problems included the fouling of the turbidity sensor optics by debris caught in the monitoring boom, and excessive noise in the turbidity readings due to higher water velocities that caused turbulence and air bubbles in the boom and/or the boom "surfing" near the water surface. A feature of the DTS-12 turbidity sensor was a variance number reported alongside the turbidity to help determine if a reading was valid. Record adjustment methods provided by the TTS Adjuster included interpolation, variable and constant shifts, and reconstruction of data from nearby reference gaging stations. Reconstruction of data was needed when there was a period of sustained data loss, particularly at Riverview and Diamond Valley. For example, correlations between turbidity and discharge at both the Riverview and Genoa Lakes sites would be made on both sides of any missing data. These correlations would then be used to reconstruct data at Riverview based on data collected at Genoa Lakes. As the stage and turbidity data were accepted or corrected, the TTS Adjuster tagged the data to reflect the type of changes that were made.

The majority of the turbidity data was of good quality, as turbidity readings generally had a low variability (not reported). The DTS-12 reported both the Best Easy Systematic (BES) turbidity estimate and the variance of 100 measurements taken in 10 seconds. The BES estimate was determined by sorting the 100 readings by value and averaging the 24th, 50th, 51st, and 76th readings. This produced a turbidity estimate that was influenced by the range of readings, but was not affected by unusual readings at either end of the data range. The accuracy of the DTS-12 sensor was 2 percent at less than 500 NTU and 4 percent at equal to or greater than 500 NTU. The quality of the data was lower when debris blocked the sensor face, or when air bubbles were present due to the combination of high water velocities traveling through the boom and the placement of the turbidity sensor near the surface.

Relationships between TSS and turbidity, TSS and discharge, and turbidity and discharge were determined from the data collected between 2004 and 2006. Unique relationships and prediction intervals were developed for each of the four sampling sites using the linear model (*lm*) command of the statistical language R (http://www.r-project.org). The *predict.lm* command was used to compute the response variable values based on a previously developed linear model and to calculate prediction or confidence intervals.

Only values of TSS greater than zero were included for the TSS-to-turbidity and TSS-to-discharge relationships. For the TSS-to-discharge relationship, data were separated into rising (March through May), falling (June through July), and baseflow (August through February) groups based on the annual hydrograph. Turbidity-to-discharge relationships were developed using all data where turbidity was greater than zero. Linear, exponential, and log-log relationships were developed, but were not used, as they did not improve the regression coefficient enough to account for their increased complexity.

Errors introduced when deriving the estimated TSS regression models from turbidity or discharge were likely to be of a greater magnitude than that introduced by the measurement process, discussed above. Resources during this project were primarily devoted to sample collection related to seasonal snowmelt, as that was the typical defining feature of the Upper Carson River hydrograph. As a result, less confidence should be placed in TSS estimates during rain events, unless those events were specifically sampled. The error in predicting TSS from these methods can be reduced by: 1) increasing the number of TSS samples collected; 2) collecting a greater number of samples from both the rising and falling limbs of rain event hydrographs (e.g. "storm-chasing"), and; 3) utilizing seasonal or event-specific regressions rather than relationships developed from multi-year datasets. However, even with the significant added cost of implementing these suggestions, error will still be present due to the natural, variable dynamics (including hysteresis) in these environments.

Suspended solids loadings were calculated using both the TSS-to-turbidity and the TSS-to-discharge relationships. The suspended solid load (SSL) was calculated as the product of the TSS (mg L^{-1}) and discharge Q ($ft^3\ s^{-1}$) with a conversion factor, such that the resultant load was in kilograms

$$SSL = \int_0^T TSS(t)Q(t)dt$$

where concentration and discharge are continuous over time t. This equation can be approximated by the discrete sum

$$SSL = \sum_{i=1}^{T/\delta t} TSS_i Q_i \delta t$$

with a fixed sampling interval that is shorter than the minimum time over which discharge or concentration can significantly change. Historical average daily discharge was obtained by the USGS NIWR website, accessed on July 17, 2007.

Duration-exceedance relationships were determined for measured turbidity and turbidity-based estimated TSS during the sampling period, and for discharge-based TSS and TSS-based turbidity estimated for the historic period. The duration of exceedance was determined by evaluating the TSS or TU value at each measurement. If the value was above the standard, one time unit was added to the exceedance duration. If the value was below the standard, the current duration was ended, and no new information was added to the dataset until the standard was again exceeded. This dataset was then subdivided into seasonal datasets based on the month number. Durations during the period of observation that were calculated at 15-minute intervals were converted to days to facilitate comparison with the historic data.

The cumulative distribution function (CDF), *F(x)*, describes the probability that *X* was less than a given value, $P(X<x)$. In R, the empirical CDF was computed using the command *ecdf*. The inverse CDF, *1-F(x)*, describes the probability that *X* was greater than a given value. The *ecdf* function was modified to produce the inverse empirical CDF, to determine the probability of exceedance. The inverse CDF was calculated and plotted for the dataset describing exceedance duration for each site.

Table 2-2. State of Nevada total suspended solids (TSS) and turbidity standards. (http://ndep.nv.gov/bwqp/standards.htm#NAC445a, Nevada Administrative Code, Chapter 445 - Water Controls, Standards for Water Quality, Legislative Council, State of Nevada, Carson City, Nevada, accessed 6-29-2007).

DRI Sampling Site	NDEP Water Quality Site	TSS Standard (mg/L)	Turbidity Standard (NTU)
Diamond Valley	C8 West Fork at Paynesville	25	10
Riverview	C9 East Fork at Riverview	80	10
Genoa	C2 Main Stem at Cradlebaugh Bridge	80	10
Brunswick Canyon	C1 Main Stem at New Empire Bridge	80	10

2.5.1 Methods for NDEP-type Exceedance Curves

To establish turbidity and TSS exceedance probability curves, all zero or negative values were converted to 0.001. This removed errors introduced by negative or zero values with the log scale, but retained these low values for analysis, such that the probability of exceedance of the lowest value is equal to 100 percent. The values were sorted and ranked, with equal values receiving the same rank. The percent rank (probability a given value will not be exceeded) was then calculated as

$$P_{rank} = 100 * \frac{m}{n}$$

where m was the rank and n was the total number of data points. The probability that a given value was exceeded (exceedance probability) was subsequently calculated as $1-P_{rank}$.

3.0 TURBIDITY AND TOTAL SUSPENDED SOILDS: 2004 to 2006

3.1. Discharge, Turbidity, and TSS

Average yearly discharge during the three years studied ranged from below average in WY2004 to above average in WY2006 (Figure 3-1). Flows from the east fork (Riverview) contribute substantially to that of the main stem and were 74 percent of that observed downstream at Brunswick Canyon in 2004 and 2005. Flows from the west fork (Diamond Valley) were smaller, and were 43 percent of those at Brunswick Canyon. The contribution of both forks were lower in 2006, 26 percent at Diamond Valley and 43 percent at Riverveiw, indicating that other sources of water within the Carson Valley increased in importance during the higher water year of WY2006. The primary event that caused this shift was the 2006 New Year's Flood, when total flows between 12/31/05 and 1/11/06 were 86 percent greater at Genoa Lakes on the main stem than the sum of total flows on the east and west forks measured at Riverview and Diamond Valley, respectively.

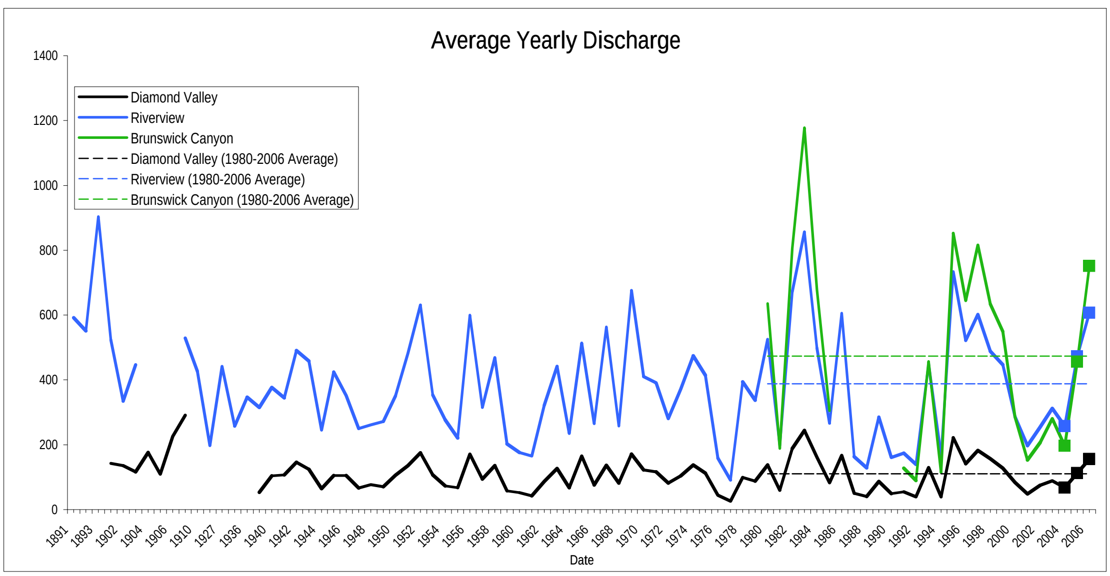

Figure 3-1. Average historical yearly discharge for three sites on the Carson River. Square points represent the three years of data included in this study. The dashed lines represent the 1980 to 2006 average of yearly discharge. Data provided by the USGS.

Water year 2006 had the greatest average flows due to both the flood and an extended snowmelt season (Figure 3-2). These elevated flows caused significant elevations in turbidity. The highest turbidity levels observed were during the flood, with peak average daily turbidities exceeding 750 NTU at Riverview, Genoa Lakes, and Brunswick Canyon, and exceeding 190 NTU at Diamond Valley. Lower turbidities were observed during seasonal snowmelt at Riverview, peaking at 250 NTU in 2006 and at 715 NTU in 2005. Peak turbidity during the 2006 snowmelt season was lower than that observed during the 2005 season, despite similar peak flows. This was likely due to the prior transport of mobile suspended solids during the 2006 New Year's Flood earlier in the year. In addition, the source of easily transportable suspended solids from the upper watershed appeared to be quickly depleted in 2006, as turbidity levels dropped rapidly after the first surge of snowmelt.

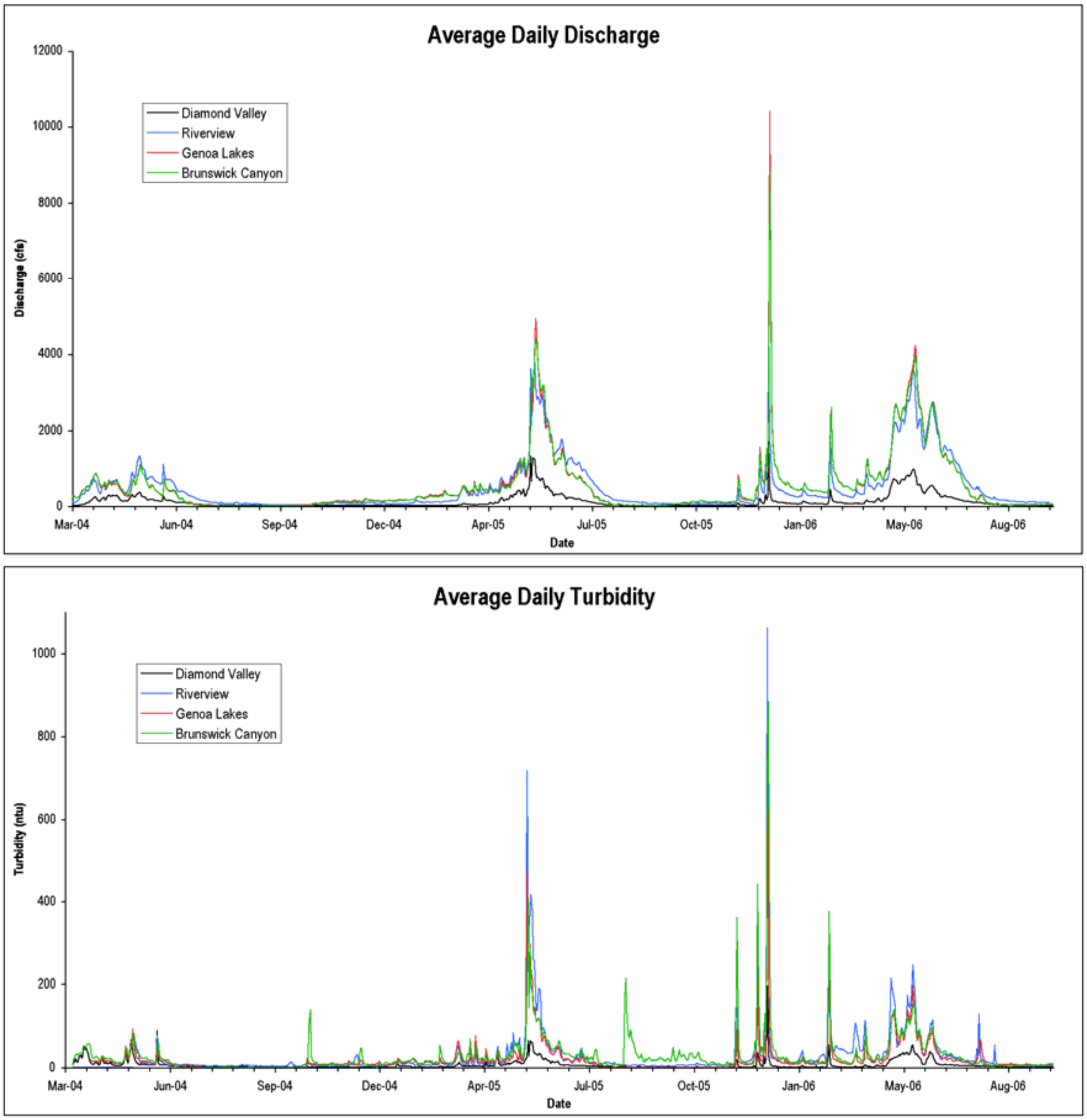

Figure 3-2. Average daily discharge (top) and turbidity (bottom) for March 2004 through August 2006. Discharge data provided by the USGS.

On a monthly basis between 2004 to 2006, turbidity and discharge were most highly elevated in May, during the rising limb of the snowmelt hydrograph (Figure 3-3). The Riverview site was more productive, characterized by higher monthly turbidity levels at relatively lower discharges compared to Genoa Lakes and Brunswick Canyon. Turbidity was not as highly elevated in June during the falling limb of the snowmelt season. Both turbidity and discharge were somewhat elevated between December and April and neither were elevated during the lower flow months of August through November. December events were the most productive suspended solids producing events, generating higher turbidity values with lower average discharge. This is due to the fact that the 2006 New Year's Flood actually started in December 2005.

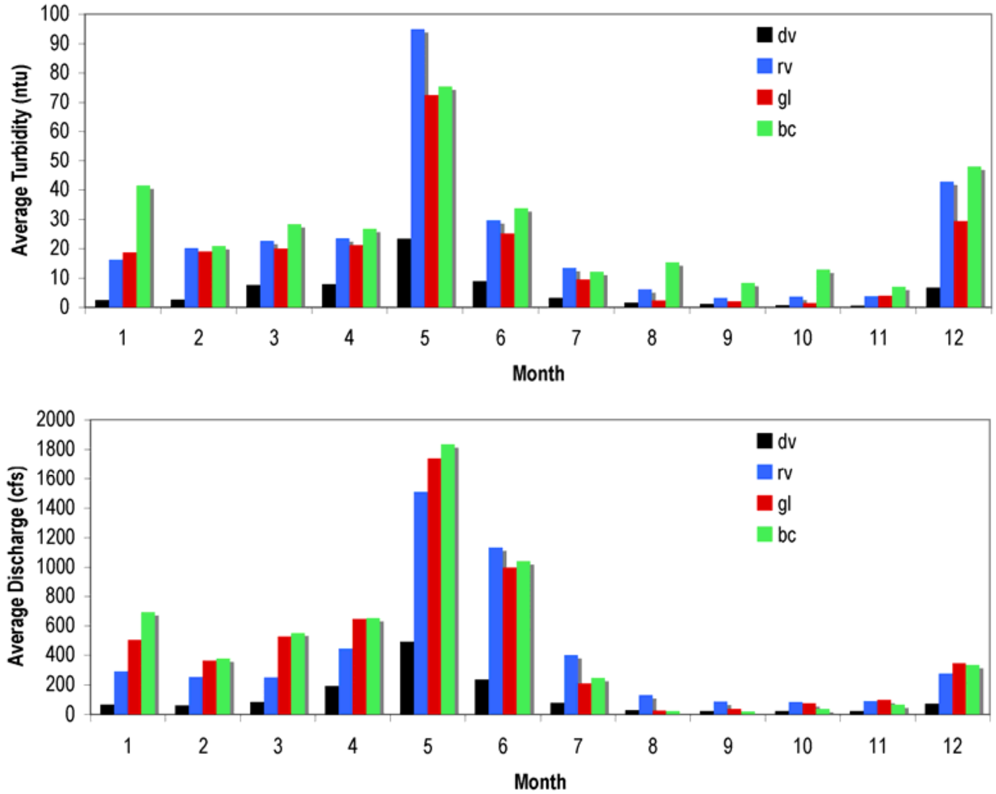

Figure 3-3. Average turbidity and discharge by month during the period of observation.

Nearly 200 TSS samples were collected during the project (Figure 3-4 and Appendix C). Samples from Diamond Valley had consistently lower TSS than that observed at the other sites.

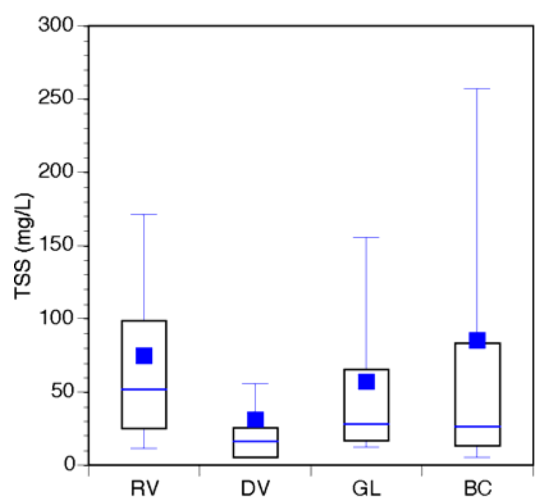

Figure 3-4. Boxplot diagram of TSS data. The line through the middle is the median value. The top and bottom lines correspond to the 75th and 25th, respectively. The whiskers extend to the 10th percentile on the bottom and the 90th percentile on top. The box represent the arithmetic mean of the sample.

3.2. Estimated TSS Concentrations

Total suspended solids concentrations were estimated using either turbidity or discharge as a surrogate. Site-specific relationships were developed using linear regressions (Table 3-1 and Figure 3-5). The regression coefficients at all sites except that at Diamond Valley were high. The poor predictive ability at Diamond Valley was due to the high degree of variability in TSS samples collected in 2006, as well as a greater variability observed in the turbidity data throughout the study. One cause of this variability was the excessive noise in the turbidity readings due to the formation of air bubbles under high water velocity conditions.

Table 3-1. Relationship between TSS and turbidity at the four sites located on the Carson River. Median relative percent difference (mRPD) and root mean square deviation (RMSD) are presented for each relationship utilizing data collected by DRI during the period of observation.

Site	Relationship	R^2	mRPD	RMSD
Diamond Valley	TSS = 0.6507·TU + 9.8241	0.49	42.4%	64.5
Riverview	TSS = 1.5454·TU - 17.1623	0.99	35.3%	22.2
Genoa Lakes	TSS = 1.5382·TU - 0.8424	0.96	13.6%	14.2
Brunswick Canyon	TSS = 1.2853·TU + 12.8469	0.86	24.9%	27.2

As continuous turbidity data were not available prior to this study, relationships between TSS and discharge were also developed to "hind-cast" (estimate) historical TSS concentrations (Table 3-2 and Figure 3-6; see Section 4).

Table 3-2. Relationship between TSS and discharge at the four sites located on the Carson River. Median relative percent difference (mRPD) and root mean square deviation (RMSD) are presented for each relationship utilizing data collected by DRI during the period of observation.

Site	Relationship	R^2	mRPD	RMSD
Diamond Valley	TSS = 0.0387·Q + 8.5338	0.40	53.3%	96.9
Riverview (Q <750 cfs)	Ln(TSS) = 0.0012·Q + 2.3547	0.65	72.6	93.5
Riverview (Q ≥ 750 cfs)	TSS = 0.13482·Q – 75.89554	0.50		
Genoa Lakes	TSS = 0.0663·Q - 1.5306	0.59	39.8%	44.6
Brunswick Canyon	TSS = 0.0632·Q	0.89	23.1%	31.2

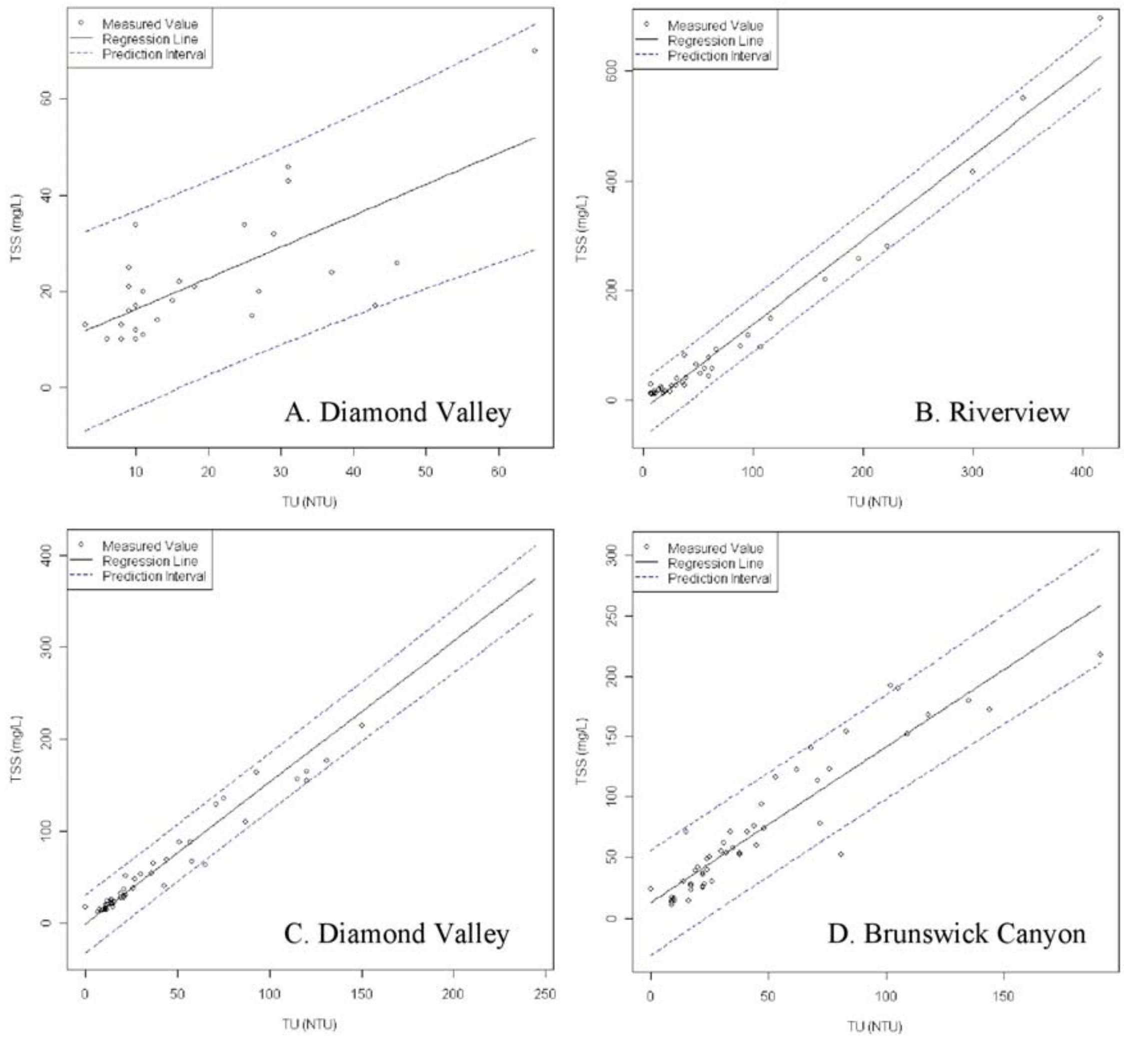

Figure 3-5. Linear regressions of turbidity versus TSS, including 95-percent prediction intervals. Samples below the TSS reporting limit of 10 mg/L were omitted, including 11 samples at Diamond Valley, 7 samples at Riverview, 5 samples at Genoa Lakes, and 5 samples at Brunswick Canyon.

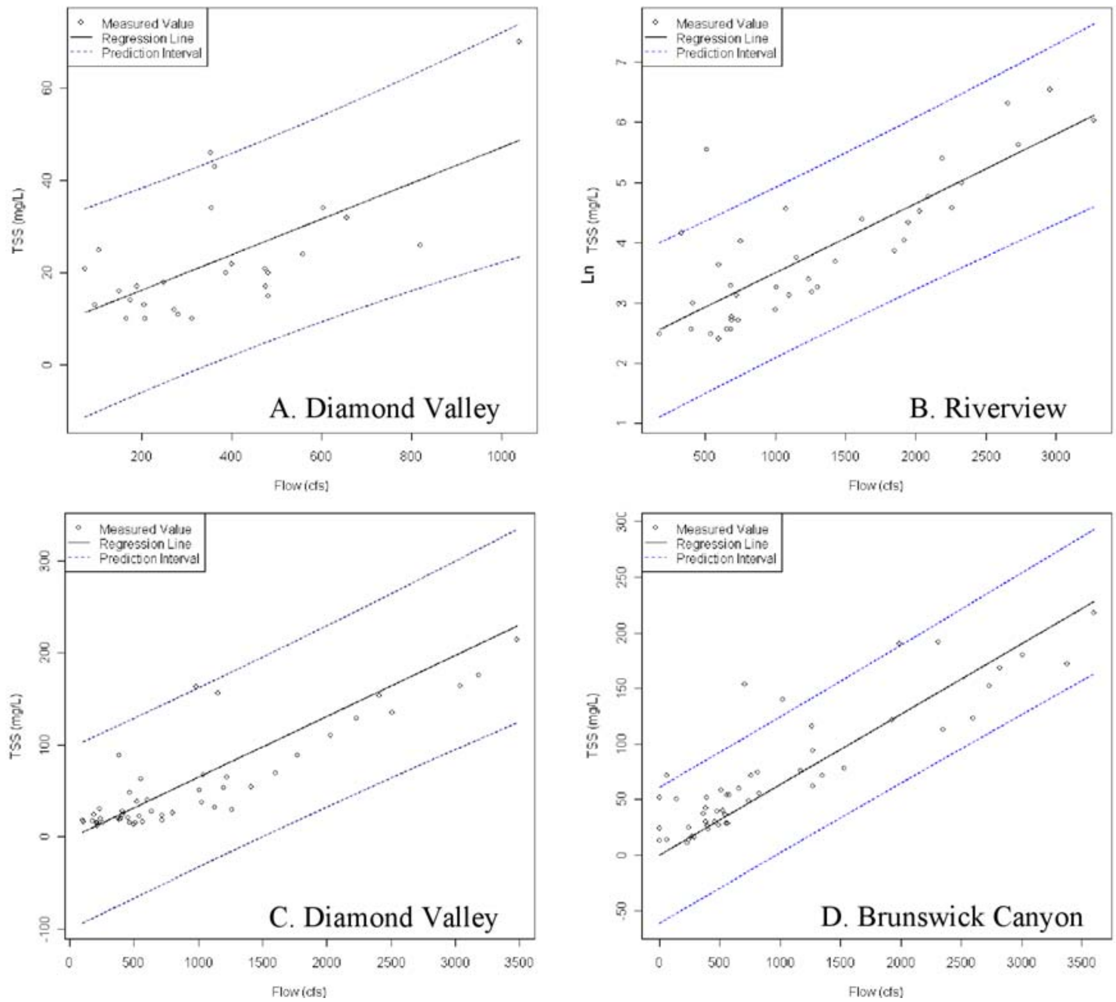

Figure 3-6. Linear regressions of discharge versus TSS, including 95-percent prediction intervals. Samples below the TSS reporting limit of 10 mg/L were omitted, as discussed in Figure 3-5.

Common transformations and relationships were investigated in an attempt to improve each relationship. Quadratic relationships resulted in slightly higher regression coefficients at most sites. Seasonal regressions were also developed (Appendix A), and found to improve the regression coefficients in some cases. However, linear relationships are presented here, as the benefit from higher regression coefficients was not offset by the increased complexity introduced by the use of multiple and quadratic equations. Not all seasonal regression coefficients had improved correlation coefficients and the use of non-linear regression prevented the calculation of confidence intervals. At Riverview, both a linear and a natural log transformation are presented. Both regressions were developed using the entire data set. However, use of the linear form greatly overestimated TSS at low discharge, and the log transformed regression greatly overestimated TSS at high Q. A mixed model was developed utilizing the log transformation at discharge less than 750 cfs and the linear relationship at discharge equal to and greater than 750 cfs. The transition value of 750 cfs was chosen, as both forms estimated TSS to within 3 percent at this discharge. This mixed model produced estimates of yearly suspended solids loadings (see Section 3.3) that were consistent with estimates generated by turbidity-based regressions in Table 3.1. Neither individual model produced acceptable loading estimates. At Brunswick Canyon, the linear relationship was forced through zero to prevent the consistent overprediction of TSS at low turbidity values.

Both the mRPD and RMSD indicated that turbidity-based surrogate regressions were a better model than discharge-based regressions. Between the two estimation methods, the discharge-surrogate method consistently underpredicted TSS concentrations during short-term events, such as thunderstorms, at all sites (Figure 3-7). This underprediction is typical of discharge-based surrogates, as they have difficulty accounting for dynamic changes in the production and mobilization of suspended solids (Lewis, 1996). For example, TSS concentrations will typically be lower in response to a slower increase in discharge due to snowmelt compared to a faster increase such as during a thunderstorm, given the same TSS loading. This is because the slower snowmelt event has a lower intensity and transports the suspended solids over a longer time period. In addition, the sampling of TSS was biased towards collections of more samples during snowmelt events, as that was the dominant feature of the hydrologic cycle in the Upper Carson Watershed. This resulted in the discharge-based surrogate regression to under predict TSS loads during rain and short-term events compared to the turbidity-based surrogate regressions.

Predictions at Genoa Lakes were characterized by having the lowest error of all four sites, a reflection of our better ability to measure turbidity at this site due to the lower water velocities. Turbidity sensors at both upstream sites were susceptible to poorer quality of readings due to high water velocities that created turbulence and air bubbles around the sensor.

The regression model for Diamond Valley produced the highest errors, with the turbidity surrogate producing slightly better mRPDs than the discharge surrogate. Both methods consistently overestimated baseflow TSS concentrations throughout the observed period (Figure 3-7). This baseline value of 9.7 mg/L observed in Figure 2-7A was actually just below the analytical laboratory's TSS reporting limit of 10 mg/L. For loading estimates, this overprediction of TSS was not important due to the water discharges during these time periods. Both methods underpredicted TSS concentrations during the 2005 snowmelt season, when compared with real samples. Neither turbidity nor discharge reflected an elevated TSS concentration measured on 3/14/05, while both methods only partially estimated peak TSS concentrations measured between 5/18/05 to 5/19/05. Excessively noisy turbidity data during parts of this time period resulted in the need to reconstruct turbidity data at Diamond Valley using both discharge at Diamond Valley and turbidity measured downstream at Genoa Lakes. This reconstructed data underestimated observed TSS data and increased the overall error of TSS estimates at Diamond Valley.

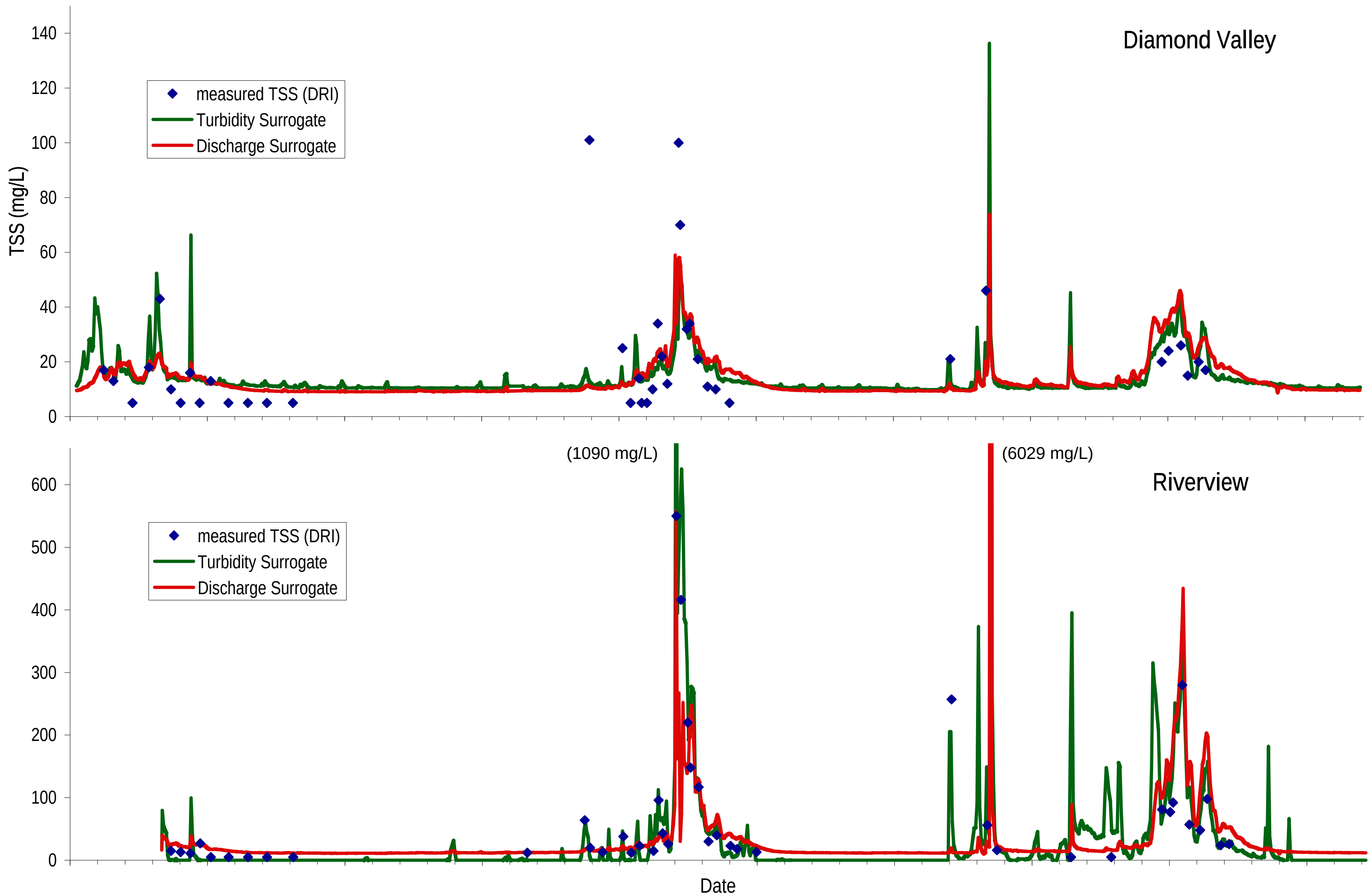

Figure 3-7. Comparison of turbidity- and discharge-based estimated TSS with measured TSS during the period of observation. Concentrations reported below the reporting limit are plotted here at half the 10 mg/L reporting limit.

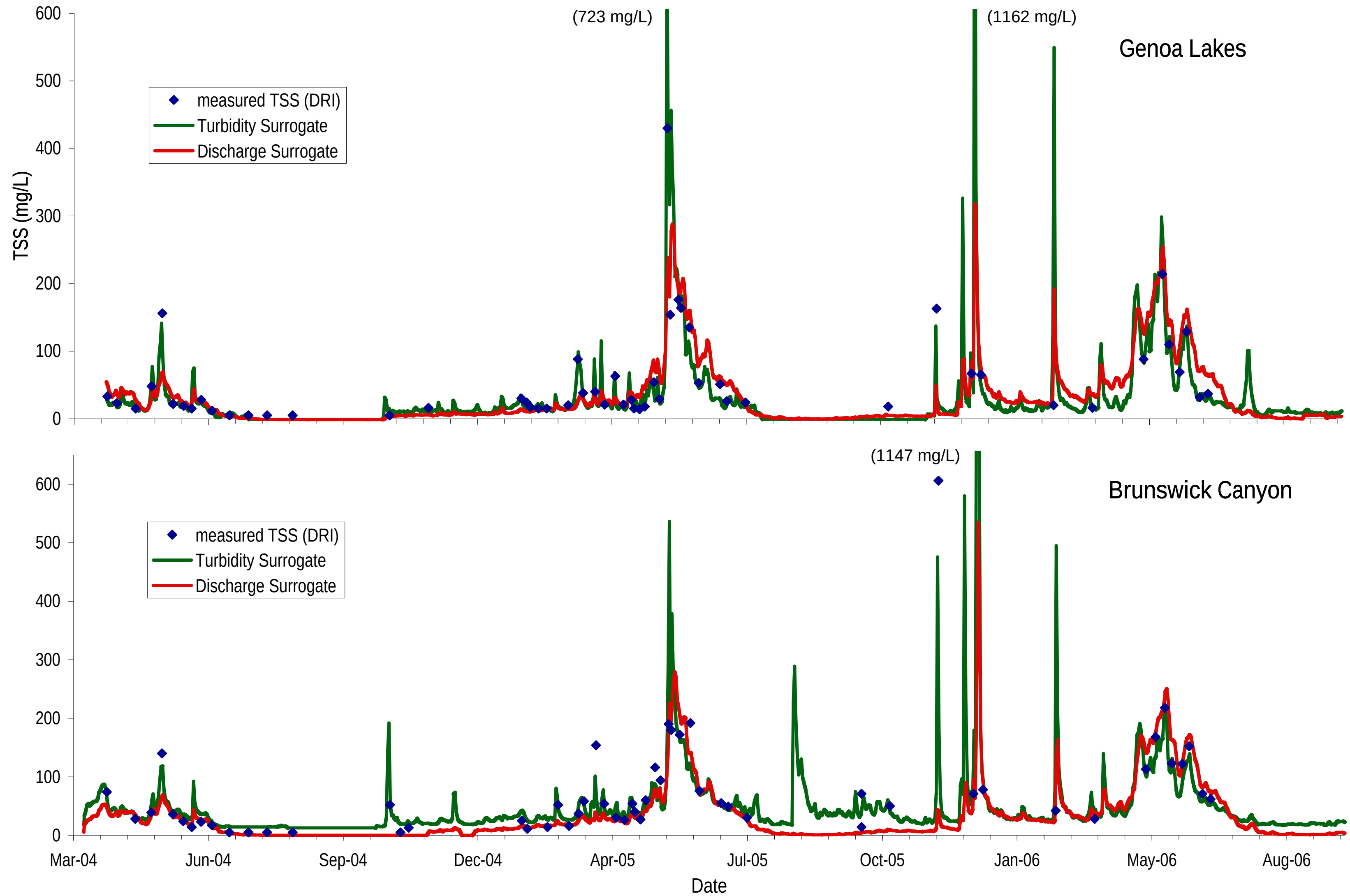

Figure 3-7. Comparison of turbidity- and discharge-based estimated TSS with measured TSS during the period of observation. Concentrations reported below the reporting limit are plotted here at half the 10 mg/L reporting limit (continued).

Predictions for Riverview and Brunswick Canyon had moderate error, with mRPDs of 35 percent and 23 percent, respectively. Baseline estimates of TSS at Riverview were elevated for the discharge-surrogate but not for the turbidity-surrogate. At Brunswick Canyon, both estimation techniques had similar errors and regression coefficients, suggesting that the underlying cause of suspended solids mobilization (e.g., thunderstorm or snowmelt) was not as important at this site. This was due to two factors. The most important factor was that the majority of the flow in the Carson River was derived from the Carson Valley and the Upper Carson River in California, so the upstream sites at Diamond Valley, Riverview, and Genoa Lakes would be more reflective of how the suspended solids were mobilized. The Brunswick Canyon site was another 20 miles downstream, allowing in-river processes to mask the signature of suspended solids mobilization. To a lesser degree, anthropogenic influences may also have played a role. The presence of Mexican Dam above Brunswick Canyon will attenuate the loading of suspended solids at Brunswick Canyon to some extent. The source of suspended solids can also be masked by the contribution of urban runoff starting from the Clear Creek drainage downstream to Brunswick Canyon, including that from the Carson City storm water system.

3.3 Loading Comparisons

Yearly suspended solids loading estimates were calculated at all sites using both turbidity- and discharge-based TSS estimates (Table 3-3). Estimated loads followed the trend in average yearly discharge, with the lowest loads in WY2004 and the highest loads observed in WY2006. The east fork was the source of the majority of the suspended solids load entering the main stem of the river, as turbidity-based loadings at Riverview ranged from 4 to 22 times greater than that observed at Diamond Valley. As a result, loadings estimated for Genoa Lakes were similar to that at Riverview. Suspended solids loading from the west fork was less susceptible to the weather patterns that increased east fork loading 18-fold between WY2004 and WY2006. As a result, loading from the west fork became increasingly unimportant to the loads observed at Genoa Lakes as average yearly discharge increased. At Brunswick Canyon, suspended solids loads were 48 percent to 61 percent greater than those at Genoa Lakes, reflective of the greater source area lower in the watershed.

Discharge-based loads were, on average, lower than the corresponding turbidity-based loads. Loadings estimated for Riverview and Brunswick Canyon using both methods were within 20 percent for all three years, but agreement between the two methods was much lower at Genoa Lakes and Diamond Valley. At Genoa Lakes, the discharge-based loadings were up to 34 percent lower, indicative of poor load estimations under high discharge conditions. At Diamond Valley, the discharge-based loadings were 4 to 17 times greater than the corresponding turbidity-based estimate, indicating that the model was significantly over-predicting suspended solids delivery. The discharge-based estimates were also characterized by greater prediction intervals (Figures 3-5 and 3-6), resulting in greater uncertainty than that estimated by turbidity-based models. Errors were greater in years characterized by intense events that generated higher TSS compared to years that had lower peak TSS but for a greater duration.

Table 3-3. Comparison of suspended solids loadings at each site using estimated TSS based on turbidity and discharge relationships. For 2004, the "Partial" load estimate only includes data that were observed. The "Estimated" load includes load estimates during the first part of the water year prior to the initiation of monitoring. The periods of missing data were between 10/1/04 and: 1) 3/8/05 for Brunswick Canyon (BC); 2) 3/5/05 for Diamond Valley (DV); 3) 3/25/05 for Genoa Lakes (GL); and 4) 5/6/05 for Riverview (RV). For the turbidity-based estimate, missing data were estimated by substituting daily average WY2005 data for missing WY2004 data. For the discharge-based estimate, estimated TSS was calculated using the regressions in Table 3-2. Loads were calculated using fifteen-minute interval USGS discharge data.

	WY2004		WY2005	WY2006
	Partial	Estimated		
Site	Suspend Solids Load ($1x10^5$ kg)			
	Turbidity-based			
DV	10 ± 11	11 ± 13	22 ± 21	35 ± 30
RV	26 ± 96	41 ± 156	468 ± 150	759 ± 637
GL	34 ± 32	50 ± 53	479 ± 131	722 ± 194
BC	67 ± 9	81 ± 29	443 ± 229	1072 ± 37
	Discharge-based			
DV	8 ± 20	42 ± 32	27 ± 50	36 ± 68
RV	27 ± 77	49 ± 79	421 ± 233	766 ± 146
GL	36 ± 97	48 ± 113	317 ± 392	532 ± 530
BC	67 ± 71	85 ± 76	428 ± 221	884 ± 381

Overall, the similarity of loading estimates derived by both methods indicated that the use of a discharge-based surrogate was an acceptable approach, at least under the conditions observed at three of the four sites between WY2004 and WY2006. Total suspended solids estimates presented for Riverview in Table 3-3 are similar to historical estimates that ranged from $7.5x10^6$ to $1.7x10^8$ kg/year (Figure 3-8). Both the Pahl (2001) and 50-day Katzer and Bennett (1980) estimates were lower than estimated by this project. Pahl used instantaneous TSS concentrations to estimate an average daily loading of $1.2x10^5$ kg/day using data collected between 1980 and 1984 and 1994 and 1998. Katzer and Bennett estimated loads using suspended sediment concentrations (SSC) over a 50-day period in 1978 at a site downstream of Riverview. Pahl's loading estimate was likely biased low due to his use of TSS data collected by NDEP. Research has indicated that the TSS method typically underreports that measured by the suspended sediment concentration (SSC) method used by the other investigators discussed here (Gray *et al*., 2000). This bias is thought to be greater in samples that contained a significant proportion of sand-sized sediment, such as those collected during storm events. For the Carson River Basin, Alvarez and Seiler (2004) report that TSS can underreport SSC by 30 to 40 percent. Caution should be used in interpreting Figure 3-8, as neither Pahl nor Katzer and Bennett scaled their results to a yearly timeframe, as they did not have a high enough sampling density to adequately reflect loadings from different types of hydrologic events.

Katzer and Bennett (1980) also estimated suspended sediment loading downstream of Riverview during a discontinuous 15-year period between 1926 and 1949. Expressed on a yearly basis, they estimated a loading of 4.6×10^7 kg/year during a time period that had an average yearly discharge of 335 cfs. Garcia and Carman (1986) estimated loading at multiple sites along the Carson River in 1980 using the sediment rating curve approach based on SSC measurements. Their estimates included 1.7×10^8 kg/year at Riverview, 8.1×10^6 kg/year at Diamond Valley, and 1.5×10^8 kg/year at Brunswick Canyon, with average yearly discharges of 525, 168, and 635 cfs, respectively. Both the 15-year Katzer and Bennett and the Garcia and Carman estimates were greater than estimated by this project. Direct comparison of these results is difficult due to the highly variable management of the Carson River over the last 120 years that has resulted in significant channel modifications including both diversions and structural modifications (Katzer and Bennett, 1980).

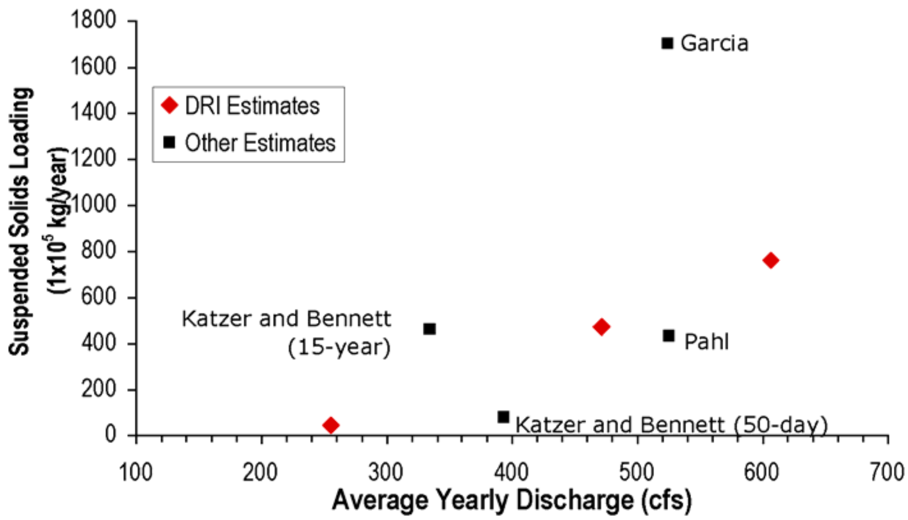

Figure 3-8. Comparison of suspended sediment/solids loadings and average yearly discharge at Riverview. DRI estimates are the turbidity-based estimates for 2004 through 2006. See text for description of other estimates. Partial-year estimates from Pahl (2001) and Katzer and Bennett (1980) were linearly scaled to a yearly basis for comparison. Pahl's analysis was based on TSS data collected by NDEP, whereas the other datasets utilized suspended sediment concentration data collected by the USGS.

4.0 ESTIMATION OF HISTORICAL DATA

4.1 Total Suspended Solids

The only historical record of near-continuous data was discharge; thus, the discharge-based relationships (Table 3-2) were used to estimate historical average daily TSS concentrations (Figure 4-1) and TSS loading (Table 4-1). The ability of the regressions to hindcast TSS samples can be compared to the approximately 50 samples per site that NDEP collected during WY1995 to WY2006. A rigorous comparison of historical NDEP data with hindcast TSS concentrations was not attempted, as nearly 60 percent of all NDEP-collected TSS samples were below the detection limit, with the remaining samples characterized by relatively low TSS concentrations. This was a direct result of NDEPs routine sampling schedule that resulted in the collection of samples primarily during lower flow periods. Yearly suspended solids loads are dominated by events having high TSS concentrations, so an effective assessment of the hindcast TSS predictions requires a greater number of samples collected during moderate and high TSS concentrations events. Mean relative percent differences (mRPDs) were calculated between historic predictions and the NDEP dataset, and ranged between 41 and 64 percent for TSS (Table 4-2). The exclusion of samples that were below the detection limit increased mRPDs between 22 and 42 percent, with the greatest improvements observed at Diamond Valley and Riverview, sites whose TSS dataset contained a greater proportion of TSS samples that were less than 10 mg/L. Caution must be exercised when interpreting other reports that are based solely on the historical NDEP data, as interpretations regarding TSS concentrations and turbidity are likely to be biased low due to the low number of NDEP-collected samples taken during high flow and high TSS concentration periods.

4.2 Turbidity

Historic turbidity levels (Figure 4-2) were estimated by developing a relationship between turbidity and discharge measured at 15-minute intervals during the period of observation (Table 4-3). Correlation coefficients for all sites were between 0.50 and 0.53, and improved slightly with the use of common transformations, but the linear relationships were used for simplicity. Predicted values appeared to be similar to historic NDEP samples, however, the lack of high turbidity samples in the NDEP dataset precludes a more thorough assessment. The relationships developed between turbidity and discharge, especially during higher flows, were complicated by hysteresis. Hysteresis occurs when a given parameter, such as turbidity, is observed to have a different relationship with discharge during the rising limb of an event hydrograph compared to the falling limb. The degree to which hysteresis occurs is dependent on a number of site-specific, event-specific, spatially complex but inter-dependent factors. For example, the source of particles entrained in the water column will vary as stage increases (variable source area), and particle sizes will increase as the water velocity increases. As water velocities decrease and/or particle sources are depleted, suspended solids will decline.

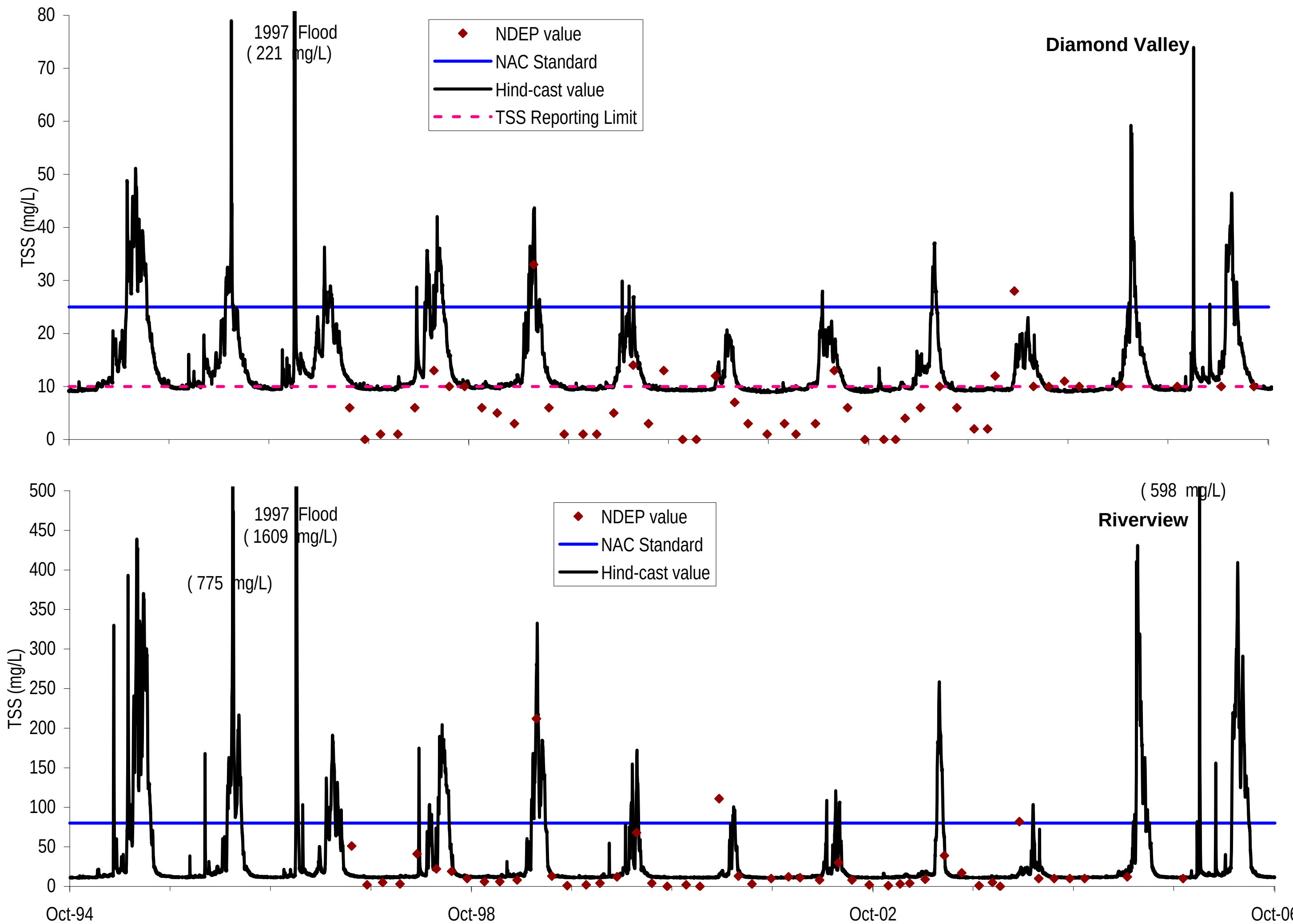

Figure 4-1. Total suspended solids (TSS) estimated for the historic period (WY1995 through WY2006). At Genoa Lakes, data prior to 2002 were based on discharge from a downstream USGS gaging station (10311000). NDEP TSS data prior to 2004 that was below the reporting limit was reported by NDEP as an estimated value.

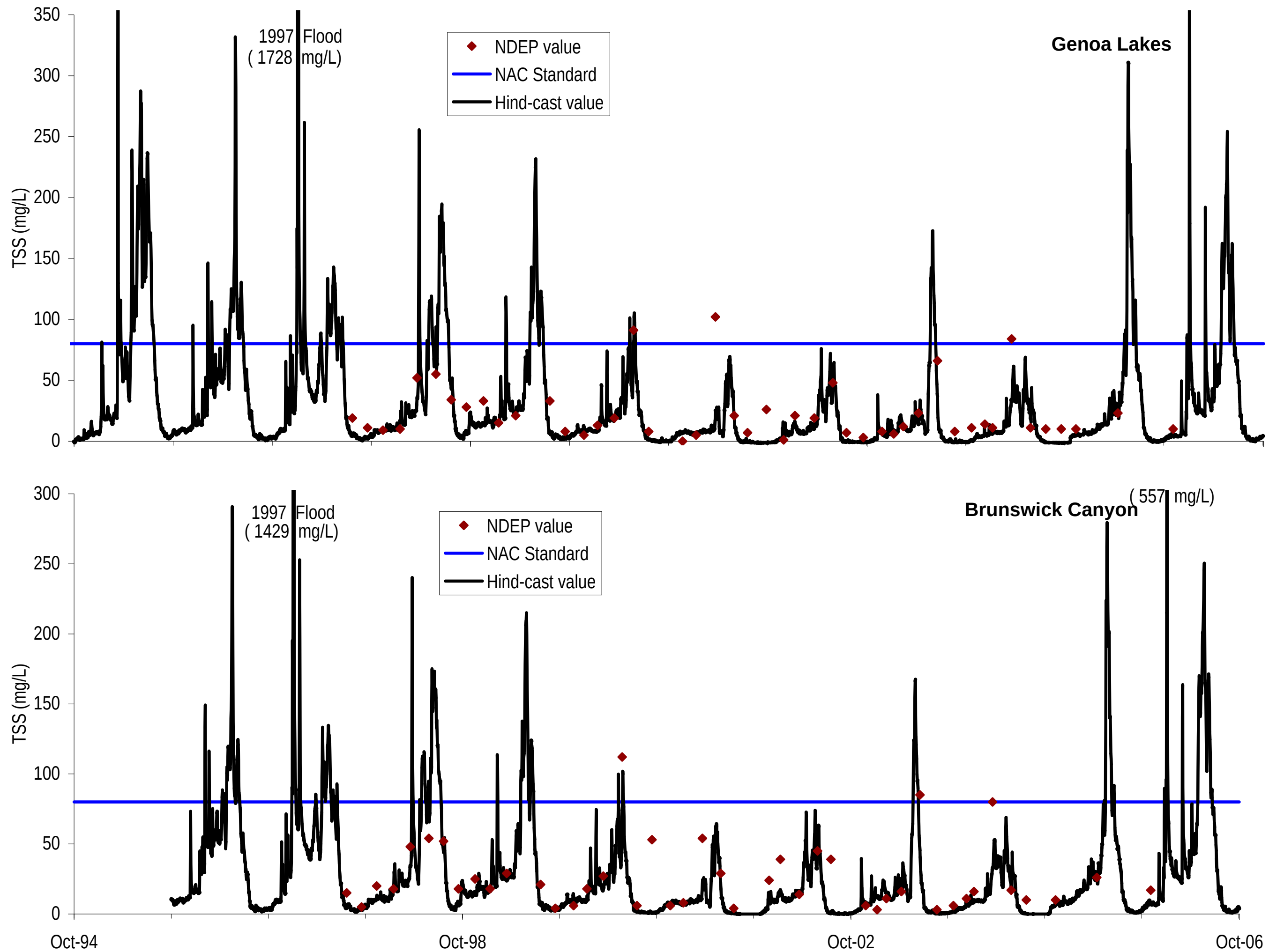

Figure 4-1. Total suspended solids (TSS) estimated for the historic period (WY1995 through WY2006). At Genoa Lakes, data prior to 2002 were based on discharge from a downstream USGS gaging station (10311000). NDEP TSS data prior to 2004 that was below the reporting limit was reported by NDEP as an estimated value. (continued).

Table 4-1. Estimated TSS loading hindcast using discharge-based relationships. At Genoa Lakes, data prior to 2002 were based on discharge from a downstream USGS gaging station (10311000). Loads were calculated using USGS daily mean discharge values.

		Rising	Falling	Baseflow	Total
	Year	Suspended Solids Loading ($1x10^5$ kg)			
Diamond Valley	1995	27 ± 20	30 ± 20	3 ± 6	60 ± 46
	1996	21 ± 17	5 ± 6	3 ± 6	29 ± 29
	1997	16 ± 15	4 ± 5	62 ± 33	81 ± 53
	1998	14 ± 13	17 ± 14	2 ± 5	33 ± 31
	1999	17 ± 14	7 ± 7	2 ± 5	26 ± 26
	2000	9 ± 11	2 ± 3	1 ± 3	13 ± 17
	2001	5 ± 6	0.5 ± 1	1 ± 2	6 ± 10
	2002	8 ± 10	2 ± 3	1 ± 3	11 ± 15
	2003	10 ± 10	5 ± 5	1 ± 3	16 ± 18
	2004	7 ± 9	1 ± 2	1 ± 3	9 ± 14
	2005	19 ± 14	5 ± 6	1 ± 3	26 ± 23
	2006	23 ± 17	7 ± 7	7 ± 8	36 ± 32
Riverview	1995	313 ± 452	828 ± 742	15 ± 55	1,156 ± 1,249
	1996	428 ± 484	134 ± 230	21 ± 60	583 ± 775
	1997	186 ± 394	48 ± 147	904 ± 445	1,137 ± 987
	1998	68 ± 217	258 ± 439	8 ± 28	335 ± 683
	1999	238 ± 328	167 ± 295	9 ± 33	415 ± 656
	2000	108 ± 263	16 ± 64	7 ± 24	131 ± 351
	2001	55 ± 186	3 ± 11	3 ± 10	61 ± 207
	2002	59 ± 195	19 ± 64	4 ± 14	82 ± 273
	2003	124 ± 185	97 ± 169	6 ± 20	227 ± 375
	2004	44 ± 162	7 ± 21	4 ± 12	55 ± 196
	2005	395 ± 394	159 ± 310	6 ± 18	560 ± 723
	2006	503 ± 503	247 ± 340	112 ± 133	861 ± 976
Genoa Lakes	1995	498 ± 346	643 ± 362	21 ± 97	1,162 ± 804
	1996	372 ± 307	87 ± 111	67 ± 146	527 ± 564
	1997	237 ± 258	59 ± 85	1,869 ± 650	2,165 ± 992
	1998	190 ± 214	326 ± 245	15 ± 100	531 ± 559
	1999	258 ± 229	130 ± 134	38 ± 132	426 ± 494
	2000	83 ± 145	11 ± 36	14 ± 79	108 ± 259
	2001	36 ± 91	0.3 ± 6	3 ± 43	39 ± 140
	2002	41 ± 103	10 ± 28	3 ± 38	54 ± 169
	2003	96 ± 116	56 ± 63	6 ± 50	158 ± 229
	2004	45 ± 115	2 ± 15	4 ± 39	51 ± 169
	2005	377 ± 248	113 ± 125	4 ± 49	494 ± 422
	2006	402 ± 309	117 ± 123	190 ± 172	708 ± 604
Brunswick Canyon	1995	403 ± 175	555 ± 195	40 ± 56	998 ± 426
	1996	350 ± 170	95 ± 63	91 ± 84	537 ± 317
	1997	245 ± 146	56 ± 43	1,316 ± 310	1,617 ± 499
	1998	205 ± 122	293 ± 133	36 ± 56	534 ± 311
	1999	245 ± 124	127 ± 72	60 ± 74	433 ± 269
	2000	89 ± 76	15 ± 19	30 ± 44	134 ± 139
	2001	47 ± 49	1 ± 3	11 ± 22	60 ± 75
	2002	59 ± 60	15 ± 16	13 ± 24	88 ± 101
	2003	96 ± 64	65 ± 40	20 ± 33	180 ± 137
	2004	63 ± 65	6 ± 9	12 ± 22	81 ± 96
	2005	315 ± 131	98 ± 65	17 ± 31	430 ± 226
	2006	445 ± 184	161 ± 83	272 ± 113	878 ± 380

Table 4-2. Median relative percent difference (mRPD) between NDEP samples and estimated historic samples from 1994 through 2006. For turbidity, estimated historic samples below zero were set to zero. The maximum possible mRPD is 200 percent.

Site	TSS mRPD (%)	TU mRPD (%)	Count
	Full NDEP Dataset		
Diamond Valley	64	200	50
Riverview	68	137	48
Genoa Lakes	52	52%	47
Brunswick Canyon	41	200	45
	NDEP Dataset where TSS ≥ 10 mg/L		
Diamond Valley	22	115	19
Riverview	38	104	24
Genoa Lakes	42	45	34
Brunswick Canyon	41	126	34

Table 4-3. Relationship between turbidity and discharge. The dataset included 15-minute turbidity data measured at each site by DRI and 15-minute discharge data provided by the USGS .

Site	Relationship	R^2
Diamond Valley	$TU = 0.05148 \cdot Q - 0.34667$	0.53
Riverview	$TU = 0.07410 \cdot Q - 9.87608$	0.50
Genoa Lakes	$TU = 0.04955 \cdot Q - 5.88498$	0.52
Brunswick Canyon	$TU = 0.05041 \cdot Q + 2.15195$	0.50

Hysteresis is observed in Figure 4.3 by following the circular path of individual 15-minute data points during a hydrologic event. For example, four sets of hysteresis curves (denoted by the box-enclosed numbers) are easily discernible at Diamond Valley (Figure 4.3A). Curve 1 represented the 2006 New Year's Flood that resulted in the greatest flows at all four sites. Hysteresis was evident, as turbidity per unit flow was over three times greater in the rising limb than in the falling limb of this event. For some events (Curves 2 and 3), turbidity was elevated despite low flows. Curve 2 resulted from a rainstorm on 5/28/04, while the series of peaks that comprised Curve 3 resulted from the first flush phase of the 2004 snowmelt season. Other events, such as the peak flows of the 2005 snowmelt season that comprise Curve 4, had low turbidity despite higher flows.

At Riverview (Figure 4.3B), several rain events exhibited high turbidity per unit flow (Curves 5-7), while the peak snowmelt from 2005 (Curve 8) was similar to the lower portion of the 2006 New Year's Flood (Curve 9). Figure 4.4 shows how complex hysteresis can be in this system. In a low snowfall year such as 2004 (yellow line), turbidity levels remained low. For a season with greater snowmelt, such as 2005, the rising limb (red) of the seasonal hydrograph delivered greater turbidity levels and was more susceptible to hysteresis than the falling limb (dark blue). For 2006, turbidity per unit flows were lower during the rising limb (orange), despite greater peak flows than 2005. This occurred as both the 2006 New Year's flood (green) and a rain event (blue) previously flushed the easily mobile suspended solids out of the system.

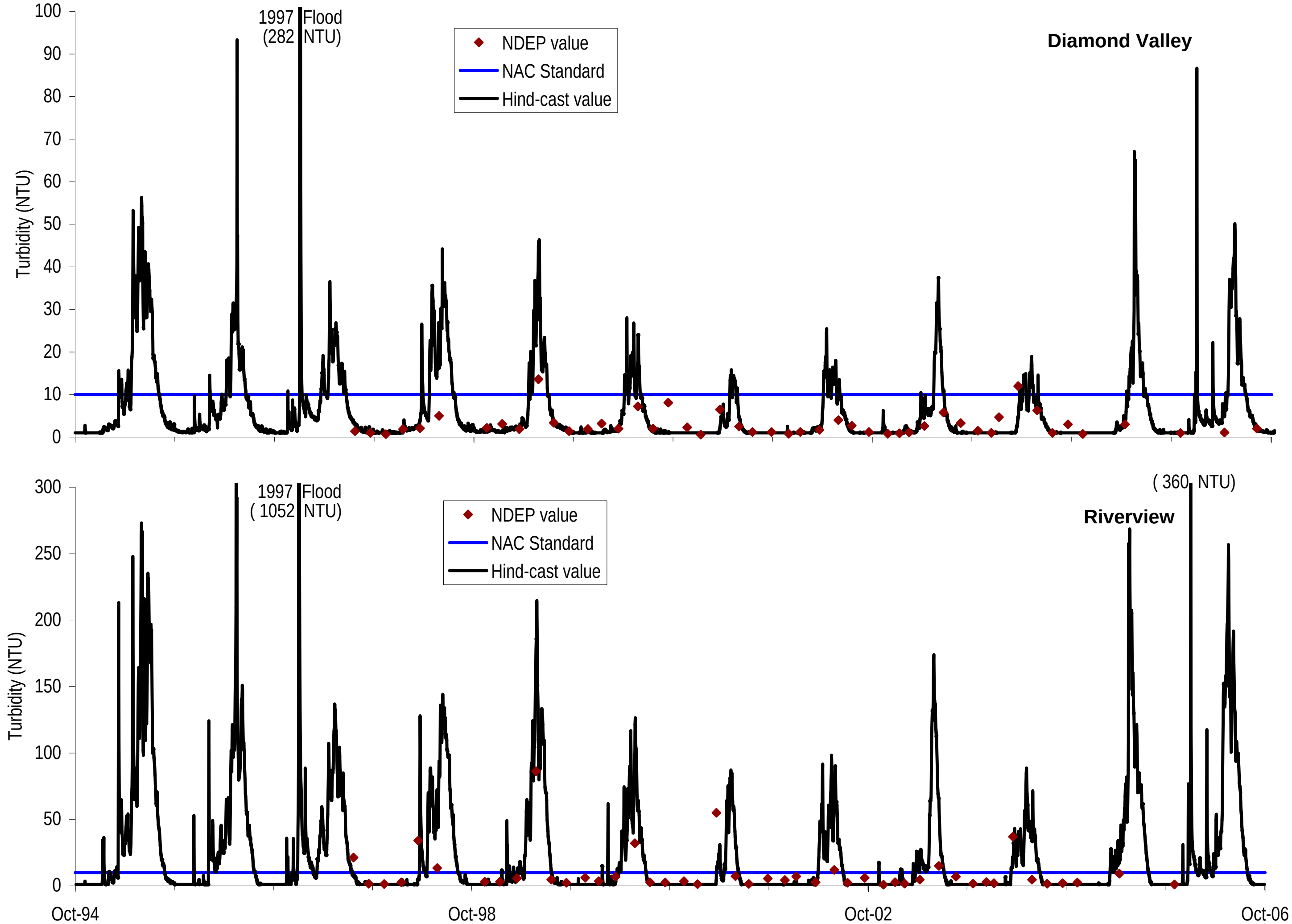

Figure 4-2. Daily turbidity estimated for the historic period (WY1995 through WY2006). At Genoa Lakes, data prior to 2002 were based on discharge from a downstream USGS gaging station (10311000).

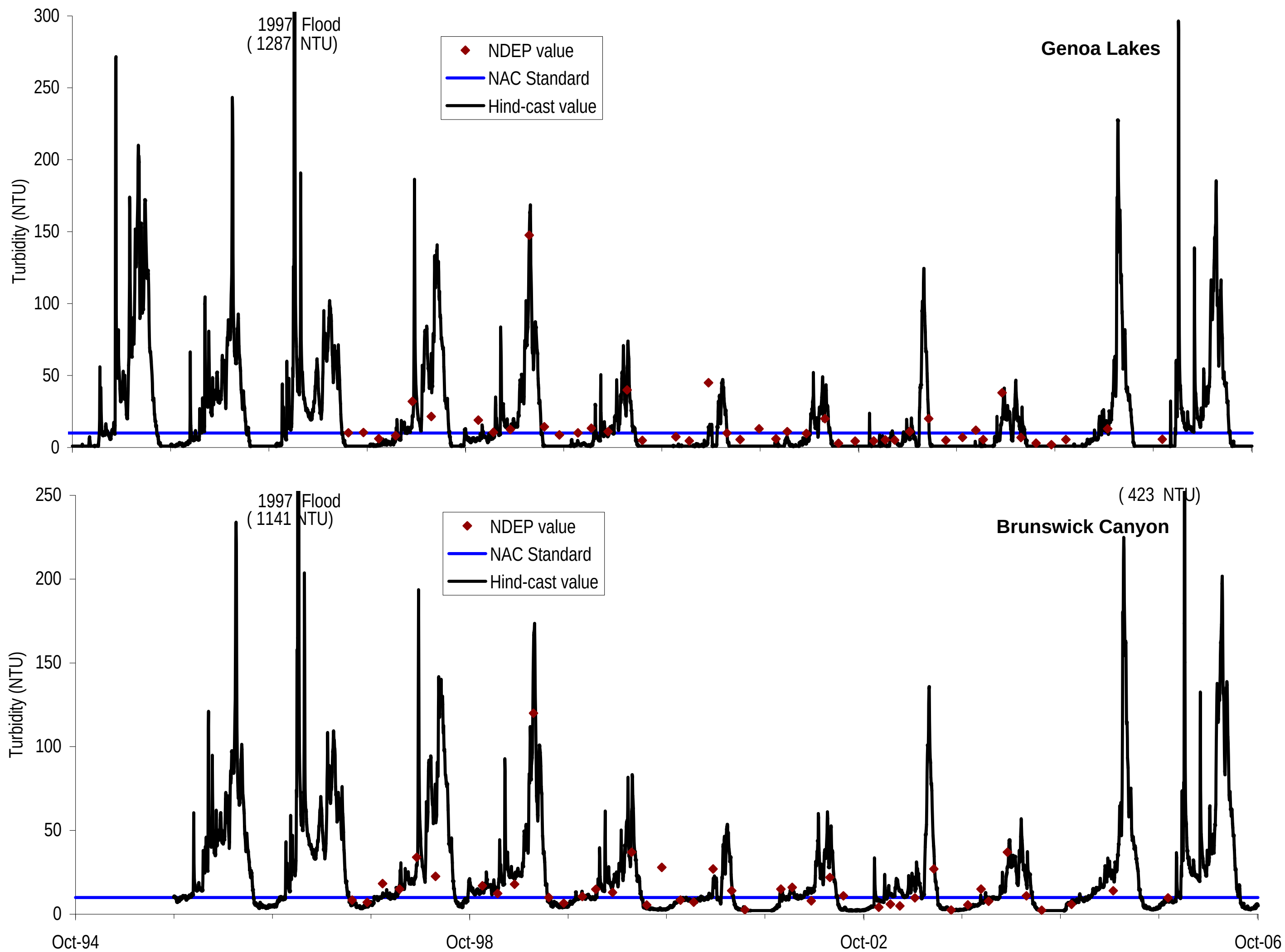

Figure 4-2. Daily turbidity estimated for the historic period (WY1995 through WY2006). At Genoa Lakes, data prior to 2002 were based on discharge from a downstream USGS gaging station (10311000) (continued).

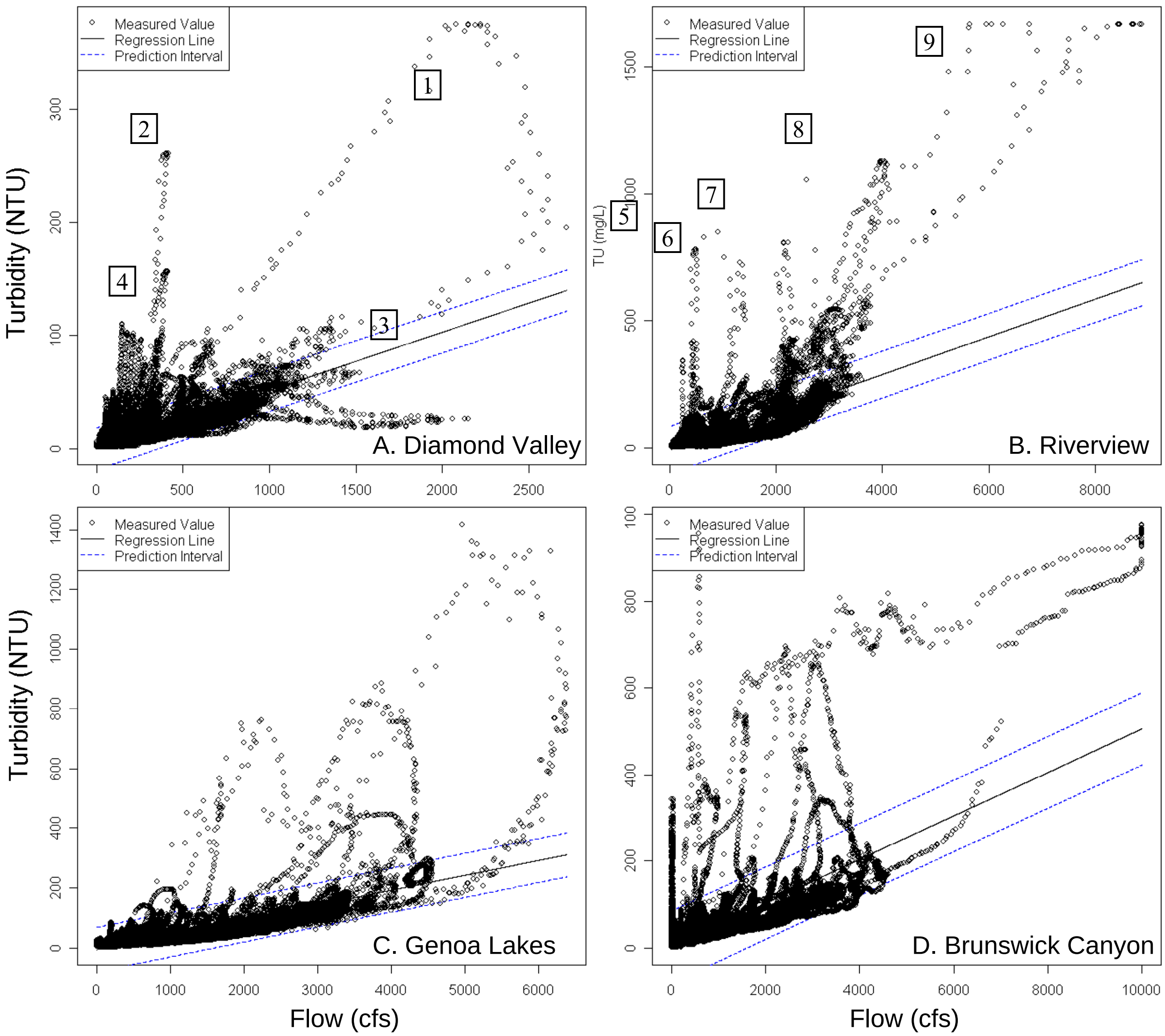

Figure 4-3. Relationship between flow and turbidity on a 15-minute basis. The box-enclosed numbers in panel A refer to the hysteresis discussion in the text.

The net result is that any simple estimate of turbidity from discharge, including that presented here, will underestimate turbidity levels during high flows and will not account for hysteresis effects. Caution must be taken when analyzing smaller datasets, such as those composed of bi-monthly grab samples, as the sampling density will not be sufficient to adequately account for high turbidity or hysteresis effects. Although the relationship between turbidity and discharge would be more easily described with fewer points, perhaps with much higher correlation coefficients, it is inaccurate, as a few data points cannot describe the complex processes that are actually taking place.

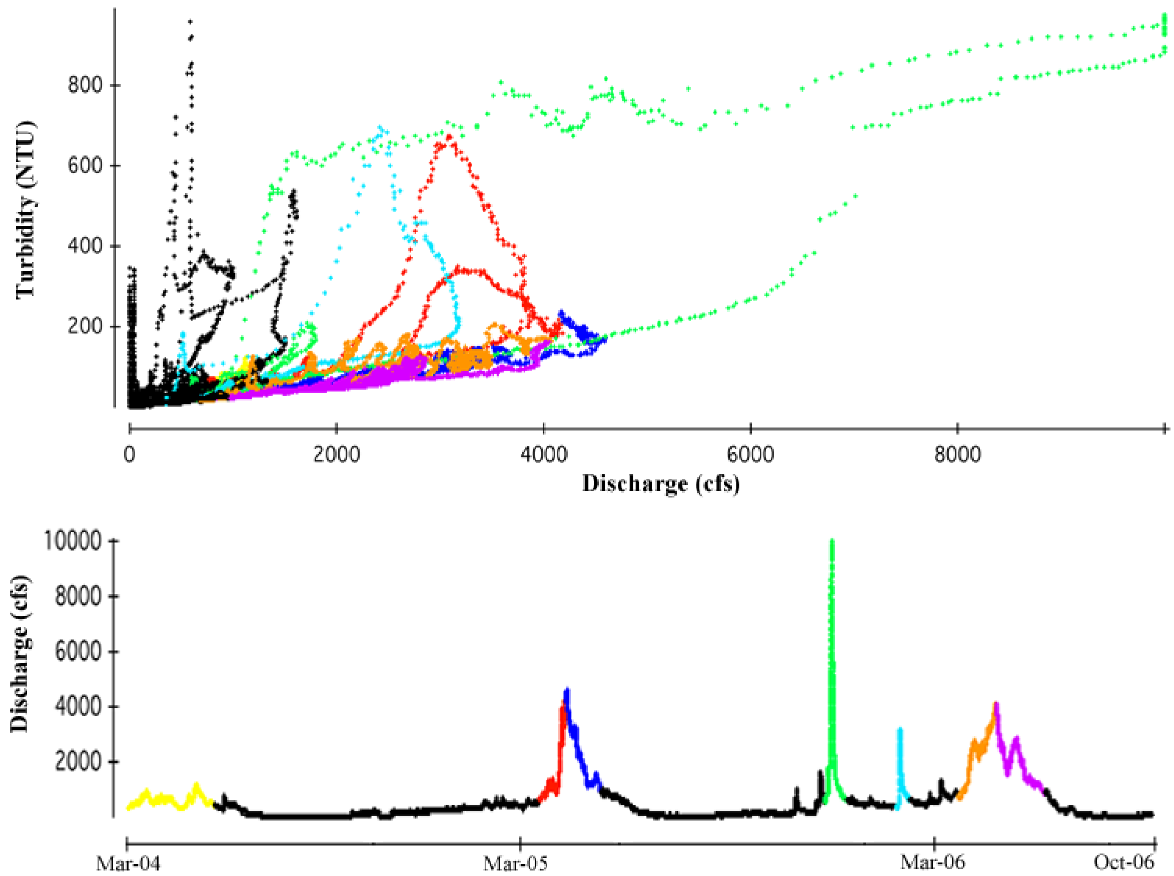

Figure 4-4. Hysteresis relationship and discharge at the Brunswick Canyon site. The colored areas are: yellow=2004 snowmelt season, red=rising limb of 2005 snowmelt season, blue=falling limb of 2005 snowmelt season, green=2006 New Year's Flood, light blue= rain event, orange= rising limb of 2006 snowmelt season, pink=falling limb of 2006 snowmelt season.

5.0 EXCEEDANCE OF NEVADA STATE STANDARDS

The frequency and duration with which the Nevada state TSS and turbidity standards were exceeded were investigated utilizing the observed data collected during WY2004 through WY2006 and the predicted historical data from WY1995 through WY2006. Three approaches were utilized, including percent standard exceedance, exceedance probability curves, and duration-exceedance curves. Percent standard exceedance provides the percent of time that the Nevada standard was exceeded within a given time period. Exceedance probability curves provide a graphical way to show the likelihood that a given TSS or turbidity level was exceeded. Finally, duration-exceedance curves show how long an exceedance event may last once the standard has been exceeded.

5.1 Percent Standard Exceedance

5.1.1. Period of Observation

From March 2004 through September 2006, TSS concentrations were observed to exceed the Nevada standards (Table 2-2) between 7 percent and 13 percent of the time (Table 5-1). Seasonally, the bulk of these exceedances began during the rising limb of the seasonal snowmelt hydrograph, where the TSS standards were exceeded between 18 percent and 27 percent of the time.

Table 5-1. Percent exceedances for TSS and turbidity during the period of observation. The TSS standard is 25 mg/L at Diamond Valley and 80 mg/L at the other three sites. TSS was estimated using turbidity-based relationships in Table 3-1. The Nevada turbidity standard is 10 NTU at all sites. Turbidity data were based on *in situ* turbidimeter readings. The period of observation was defined in Table 2-1. Rising refers to the rising limb of seasonal snowmelt in April and May, falling to the falling limb in June and July, with baseflow representing the rest of the water year.

Sample	Diamond Valley	Riverview	Genoa	Brunswick Canyon
		TSS – Period of Observation		
All Data	7	9	11	13
Rising	18	27	22	25
Falling	3	6	8	10
Baseflow	1	2	3	7
		Turbidity – Period of Observation		
All Data	14	43	60	68
Rising	37	77	86	71
Falling	12	59	70	60
Baseflow	2	23	33	52

Turbidity standards were exceeded more often than TSS standards, and the percent exceedance was much more variable between different sites and during different seasons. At the low end, Diamond Valley exceeded State standards 14 percent of the time during the period of observation, and 37 percent of the time during the rising limb of the snowmelt hydrograph. On the high end, Brunswick Canyon exceeded State standards 68 percent of the time, with a marginally higher exceedance percentage (71%) during the rising limb. The frequency of turbidity exceedances increased moving downstream from Riverview to Brunswick Canyon, primarily a response to a higher frequency of exceedances during baseflow conditions. Baseflow conditions had a controlling influence on the entire dataset, as the baseflow period represented seven months out of the water year. Baseflow exceedances at Genoa Lakes were less frequent than at Brunswick Canyon, but were offset by the highest percent exceedance observed in both the rising and falling limbs.

Differences between the frequency of TSS and turbidity exceedances were attributed to two factors. First, the Nevada state standards for TSS and turbidity appear to have been determined independently from each other despite the fact that these two parameters are inter-related (Section 3). The linear equations between TSS and turbidity presented in Table 3-1 can be used to convert the existing Nevada TSS standards to their equivalent turbidity:

1) 22 ± 22 NTU at Diamond Valley with a TSS threshold of 25 mg/L.
2) 63 ± 32 NTU at Riverview with a TSS threshold of 80 mg/L.
3) 52 ± 20 NTU at Genoa Lakes with a TSS threshold of 80 mg/L.
4) 51 ± 31 NTU at Brunswick Canyon with a TSS threshold of 80 mg/L.

Likewise, the existing Nevada turbidity standards can be converted to their TSS equivalent:

5) 16 ± 20 mg/L of TSS at Diamond Valley with a turbidity threshold of 10 NTU.
6) <5 ± 50 mg/L of TSS at Riverview with a turbidity threshold of 10 NTU.
7) 15 ± 31 mg/L of TSS at Genoa Lakes with a turbidity threshold of 10 NTU.
8) 26 ± 43 mg/L of TSS at Brunswick Canyon with a turbidity threshold of 10 NTU.

The equivalent turbidity levels based on current Nevada TSS thresholds (1 through 4) are a factor of two higher at Diamond Valley, and a factor of five to six higher at the other three sites compared to current Nevada turbidity thresholds. Conversely, the equivalent TSS concentrations based on current Nevada turbidity thresholds (5 through 8) are 1.5, 32, 5, and 3 times lower than current Nevada TSS thresholds at Diamond Valley, Riverview, Genoa Lakes, and Brunswick Canyon, respectively. The net result is that Nevada's current turbidity threshold is much more restrictive than the current TSS threshold at all four sites. This creates an ambiguity, as the same physical processes control turbidity levels and TSS concentrations in the river. This ambiguity can be resolved by linking turbidity and TSS thresholds with relationships like that presented in Table 3-1 when the thresholds are next revised.

A second factor contributing to the greater turbidity exceedances, especially during baseflow, was the sensitivity of turbidity readings to factors other than suspended solids. Turbidity is an optical measurement that is affected by a variety of factors, including the color of the water, the presence of organic materials, and the shape and size of particles contributing to suspended solids. Variations in any of these factors can cause apparent changes in turbidity readings despite a consistent suspended solids concentration. Although specific information is not available on how these factors affect the DTS-12 sensors used in this study, data from a similar sensor (OBS-3) shows that the sensitivity of the sensor can easily change four-fold as particles increase from 10 um to 100 um in diameter, with 200-fold changes observed over the broader particle size scale (D&A Analytical, Sediment

Size Effects. http://www.d-a-instruments.com/sand_mud.html. Accessed on July 23, 2007; Conner and Visser, 1992; Ludwig and Hanes, 1990). As a result, the apparent turbidity reported by the sensor will decrease with increasing particle size for a given concentration of suspended solids. The inherent degree of susceptibility of a turbidity sensor to each of the aforementioned factors is manufacturer and sensor specific, as there is a wide range of optical techniques that can be employed to measure turbidity. The greater number of exceedances of the turbidity standard, especially during baseflow conditions, may be partly due to these factors affecting turbidity readings. Water samples collected during the summer and fall were more highly colored and likely had greater levels of organic matter and finer suspended solids than the upstream sites, factors that would result in higher apparent turbidity. These factors are an important reason why turbidity/TSS relationships must be developed specifically for each site.

5.1.2. Predicted Historic Period

Historic period exceedances differed from the period of observation exceedances in two important ways. First, historic TSS was estimated from discharge-based (Table 3-2) rather than from turbidity-based (Table 3-1) data. Secondly, the historic data included 12 years of predicted data from WY1995 through WY2006, rather than the 30 months of observed data during the period of observation. The latter dataset is not subject to predictive error because it was observed directly, whereas the former dataset was subject to predictive error, but encompassed a much wider variety of hydrologic and climatic conditions.

Overall, the frequency at which the TSS and turbidity standards were exceeded was similar for both the historic (Table 5-2) and observed (Table 5-1) datasets, with a few exceptions. First, the TSS standard was violated three to four times more often in the historic data, indicating that historic snowmelt events occurred later in the year, and thus did not fit into the June 1 delineation between the rising and falling limbs based on observed data. Second, baseflow exceedances during the historic period occurred less often than during the observed period. Third, the percent of turbidity exceedances was much more variable for the historic dataset than for the observed dataset.

Table 5-2. Percent exceedances for TSS and turbidity standards during the historic period. The TSS standard at Diamond Valley is 25 mg/L and 80 mg/L at the other three sites. The Nevada turbidity standard is 10 NTU at all sites. Results are based on estimates from discharge-based relationships.

Sample	Diamond Valley	Riverview	Genoa	Brunswick Canyon
		TSS – Historic		
All Data	7	10	11	12
Rising	17	17	20	22
Falling	13	28	26	28
Baseflow	<1	1	2	2
		TU – Historic		
All Data	18	37	34	49
Rising	45	76	70	77
Falling	34	71	66	67
Baseflow	1	83	6	20

5.2 Exceedance Probability Curves

Exceedance probability curves (Figure 5-1) provide a graphical way to show the likelihood that a given TSS or turbidity level will be exceeded. For example, a 50-percent exceedance probability indicated the specific turbidity level or TSS concentration that was exceeded 50 percent of the time.

Using the estimated historic data, TSS and turbidity levels at the 50-percent exceedance probability level were similar at Diamond Valley, Riverview, and Genoa Lakes. Total suspended solids exceeded 10 to 13 mg/L and turbidity exceeded 1 to 3 NTU 50 percent of the time at these sites. Downstream at Brunswick Canyon, TSS and turbidity levels that were exceeded 50 percent of the time were three times higher, 32 mg/L TSS and 10 NTU. As previously discussed, there are a number of factors that caused greater concentration of suspended solids to be observed at Brunswick Canyon.

Turbidity and TSS concentrations at the 20-percent exceedance probability level were more representative of levels during storm events and seasonal snowmelt. At this level, there was much less agreement between sites. Total suspended solids increased downstream, going from 16 mg/L and 23 mg/L at Diamond Valley and Riverview, to 48 mg/L at Genoa Lakes and 60 mg/L at Brunswick Canyon. Turbidity values were less consistent with both Riverview and Brunswick Canyon sites at 36 to 40 NTU. Genoa Lakes and Diamond Valley were lower, at 27 and 9 NTU, respectively.

The exceedance probabilities derived from the period of observation (dashed lines) and the estimated historic (solid lines) datasets were similar across the range of turbidity and TSS only at Diamond Valley. This indicated, in particular, that there was good agreement in the distribution of estimated TSS generated from the three-year, turbidity-based dataset and the historic 11-year, discharge-based dataset. At Riverview, agreement between the datasets occurred only when the exceedance probability was less than 30 percent. For TSS, the model derived for the period of observation (TSS vs. turbidity) was capable of estimating values below the reporting limit (10 mg/L), whereas the historic model was not (TSS vs. flow). Interpretation of these estimated TSS values lower than 10 mg/L reporting limit should be done with caution, and were included in Figure 5.1 to aid comprehension of the trends. For turbidity, the distribution of estimated historic data resulted in lower exceedance probabilities when turbidity was lower than 18 NTU compared to that observed during the three years of direct observation. This underprediction also occurred at Genoa Lakes for TSS concentrations less then 27 mg/L and turbidity less than 20 NTU. This could result from either the historic regression model underpredicting low turbidities, or a shift in the turbidity distribution to include a greater population of lower values. As this trend was not observed for TSS at Riverview, a physical shift in the distribution of turbidity values at Riverview was not likely. For Genoa Lakes, however, both TSS and turbidity were impacted, so a physical change resulting in a greater percentage of higher turbidity values during the period of observation could not be discounted.

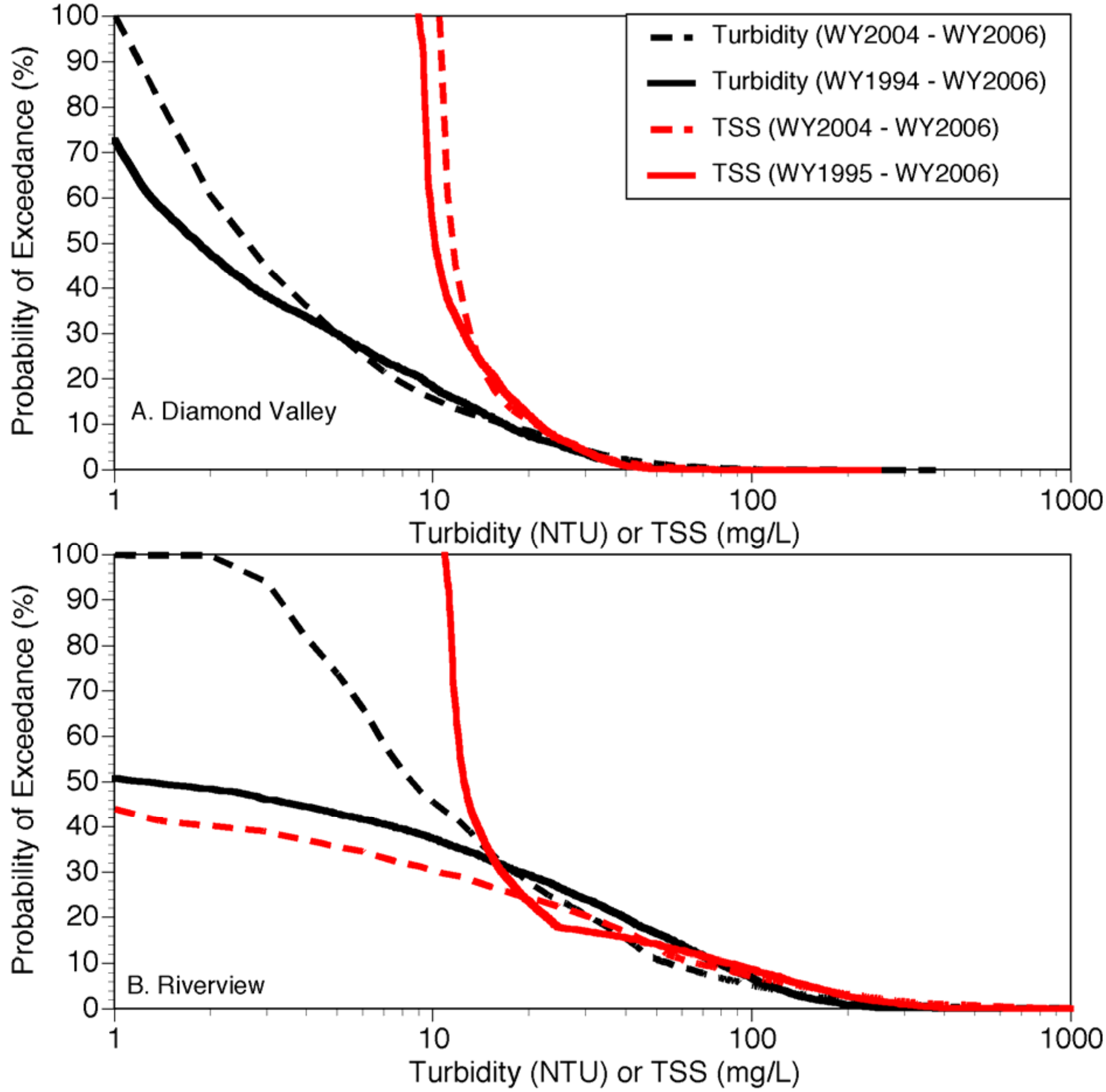

Figure 5-1. Exceedance probability curves for turbidity and TSS for the period of observation (WY2004-WY2006) and the historical period (WY1995-2006).

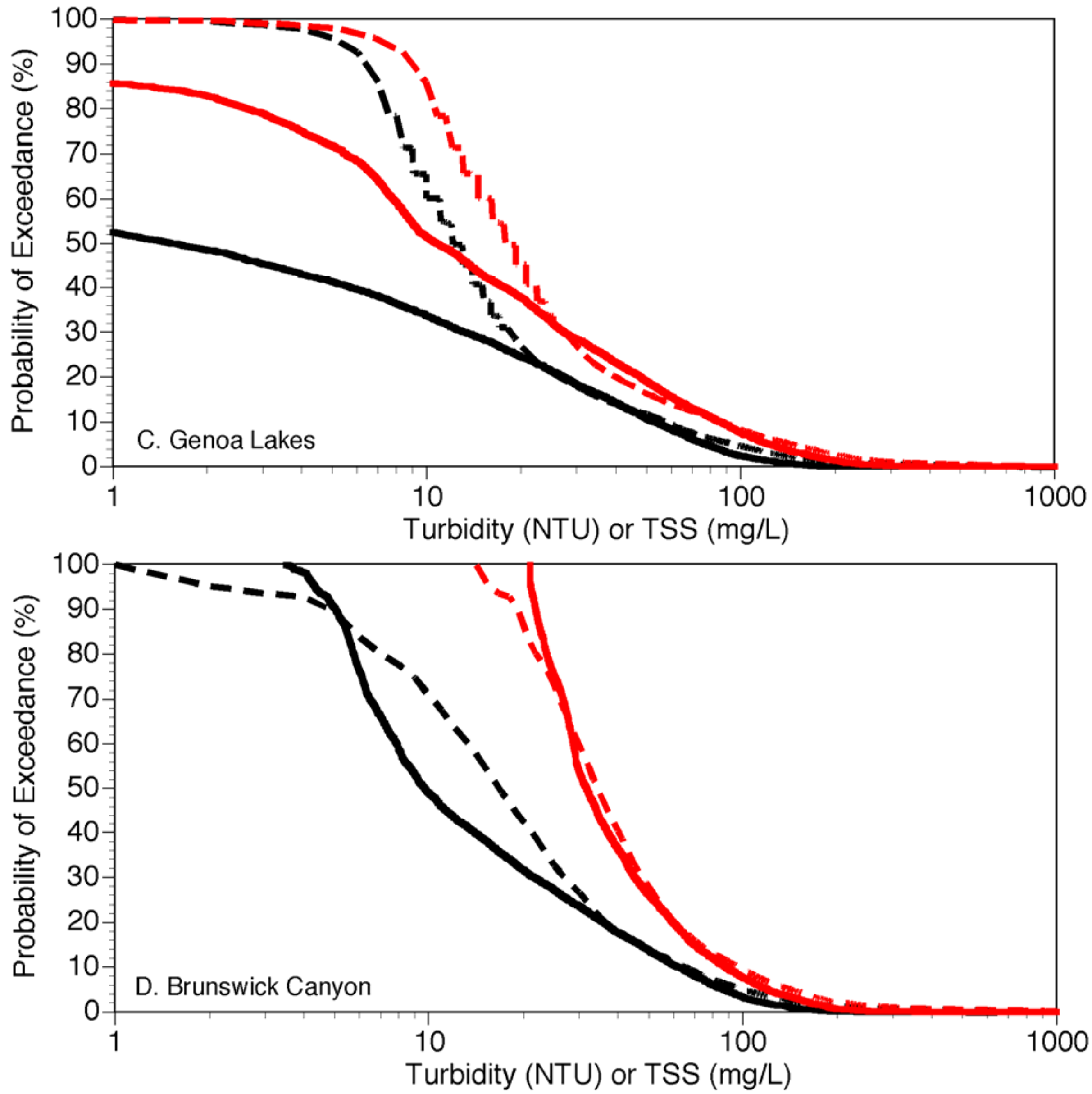

Figure 5-1. Exceedance probability curves for turbidity and TSS for the period of observation (WY2004-WY2006) and the historical period (WY1995-2006) (continued).

5.3. Duration-Exceedance Curves

5.3.1. Period of Observation

Duration-exceedance plots visually represent how long an event may last, once it has exceeded the Nevada standard for TSS or turbidity. For example, the black line in Figure 5-2A shows that when an event exceeds the Nevada TSS Standard at Diamond Valley, there is a 40-percent chance that the event will last 10 days. The data were also broken down into seasonal trends (red, blue, and green lines), with events that spanned multiple seasons attributed to the season in which they began.

The maximum duration for which the current TSS standard was violated increased going downstream. Maximum durations ranged from between 12 and 16 days upstream at Diamond Valley and Riverview, to nearly 20 days at Genoa Lakes and 30 days downstream at Brunswick Canyon. The probability that these maximum-duration events occurred was approximately 40 percent at all sites. The shape of the duration-exceedance curves (black lines) mimicked those of the rising limb (blue line), indicating the events during the rising limb were more important than from any other season. Short-duration events during the falling limb did occur at Riverview and Genoa Lakes, but were limited to events of up to four days with a 54-percent probability. Downstream, there was a 45-percent probability that a TSS exceedance event would last nine days at Brunswick Canyon. The probability of baseflow events was generally low, less than 25-percent probability to occur with a three-day duration.

The maximum-duration event that exceeded the turbidity threshold (Figure 5-3) was much greater than for TSS. There was between a 40 percent and 50 percent probability that an event would exceed turbidity up to 30 days at Diamond Valley, to 80 days at Riverview and Genoa Lakes, and to over 120 days at Brunswick Canyon. As with TSS duration-exceedance curves, events starting during the rising limb primarily controlled the shape and duration of the overall curve. This was not true at Riverview, where events starting during both the rising limb and baseflow codominated. The greatest duration of an event exceeding the turbidity threshold during baseflow conditions was at Brunswick Canyon, having a 40-percent probability of lasting up to 43 days.

5.3.2. Predicted Historic Period

Duration-exceedance curves for TSS, based on the estimated historic data, were characterized by maximum duration events significantly longer than the data from the period of observation (Figure 5-4). Historic maximum durations ranged up to approximately 80 days at Diamond Valley, Genoa Lakes, and Brunswick Canyon, and up to 65 days at Riverview. At the 50-percent probability level, historic TSS durations were 32, 55, 47, and 57 days compared to 5, 3, 13, and 22 days for period-of-observation durations, at Diamond Valley, Riverview, Genoa Lakes, and Brunswick Canyon, respectively. The shift to longer durations while maintaining similar percent exceedances between the datasets implies that there were fewer historic exceedance events, but those that occurred were of a longer duration than those during the period of observation.

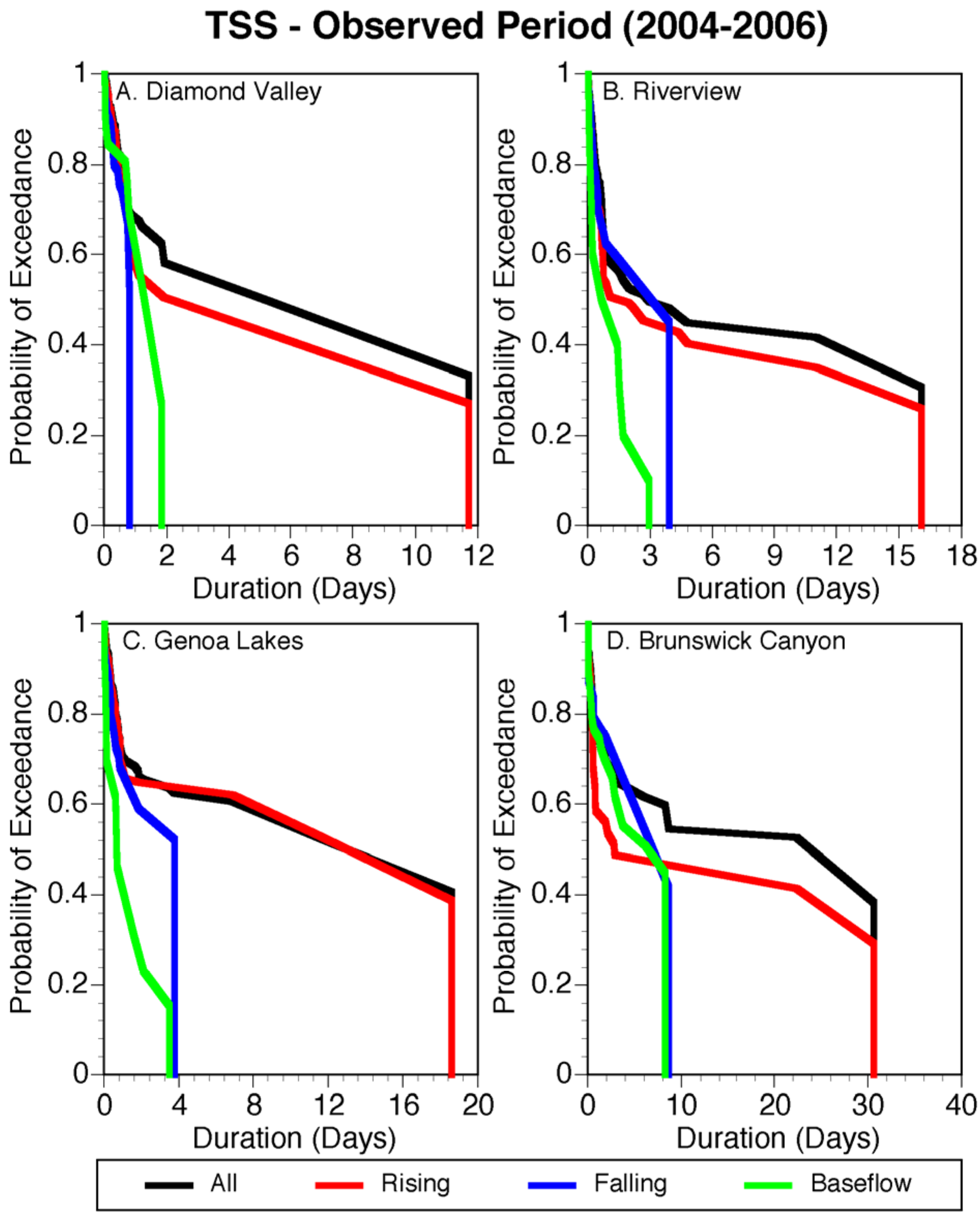

Figure 5-2. Duration-exceedance curves for TSS during the entire period of observation. The period of observation was 939 days at Diamond Valley, 877 days at Riverview, 919 days at Genoa Lakes, and 936 days at Brunswick Canyon.

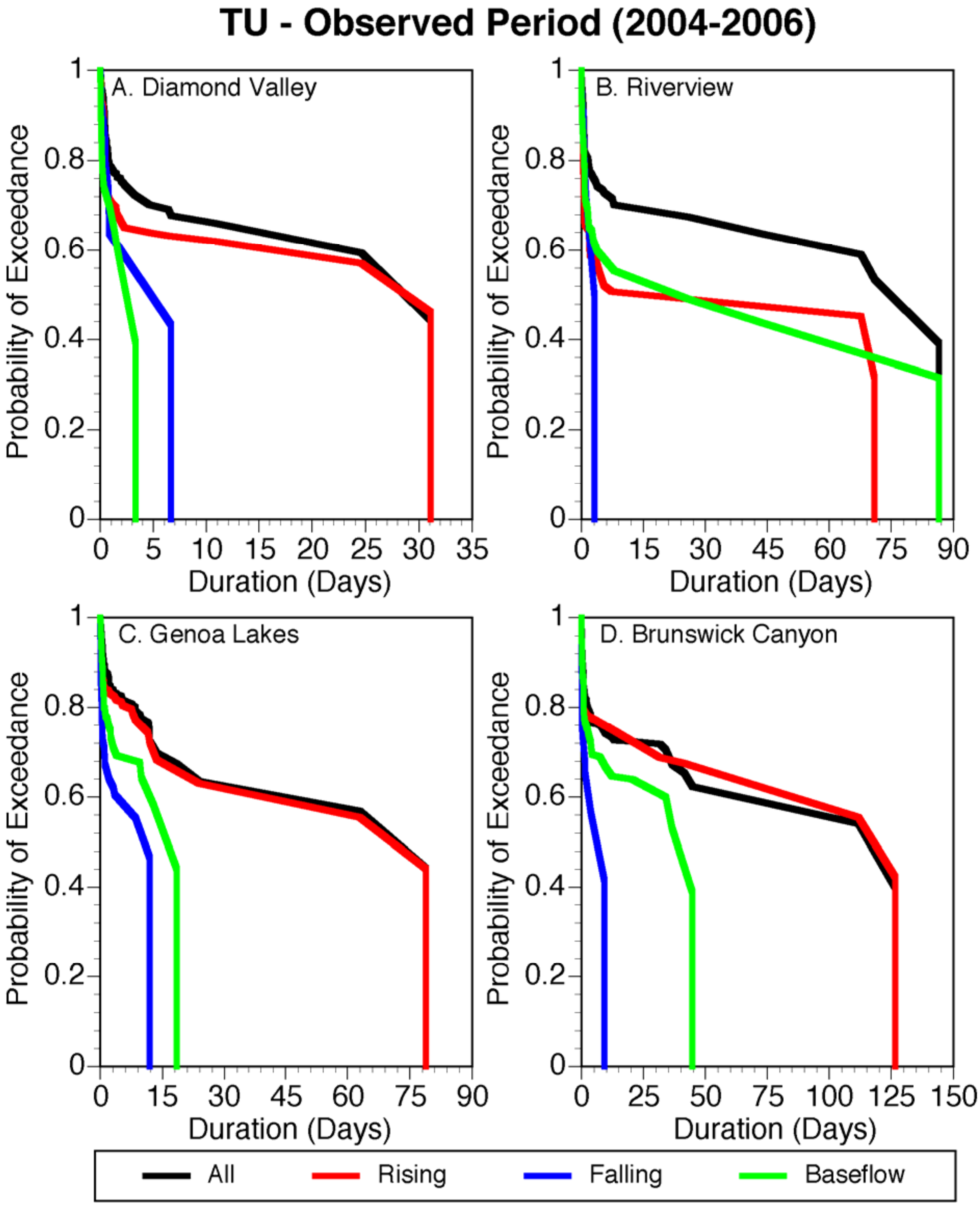

Figure 5-3. Duration-exceedance curves for turbidity during the entire period of observation. The period of observation was 939 days at Diamond Valley, 877 days at Riverview, 919 days at Genoa Lakes, and 936 days at Brunswick Canyon.

There were several significant differences in the duration-exceedance curves. First, the overall shape of the historic curve at Riverview was convex rather than concave as at the other sites. As a result, the probability of an exceedance event lasting 50 days at Riverview was 20 percent more probable than at Diamond Valley or Genoa Lakes. Second, the duration of exceedance events during the falling limb with a 50-percent probability increased from 1, 3, 4, and 7 days in the observed data to 22, 5, 18, and 18 days in the historic data at Diamond Valley, Riverview, Genoa Lakes, and Brunswick Canyon, respectively. Finally, of the three different seasons, baseflow trends were the most similar between the two datasets. The maximum duration of baseflow exceedance events increased from 2 to 8 days in the observed data to 4 to 18 days in the historic dataset. The small relative impact difference in baseflow exceedances coincides with the assumption that the Upper Carson River hydrograph is strongly controlled by seasonal snowmelt.

Historic turbidity duration-exceedance curves were also characterized by events of greater duration (Figure 5-5). The maximum duration of an exceedance event ranged from just over 100 days at Diamond Valley and 170 days at Riverview, to nearly 170 days at Genoa Lakes and over 240 days at Brunswick Canyon. At the 50-percent probability level, the exceedance event durations increased from 27, 75, 75 and 120 days in the period of observation to 55, 150, 120, and 240 days at Diamond Valley, Riverview, Genoa Lakes, and Brunswick Canyon, respectively. As with the TSS, Brunswick Canyon was a convex curve, causing at least a 20-percent greater probability than at the other sites

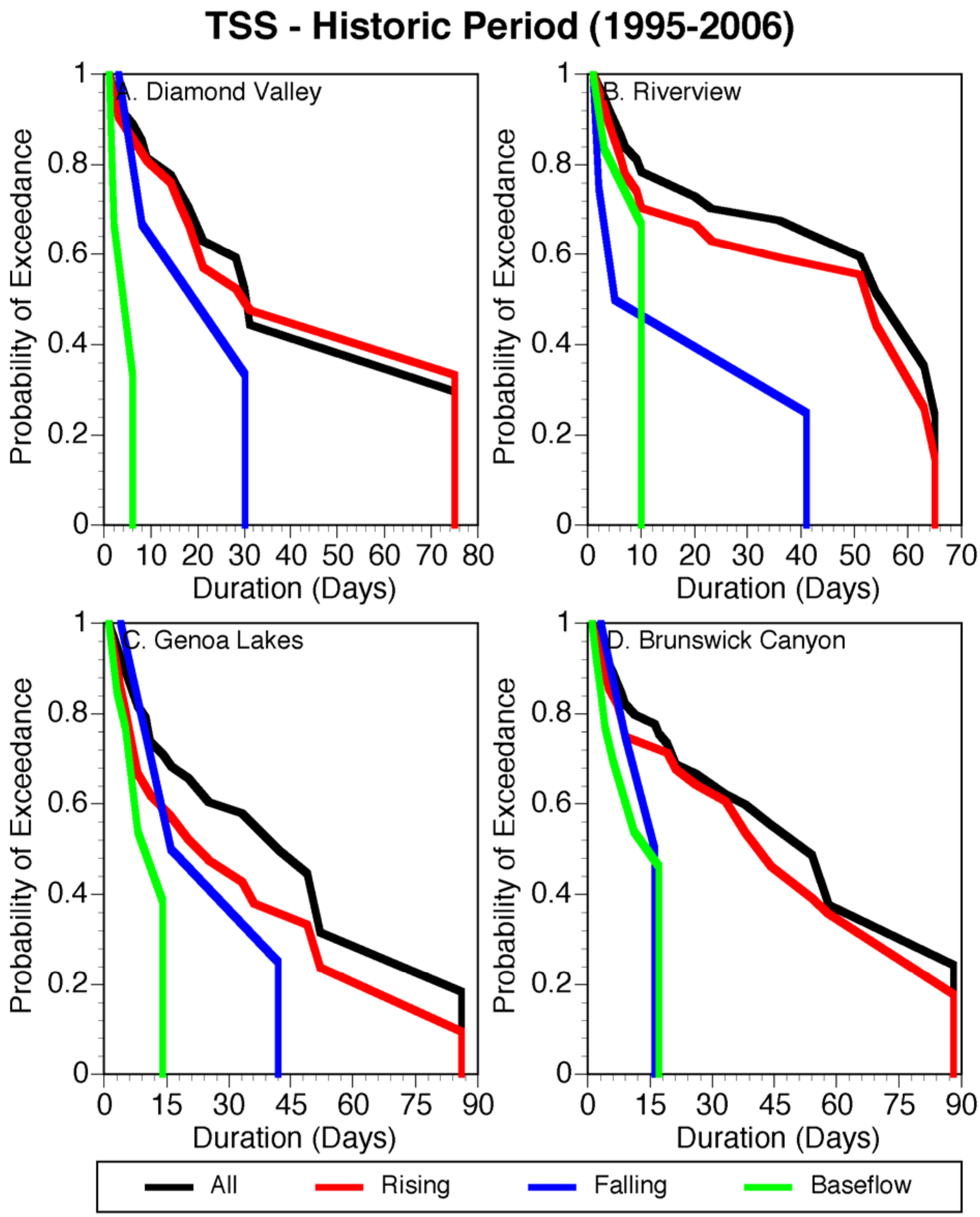

Figure 5-4. Duration-exceedance curves for TSS during the WY1995 through WY2006 historic period.

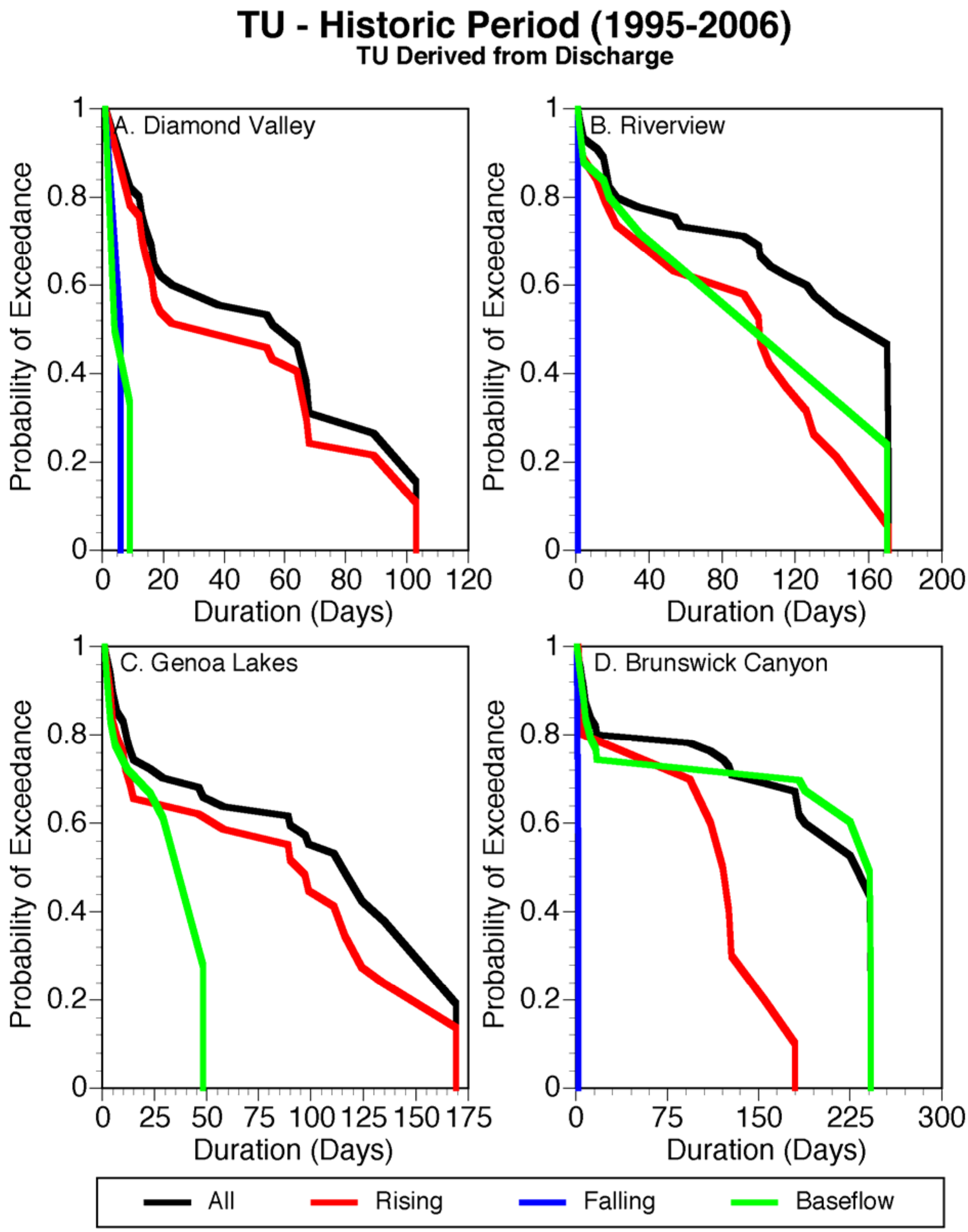

Figure 5-5. Duration-exceedance curves for TU during the WY1995 through WY2006 historic period. The plot for Riverview could not be plotted, as 100 percent of the data exceeded the 10 NTU Nevada standard.

6.0 SUMMARY

The objectives of this research were to improve the knowledge of the duration and frequency of suspended solids levels in the Upper Carson River in Nevada. This was accomplished through the establishment of a continuous turbidity record at four sites on the Carson River between March and May 2004 through October 2006. This time period included annual average discharges that were below, equivalent to, and exceeded the 26-year average between 1980 and 2006.

Continuous turbidity was used as a surrogate for TSS concentrations by developing site-specific relationships between discrete TSS samples and turbidity. Average TSS concentrations were estimated on a daily basis, while TSS loadings were estimated on a yearly basis. Continuous turbidity data were not available prior to this study, thus relationships were also developed between discharge and turbidity, and discharge and TSS to predict historical levels of TSS and turbidity from WY1995 through WY2006. Turbidity-based surrogate relationships produced better estimates of TSS concentrations and turbidity than discharge-based relationships, however, both methods produced similar yearly TSS loadings during the period of observation. For the historical predictions, the highest TSS loads were observed in 1997 at 1,137 ± 987 $x10^5$ kg at Riverview and 1,617 ± 499 $x10^5$ kg at Brunswick Canyon. The smallest loads were observed in 2001at 61 ± 207 $x10^5$ kg at Riverview and 60 ± 75 $x10^5$ kg at Brunswick Canyon.

Total suspended solids were found to exceed the Nevada State standard between 7 and 13 percent of the time at all sites during the period of observation. Turbidity was more variable across the basin, exceeding the Nevada standard 14 percent of the time at Diamond Valley, 43 percent at Riverview, 60 percent at Genoa Lakes, and 68 percent at Brunswick Canyon. Exceedance events were most likely to occur during the rising limb of seasonal snowmelt, from March through May. The same trends were observed in the predicted historical dataset.

The large discrepancy between the percent exceedance values of TSS and turbidity indicated that the current Nevada thresholds for TSS and turbidity were developed independently, despite the same physical process controlling both parameters. Current Nevada turbidity thresholds were found to be more restrictive than TSS thresholds at all four sites. The relationships developed during this project can be used to mitigate this discrepancy by explicitly linking turbidity levels to TSS concentrations.

During low-flow conditions, turbidity and TSS concentrations were similar between the four sites. However, during higher flows, turbidity levels and TSS concentrations increased downstream. At the 20-percent exceedance probability level, TSS levels were 16 mg/L and 23 mg/L at Diamond Valley and Riverview, 48 mg/L at Genoa Lakes, and 60 mg/L at Brunswick Canyon. When the standard was exceeded during the period of observation, the maximum duration of the event ranged from 12 and 16 days upstream at Diamond Valley and Riverview, to nearly 20 days at Genoa Lakes, and up to 30 days downstream at Brunswick Canyon. For most sites, the events initiated during the rising limb of seasonal snowmelt exerted a controlling influence on the shape and extent of the duration-exceedance curves. Maximum-duration events derived from the estimated historical data were significantly longer, ranging from 65 days at Riverview to about 80 days at Diamond Valley, Genoa Lakes, and Brunswick Canyon. Results indicate that there were a fewer number of historic exceedance events per year during the historic period, but those that occurred had a greater probability of having a longer duration than those during the period of observation.

7.0 ACKNOWLEDGEMENTS

This work was funded under Contract Award # DEP 04-039 by the Nevada Division of Environmental Protection. The authors would like to thank Paul Pugsley (USDA), Todd Mihevc (DRI), and Jim Brock (DRI) for invaluable assistance with site selection and equipment installation. We would also like to thank the Washoe Tribe for providing us access to the Riverview Site on the east fork of the Carson River and to the Genoa Lakes Golf Course for access to the Genoa Lakes sampling site. Last, we thank Paula Adkins, Jeramie Memmott, and Ryan Sharrer for their assistance with fieldwork, and Randy Pahl and Jean Stone at NDEP for their insightful comments throughout the course of this project.

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APPENDIX A: Seasonal TSS Regressions

Regression equations of TSS and discharge by season. Rising limb refers to April and May, falling limb refers to June and July, and baseflow refers to October through March and August through September. DV = Diamond Valley, RV = Riverview, GL = Genoa Lakes, BC = Brunswick Canyon.

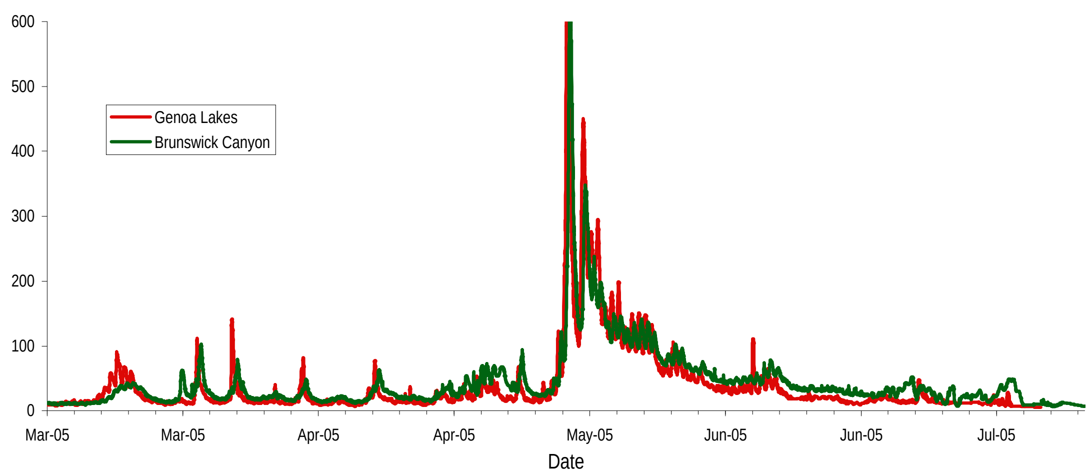
Site	Season	Relationship	R^2
DV	Rising Limb	TSS = 0.0420·Q + 7.4509	0.5112
DV	Falling Limb	TSS = 0.0213·Q + 8.1645	0.2828
DV	Baseflow	TSS = 0.0897·Q + 14.4588	1.0*
RV	Rising Limb Exponential	Log(TSS) = 0.0013·Q + 2.2569	0.8117
RV	Falling Limb	TSS = 0.0566·Q - 34.2760	0.7409
RV	Baseflow	TSS = 0.0221·Q + 73.4229	-0.4963
GL	Rising Limb Exponential	Log(TSS) = 0.0008·Q + 2.8536	0.6716
GL	Falling Limb	TSS = 0.0545·Q - 7.9749	0.907
GL	Baseflow	TSS = 0.0804·Q + 5.3037	0.5225
BC	Rising Limb	TSS = 0.0517·Q + 23.5612	0.7578
BC	Falling Limb	TSS = 0.0655·Q - 2.9567	0.8906
BC	Baseflow	TSS = 0.0330·Q + 29.9459	0.2583

*Only two points included in analysis.

APPENDIX B: Brunswick Canyon Manual Turbidity Measurements

During reconstruction of the Deer Run Bridge in 2005, grab samples were collected approximately 1,000 feet upstream and 500 feet downstream to assess if the construction activities impacted turbidity. No significant differences were observed.

Sample	Turbidity (NTU)	
Collected	Upstream	Downstream
3/9/05 11:35	8	6.7
3/10/05 15:50	15	16
3/15/05 14:56	16.8	17.3
3/29/05 13:15	28.4	28.3
4/5/05 11:05	13.2	11.8
4/8/05 12:09	23.7	23.1
4/15/05 11:56	8.3	7.5
4/19/05 15:00	20.9	23.6
4/22/05 12:16	12.4	13
5/3/05 14:40	18.6	18.4
5/11/05 12:17	17.6	18.3
5/13/05 11:55	16.1	24
5/17/05 12:35	383	380
5/27/05 16:35	131	133
5/31/05 12:35	70.3	71.4
6/8/05 11:05	32.4	29.2
6/24/05 11:00	17.6	18.9
6/30/05 16:30	14.6	14.2
7/13/05 15:30	10.2	10.7



Careful study of the 15-minute turbidity data during this time period did not reveal any unexplained turbidity spikes.

APPENDIX C: TSS Measurements

TSS measured by Nevada State Health Laboratory with a reporting limit of 10 mg/L. Turbidity was measured by the turbidimeter located in the monitoring boom at time water sample for TSS was collected.

Sample Collected	Site	TSS (mg/L)	Turbidity (NTU)
3/25/04 19:00	Brunswick Canyon	74	43.0
4/15/04 16:30	Brunswick Canyon	28	16.9
4/27/04 14:45	Brunswick Canyon	39	19.8
5/5/04 13:45	Brunswick Canyon	140	74.0
5/13/04 15:00	Brunswick Canyon	36	21.5
5/21/04 10:30	Brunswick Canyon	24	16.9
5/27/04 15:00	Brunswick Canyon	14	9.5
6/3/04 14:00	Brunswick Canyon	23	16.8
6/11/04 14:45	Brunswick Canyon	17	9.5
6/24/04 13:15	Brunswick Canyon	<10	1.9
7/8/04 17:00	Brunswick Canyon	<10	0.8
7/22/04 14:00	Brunswick Canyon	<10	1.1
8/10/04 12:45	Brunswick Canyon	<10	0.0
10/21/04 15:45	Brunswick Canyon	52	75.0
10/29/04 12:00	Brunswick Canyon	<10	5.1
11/4/04 14:30	Brunswick Canyon	13	8.8
1/27/05 13:15	Brunswick Canyon	25	19.8
1/31/05 15:30	Brunswick Canyon	11	9.2
2/15/05 14:45	Brunswick Canyon	14	10.0
2/23/05 11:00	Brunswick Canyon	52	38.4
3/3/05 15:15	Brunswick Canyon	16	9.9
3/10/05 15:30	Brunswick Canyon	37	21.8
3/14/05 15:00	Brunswick Canyon	58	0.0
3/23/05 14:00	Brunswick Canyon	154	62.2
3/29/05 14:00	Brunswick Canyon	54	35.9
4/7/05 10:30	Brunswick Canyon	30	25.6
4/13/05 15:30	Brunswick Canyon	26	20.9
4/19/05 14:15	Brunswick Canyon	54	32.9
4/21/05 9:30	Brunswick Canyon	40	24.5
4/25/05 13:30	Brunswick Canyon	27	16.5
4/29/05 10:15	Brunswick Canyon	60	35.0
5/6/05 10:45	Brunswick Canyon	116	87.8
5/10/05 11:45	Brunswick Canyon	94	51.6
5/16/05 10:15	Brunswick Canyon	190	88.1
5/18/05 8:45	Brunswick Canyon	180	134.0
5/24/05 14:15	Brunswick Canyon	172	144.0
6/1/05 15:15	Brunswick Canyon	192	101.7
6/8/05 10:15	Brunswick Canyon	76	44.9
6/24/05 10:15	Brunswick Canyon	55	30.4

Sample Collected	Site	TSS (mg/L)	Turbidity (NTU)
6/29/05 15:45	Brunswick Canyon	49	24.1
7/13/05 14:30	Brunswick Canyon	30	24.5
10/6/05 14:00	Brunswick Canyon	71	35.3
10/6/05 14:15	Brunswick Canyon	14	15.7
10/27/05 15:30	Brunswick Canyon	50	25.4
12/2/05 15:30	Brunswick Canyon	606	345.1
12/28/05 16:15	Brunswick Canyon	71	41.5
1/4/06 17:30	Brunswick Canyon	78	71.7
2/27/06 15:45	Brunswick Canyon	42	19.3
3/28/06 10:45	Brunswick Canyon	28	25.0
5/5/06 10:30	Brunswick Canyon	113	70.8
5/12/06 17:30	Brunswick Canyon	168	116.7
5/19/06 16:00	Brunswick Canyon	218	185.0
5/24/06 17:00	Brunswick Canyon	123	76.7
6/1/06 13:45	Brunswick Canyon	122	63.8
6/6/06 15:45	Brunswick Canyon	152	107.6
6/16/06 12:45	Brunswick Canyon	71	35.1
6/22/06 15:15	Brunswick Canyon	62	35.1
3/25/04 12:45	Diamond Valley	17	9.7
4/1/04 12:30	Diamond Valley	13	8.5
4/15/04 11:00	Diamond Valley	<10	0.0
4/27/04 10:00	Diamond Valley	18	11.8
5/5/04 10:00	Diamond Valley	43	25.0
5/13/04 11:30	Diamond Valley	10	5.7
5/20/04 13:00	Diamond Valley	<10	0.0
5/27/04 10:45	Diamond Valley	16	8.1
6/3/04 10:30	Diamond Valley	<10	0.0
6/11/04 11:00	Diamond Valley	13	3.1
6/24/04 10:00	Diamond Valley	<10	3.0
7/8/04 12:45	Diamond Valley	<10	2.5
7/22/04 11:00	Diamond Valley	<10	2.6
8/10/04 10:00	Diamond Valley	<10	0.0
3/14/05 11:45	Diamond Valley	101	4.0
4/7/05 13:30	Diamond Valley	25	9.4
4/13/05 11:30	Diamond Valley	<10	3.5
4/19/05 11:15	Diamond Valley	14	9.9
4/21/05 12:30	Diamond Valley	<10	4.2
4/25/05 10:45	Diamond Valley	<10	0.0
4/29/05 13:00	Diamond Valley	10	16.1
5/3/05 7:00	Diamond Valley	34	23.3
5/6/05 7:00	Diamond Valley	22	19.5
5/10/05 6:30	Diamond Valley	12	11.0
5/16/05 7:15	Diamond Valley	418	154.2
5/18/05 12:45	Diamond Valley	100	43.6
5/19/05 15:00	Diamond Valley	70	40.9
5/24/05 11:00	Diamond Valley	32	26.3
5/26/05 12:45	Diamond Valley	34	24.6

Sample Collected	Site	TSS (mg/L)	Turbidity (NTU)
6/1/05 12:00	Diamond Valley	21	0.0
6/8/05 14:00	Diamond Valley	11	10.9
6/14/05 12:30	Diamond Valley	10	0.0
6/24/05 14:00	Diamond Valley	<10	4.6
12/2/05 12:30	Diamond Valley	21	9.0
12/28/05 13:00	Diamond Valley	46	33.4
5/5/06 14:15	Diamond Valley	20	0.0
5/10/06 14:15	Diamond Valley	24	37.5
5/19/06 13:00	Diamond Valley	26	41.0
5/24/06 13:45	Diamond Valley	15	30.0
6/1/06 10:45	Diamond Valley	20	10.0
6/6/06 13:00	Diamond Valley	17	40.9
3/25/04 15:15	Genoa Lakes	33	22.3
4/1/04 15:15	Genoa Lakes	23	15.6
4/15/04 14:00	Genoa Lakes	15	10.9
4/27/04 12:00	Genoa Lakes	48	27.5
5/5/04 11:45	Genoa Lakes	156	112.2
5/13/04 13:30	Genoa Lakes	22	13.3
5/21/04 8:45	Genoa Lakes	19	11.3
5/27/04 9:00	Genoa Lakes	15	8.4
6/3/04 12:15	Genoa Lakes	28	19.8
6/11/04 13:00	Genoa Lakes	12	5.5
6/24/04 11:45	Genoa Lakes	<10	3.1
7/8/04 15:00	Genoa Lakes	<10	4.4
7/22/04 12:30	Genoa Lakes	<10	0.0
8/10/04 11:45	Genoa Lakes	<10	0.0
10/21/04 14:15	Genoa Lakes	<10	0.0
11/19/04 13:00	Genoa Lakes	16	7.4
1/27/05 15:00	Genoa Lakes	30	21.9
1/31/05 13:30	Genoa Lakes	24	14.2
2/3/05 11:45	Genoa Lakes	17	12.1
2/9/05 13:00	Genoa Lakes	15	10.0
2/15/05 13:30	Genoa Lakes	15	7.8
3/3/05 13:00	Genoa Lakes	20	12.0
3/10/05 14:00	Genoa Lakes	88	50.8
3/14/05 13:15	Genoa Lakes	38	25.7
3/23/05 12:30	Genoa Lakes	40	96.1
3/30/05 15:00	Genoa Lakes	21	14.3
4/7/05 12:15	Genoa Lakes	63	54.1
4/13/05 14:15	Genoa Lakes	21	15.3
4/19/05 12:30	Genoa Lakes	28	20.0
4/21/05 11:00	Genoa Lakes	15	13.6
4/25/05 12:00	Genoa Lakes	14	9.8
4/29/05 11:45	Genoa Lakes	18	14.5
5/6/05 8:45	Genoa Lakes	54	36.0
5/10/05 8:30	Genoa Lakes	29	21.8
5/16/05 7:45	Genoa Lakes	430	233.7

Sample Collected	Site	TSS (mg/L)	Turbidity (NTU)
5/18/05 11:00	Genoa Lakes	154	118.6
5/24/05 12:30	Genoa Lakes	176	133.2
5/26/05 10:15	Genoa Lakes	164	154.1
6/1/05 13:15	Genoa Lakes	135	72.5
6/8/05 12:45	Genoa Lakes	53	37.5
6/24/05 12:45	Genoa Lakes	51	21.0
6/29/05 14:00	Genoa Lakes	26	13.9
7/13/05 10:00	Genoa Lakes	24	0.0
10/27/05 12:45	Genoa Lakes	18	19.0
12/2/05 13:45	Genoa Lakes	163	83.1
12/28/05 14:30	Genoa Lakes	67	56.9
1/4/06 15:45	Genoa Lakes	65	35.4
2/27/06 13:30	Genoa Lakes	20	12.0
3/28/06 12:45	Genoa Lakes	16	11.6
5/5/06 12:45	Genoa Lakes	88	57.0
5/19/06 14:30	Genoa Lakes	214	155.7
5/24/06 15:15	Genoa Lakes	110	82.0
6/1/06 12:00	Genoa Lakes	69	46.7
6/6/06 14:30	Genoa Lakes	129	74.2
6/16/06 11:15	Genoa Lakes	32	19.3
6/22/06 13:45	Genoa Lakes	37	20.4
5/13/04 9:45	Riverview	15	10.2
5/20/04 10:00	Riverview	13	8.4
5/27/04 12:00	Riverview	11	8.2
6/3/04 17:00	Riverview	27	0.0
6/11/04 9:15	Riverview	<10	7.5
6/24/04 8:45	Riverview	<10	7.5
7/8/04 10:15	Riverview	<10	0.0
7/22/04 9:00	Riverview	<10	2.8
8/10/04 9:00	Riverview	<10	0.0
1/27/05 17:00	Riverview	12	9.9
3/10/05 11:15	Riverview	64	47.8
3/14/05 10:30	Riverview	20	16.8
3/23/05 10:30	Riverview	13	19.5
4/7/05 14:30	Riverview	38	38.6
4/13/05 10:30	Riverview	12	12.5
4/19/05 10:15	Riverview	23	20.3
4/29/05 13:45	Riverview	15	41.1
5/3/05 5:15	Riverview	96	126.5
5/6/05 5:45	Riverview	43	62.7
5/10/05 5:30	Riverview	26	41.5
5/16/05 5:00	Riverview	550	385.3
5/18/05 14:00	Riverview	696	438.2
5/19/05 13:15	Riverview	416	323.1
5/24/05 9:30	Riverview	220	419.3
5/26/05 12:30	Riverview	148	116.9
6/1/05 10:45	Riverview	117	107.9

Sample Collected	Site	TSS (mg/L)	Turbidity (NTU)
6/8/05 15:00	Riverview	30	36.3
6/14/05 14:30	Riverview	40	52.4
6/24/05 15:15	Riverview	23	16.1
6/29/05 10:30	Riverview	18	15.0
7/13/05 12:45	Riverview	13	10.7
12/2/05 11:30	Riverview	257	201.5
12/28/05 11:45	Riverview	56	63.5
1/4/06 12:45	Riverview	16	39.9
2/27/06 10:15	Riverview	<10	23.4
3/28/06 15:00	Riverview	<10	101.7
5/4/06 15:45	Riverview	81	61.0
5/10/06 11:45	Riverview	77	60.4
5/12/06 15:15	Riverview	92	65.9
5/19/06 10:15	Riverview	280	221.3
5/24/06 12:30	Riverview	57	56.3
6/1/06 9:15	Riverview	48	52.5
6/6/06 11:45	Riverview	98	87.9
6/16/06 8:45	Riverview	24	26.5
6/22/06 11:45	Riverview	26	29.2

APPENDIX D: Spatial Investigation of Turbidity

To assess the spatial heterogeneity of turbidity across the river, samples were collected at Brunswick Canyon between March and July 2005. Brunswick Canyon was chosen because it had the slowest water velocities of the four sites studied. Turbidity was measured from each depth-integrated sample prior to placing the sample into the churn splitter. Left, left center, right center, and right refer to the bridge position where the sample was collected. Lab TU refers to the turbidity measured in the final composite sample retrieved from the churn splitter.

Results from a semi-qualitative analysis of variance did not reveal any significant difference between turbidity measured at each position and the composite lab measured turbidity.

Sample Collected	Left	Left Center	Right Center	Right	Lab TU
3/10/05 15:27	14	13.6	13.6	14.5	13.6
3/29/05 13:40	26	24.9	24.6	25.9	26.4
4/8/05 12:38	22.7	26.6	24.3	23	21.6
4/15/05 12:33	7.21	6.4	6.65	6.4	7
4/19/05 15:05	22.7	22.4	24.4	23.6	25
4/22/05 13:03	13	13.1	13.1	14	12.9
5/3/05 15:40	19.4	19.3	19.6	19	18.8
5/11/05 10:56	18.6	17.9	19	17.4	18
5/13/05 12:41	15.8	16.6	17.9	17.5	18.8
5/17/05 13:42	341	344	372	375	337
5/27/05 15:30	132	135	131	135	127
5/31/05 13:27	76.3	70.8	73.4	71	72.1
6/8/05 10:10	27.3	28.1	31.5	28.4	27.9
6/24/05 10:05	19.5	19.8	18.2	19.7	18.3
6/30/05 15:35	14.6	14.9	14.2	15.4	14
7/13/05 14:20	9.67	10.7	9.85	11.8	11.2