Lower Rosewood Creek Restoration Project: Suspended Sediment Loads and Particle Size, 2002-2007

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ABSTRACT

Rosewood Creek is a small, urban creek in the northeastern part of the Lake Tahoe Basin. In an effort to improve the sensitive environmental zone and mitigate suspended sediment into Third Creek and ultimately into Lake Tahoe, the Rosewood Creek Restoration Project was constructed during spring and summer 2003. The overall objectives of this research were to utilize preconstruction monitoring to assess the impact of Rosewood Creek suspended sediment delivery to Third Creek, and to quantify the ability of the restoration project to alter the mass and particle-size distribution of suspended sediment after construction. In-situ monitoring was conducted between November 2002 and October 2007. Data collected at each site included continuous measurements of water discharge, turbidity, EC, and water temperature. Discrete water samples were collected by an automated vacuum sampler and analyzed for suspended sediment concentration (SSC) and particle-size distribution. In-stream turbidity was used as a surrogate for SSC through the development of linear regression models that described the relationship between turbidity and SSC.

Sediment delivery by Rosewood Creek was a significant contributor of sediment to Third Creek, primarily during low-elevation hydrologic events. On average, Rosewood Creek transported an average of 145,985 kg of suspended sediment during each year from Water Year 2003 through Water Year 2007. Surveys conducted on upstream creek segments indicated high bank erosion potentials caused by poorly stabilized, steeply incised banks.

Suspended sediment loads exiting the restoration project were 20 percent higher than those entering during the first post-construction snowmelt season. Distinct periods of coarser-grained suspended sediment were observed and were attributed to the presence of unconsolidated sediments after construction, and from sediment remaining in the project area that had eroded from banks and channel failures during previous events. The ability of the restoration project to mobilize sediment relative to water volume was lower and less variable in the third and fourth post-construction years, indicating a diminishing influence of disturbance from project construction.

An assessment of effectiveness of the project on delivery of suspended sediment loads was difficult to achieve because of the significant contribution of surface runoff within the project area during 28 of the 51 post-construction events. Of the remaining 23 events, the restoration project reduced sediment loads by a total of 14,000 kg during 10 events and increased sediment loads by 9,000 kg in 13 events. The project was most effective at reducing suspended sediment loads during rain-on-snow events, presumably because of lower precipitation intensities and water velocities with this type of event relative to either rain or snowmelt events.

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INTRODUCTION

Rosewood Creek is a small, urban tributary located within the Third Creek watershed in Incline Village, Nevada (Figure 1). Visual observations have suggested that the loading of suspended sediment from Rosewood Creek can significantly increase the load of suspended sediment carried by Third Creek into Lake Tahoe. Once in the lake, suspended sediment can have a direct negative impact on visual water clarity (Jassby *et al*., 1999) and it can serve as a source of nutrients that may stimulate algal growth. Identification and reduction of sediment sources from the Third Creek watershed are important, as the historical average monthly *yield* of suspended sediment by Third Creek into Lake Tahoe has consistently been greater than the other streams monitored by the Lake Tahoe Interagency Monitoring Program (Rowe *et al*., 2002).

The Rosewood Creek Restoration Project was constructed during spring and summer 2003 to improve the quality of water discharged by the creek, as well as to restore a historical sensitive environmental zone. The project increased the overall length of Rosewood Creek by approximately 975 linear meters, resulting in the movement of its confluence with Third Creek from just south of State Route 28 to just north of Lakeshore Blvd. The restored channel ranged from 2 to 9 percent in gradient, and consisted of mostly Rosgen Type "E" channels, with some Type "A" channels in the upper areas of the restoration. The project was expected to improve quality of water discharged from Rosewood Creek by: 1) increasing the distance that sediments and nutrients must travel before discharging into the higher-velocity waters of Third Creek; 2) providing erosion control measures and a healthy riparian zone around the creek that are capable of mitigating poor water quality; 3) routing the creek through five flood-spreading basins (e.g., Figure 2); and 4) construction of a storm detention basin to pre-treat water entering the creek above Incline Way.

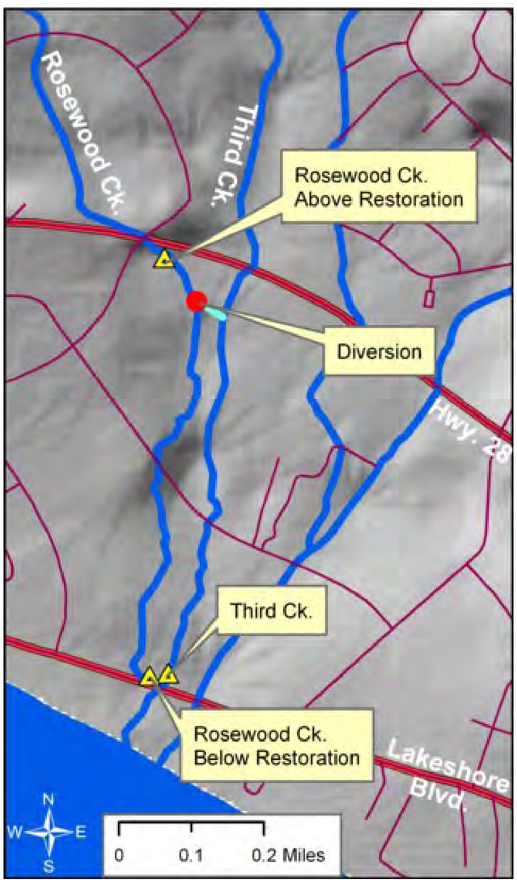

Figure 1. Map of the Rosewood Creek Restoration Project within Incline Village, NV. Water quality monitoring sites are denoted by yellow triangles. The project area extends south from the diversion that was installed as part of the restoration project.

Water flows into the completed project area are currently managed by the Incline Village General Improvement District. Peak flows are controlled by a new diversion structure located at the upstream end of the project. The particular positioning of headgate boards allows a portion of water to enter Rosewood Creek with the excess being diverted into

Third Creek. Since construction, the boards have been positioned to only allow a minimum amount of water to enter the project, up to 0.40 cubic meters per second (cms) (Miller, 2004). This was done to protect the project from high-flow erosive damage while the vegetation matured. The Rosewood Creek Restoration Project Operations and Maintenance Plan called for the boards to be reconfigured to allow up to 0.68 cms to enter the project starting in 2007, but that has yet to occur.

Figure 2. The flood-spreading zone above Incline Way during construction and during two hydrologic events.

The overall objectives of this research were to: 1) quantify the magnitude of suspended sediment delivery by Rosewood Creek into Third Creek; and 2) evaluate the efficacy of the Rosewood Creek Restoration Project to alter the quantity (mass) and composition (particle-size) of suspended sediment delivered by Rosewood Creek into Third Creek. Pre-project monitoring was initiated in November 2002, with data reported here through September 2007. Data collected at each site included continuous measurements of water discharge, turbidity, specific conductivity (EC), water temperature, and discrete measurements of suspended sediment concentration (SSC) and particle-size. Particle-size analysis was carried out as the particle-size of suspended sediment exerts a fundamental control on its settling velocity and its ability to remain entrained in stream flow or to settle out. Additionally, finer-sized particles can transport a greater amount of nutrients like P, as they have a greater specific surface area than coarse particles. General trends in particle size will be discussed here, while more explicit relationships will be discussed in a future report.

METHODS

Field Sites, Equipment, and Sample Acquisition

The first Rosewood Creek monitoring site was installed in November 2002, below State Route 28 (RW-Abv) but above the restoration zone so it would not be influenced by construction activities (Figure 1). The Third Creek (Third) site was co-located with USGS gage number 10336698 at the Aspen Grove Park in Incline Village, Nevada. The last site, located on Rosewood Creek below the restoration area (RW-Blw), was installed in November 2003. All three sites were equipped with an in-stream turbidimeter (OBS-3, D&A Instrument Co., Logan, UT), EC and water temperature sensor (Campbell Scientific, Logan, UT), and pressure transducer (KPSI, Hampton, VA) to monitor stage. Data from these sensors were recorded every 10 minutes by a datalogger (Campbell Scientific).

Discrete water samples were collected by an automated vacuum sampler ("autosampler": Manning Environmental VST, Georgetown, TX, and Teledyne ISCO 3700, Lincoln, NE). A modified version of the Turbidity Threshold Program (Rand Eads, Redwood Sciences Laboratory, U.S. Forest Service) was used to trigger sample collection by changes in turbidity. In fall 2007, the three sampling stations were reconfigured with improved sensors, communications equipment, and software. OBS-3 turbidimeters at RW-Abv, RW-Blw, and Third Creek sites were replaced with DTS-12 sensors (Forest Technology Systems, Victoria, British Columbia, Canada) that had integrated wipers necessary to reduce the senosor's susceptibility to biofouling.

Quality assurance was performed on all data using StreamTrac software (Forest Technology Systems, Blaine, WA) for RW-Abv from December 1, 2002 to October 1, 2007, and for RW-Blw from October 1, 2003 to October 1, 2007. Raw stage and raw turbidity values were adjusted when needed using various graphical editing techniques including: point editing, reconstruction from surrogates, linear interpolation, and swing shifting. Corrections were also applied to correct for biofouling or other sensor blockage. Six auxiliary sites within the lower Rosewood Creek restoration project were monitored for stage only with capacitive sensors (WT-HR TruTrack, TruTrack Ltd., New Zealand). For these six auxiliary sites, data integrity was assessed and modified using TTS Adjuster (Redwood Sciences Laboratory, U.S. Forest Service, Arcata, CA). These sites are discussed further beginning on page 39.

Meteorological data was obtained from DRI's Incline Creek meteorological station located on the roof of a pump house building near the Diamond Peak Ski Area. This location is proximate to Third creek, with an elevation similar to that of the upper portions of the Rosewood Creek watershed. Measurements included air temperature and relative humidity (CS215-L, Campbell Scientific Logan, Utah), wind direction and speed (05103-L, R.M.Young, Traverse City, Michigan), snow depth, and precipitation (MetOne Instruments, Grants Pass, Oregon).

Discharge Calculations

Water discharge data were obtained from the U.S. Geological Survey (USGS) station at the Third Creek site. For all eight Rosewood Creek sites, rating curves were established using numerous field discharge measurements and continuous stage measurements. Field measurements were conducted with a Marsh-McBirney, Inc., Flo-Mate model 2000 following standard USGS procedures (Shelton, 1994; Edwards and Glysson, 1998). The RW-Abv site did not have a stable cross section, requiring at least monthly visits to account for shifts in the rating curve.

Water volumes entering the actual restoration project below the diversion were not always the same as those measured several hundred feet upstream at RW-Abv for two reasons. First, surface water inputs entered the stream just above the diversion, typically during the onset of the snowmelt season. Second, some of the flow entering the diversion structure was diverted into Third Creek. This was initially done to protect the newly constructed restoration project from damage caused by high flows. To date, the Rosewood Creek side of the diversion structure has remained in the one board open, four boards closed position and the Third Creek side with one board closed, four boards open. By design (Miller, 2004), this would allow flows less than 0.116 cms to fully enter Rosewood Creek, but attenuate larger flows (red line in Figure 3). For example, only 52 percent of an incoming 0.382 cms would continue into Rosewood Creek. In practice, however, discharge in excess of 0.038 cms entering the structure resulted in a partial diversion into Third Creek. Between 0.038 and 0.116 cms discharge entering the restoration project had the following relationship:

$$Q_{below} = 0.6978 \times Q_{above} + 0.01227 \quad (R^2 = 0.96,\ p \leq 0.0001)$$

where Q_{below} was the discharge exiting the diversion structure and entering the restoration project in cms, and Q_{above} was the discharge entering the diversion structure in cms. Based on this loss, the original relationship presented in the Operations and Maintenance (O&M; Miller, 2004) document was shifted for flows greater than 0.116 cms

$$Q_{below} = -0.0245 * (Q_{above})^2 + 0.394 \times Q_{above} + 0.0504$$

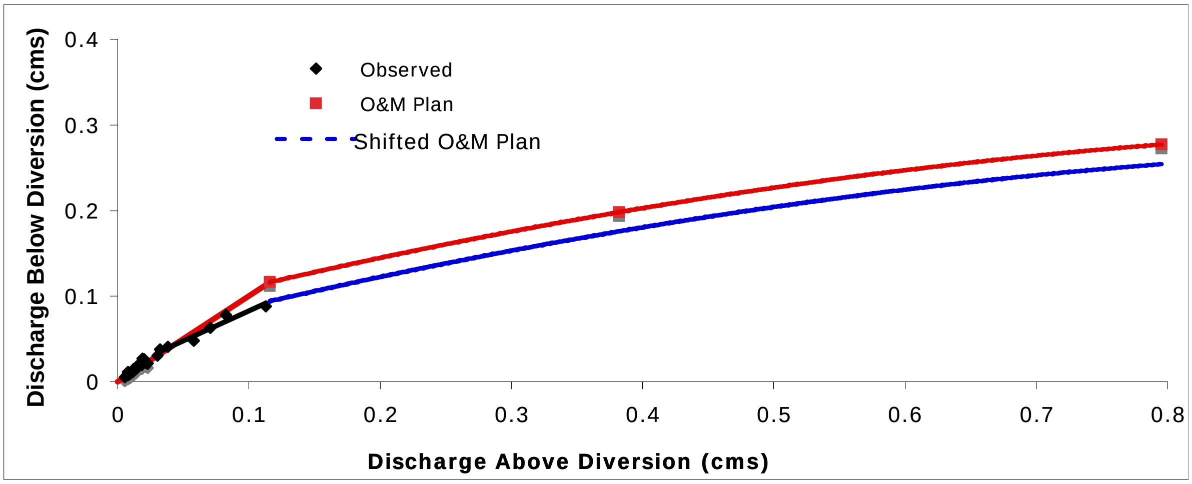

Figure 3. Alteration of discharge as it passes through the diversion structure at the top of the restoration project. The diversion structure had one board open to Rosewood Creek and one board closed to Third Creek during the period of observation.

Relative to the original O&M equation, this correction reduced predicted flows entering Rosewood Creek by an additional 8 percent. Continuous measurements of stage above and below the diversion structure were started in June 2006 to directly measure water "loss" through the structure. This curve will be revised when measurements at flows higher than 0.116 cms are observed.

Suspended Sediment Concentration and Turbidity

A subset of the samples collected by autosampler was analyzed for SSC by the Soil Characterization Laboratory at the Desert Research Institute, Reno, NV, following the ASTM D3977-97 method (2007a). Turbidity is a specific class of light scattering measurements, expressed in nephelometric turbidity units (NTU). Water samples were concentrated to dryness by evaporation in a tarred beaker. Samples were selected for analysis based on their turbidity and position on the hydrograph, yielding between three and five samples for each identified hydrologic event. Linear regressions determined via the statistical program R (http://www.r-project.org) were used to create the models needed to estimate SSC on a 10-minute basis utilizing in-stream turbidity measurements. Data were also investigated using sequential linear regression (SLR), a statistical tool for the development of linear functional relationships between a response (y, SSC) and several explanatory variables ($x_1, \dots, x_n$, e.g., turbidity). An explanatory variable was included in the SLR model only if it had a probability, or *p*-value, greater than 0.05. The random error for both methods was assumed to have a normal distribution with mean zero and variance σ^2. For a sample of observations, random errors were also assumed to be independent and identically distributed. These assumptions were graphically evaluated for normality, independence, and constant variance using normal probability plots, histograms, and plots of residuals against the response and against explanatory variables. The graphical evaluations showed that assumptions were not typically violated. Data were also subjected to log and other common transformations; however, correlation coefficients were not significantly improved to justify the added complexity of transformation. The accuracy of the prediction of mean response, or point-wise prediction interval (PI), was reported at the 95-percent PI level.

Laser Particle Size Analysis

Laser particle size analysis (LPSA) was used to determine the percentage of specific size-class fractions between 0.02 µm and 1500 µm in diameter in a sediment sample (Gee and Or, 2002). The procedure was based on ASTM C1070 – 01 for the determination particle size distribution analysis (PSDA) of alumina and quartz by laser light scattering (ASTM, 2007b). This procedure is based on the Mie theory of light scattering by a spherical particle using a Micromeretics Saturn DigiSizer 5200®. The sample is internally dispersed using ultra-sonication in an aqueous medium of 0.005 percent surfactant (Na pyrophosphate) and circulated through the path of the laser light beam. As the particles pass through the laser beam, the light scatters at angles inversely proportional to their size and with intensity directly proportional to their size. A forty-five-degree rotational Charged-Coupled Device (CCD) detector collects the scattered light, which is converted to electrical signals and analyzed in a microprocessor. Data reduction consists of a mathematical convolution based on scattering model sets, each calculated from general Mie theory for narrow distributions of isotropic spheres of a specific index of refraction and suspended in liquid of a specific index of refraction. Data reported by the Saturn DigiSizer relates directly to an equivalent Mie sphere. Mie theory consists of a 'real' refractive index (1.550 for soils) and an 'imaginary' refractive index (0.100 for soils) determined by Micromeretics Laboratories. The predictive model error (weighted residual) is proportional to the measure of the calculated Mie theory model to predictions of the observed laser light scattering pattern.

For suspended sediment samples, the previously dried sediment was exposed to a surfactant, poured into the machine, and internally dispersed with ultra-sonication. This particular method has the advantage of analyzing the entire sample, enabling the ability to determine a mean, mode, and kurtosis of the entire particle size distribution. For bank and bed sediment samples, a subsample was externally dispersed, sieved to remove sand-sized fractions, and analyzed for particle size. This method has the advantage of increased resolution of fine sediment by removing larger particles, thereby reducing errors association with multiple light scattering. For both methods, the reported particle size distribution incorporated the average of six consecutive particle size analyses. Yolo and Warden soil secondary standards were run on a weekly basis, with quality assurance checks against the primary garnet standard run when necessary. A background run was conducted twice a day to 'zero out' analysis liquid scatter, dust accumulation, or any diffractive change to the system. The background correction was minor for low-angle diffractions that were equivalent to very large diameter particles. Smaller-diameter particles correspond to high-angle diffraction, resulting in the Digisizer being much more sensitive and accurate to smaller-diameter particles.

In March 2003, a test was run (n=7) to determine if the particle size varied between samples that had undergone drying for SSC analysis with subsequent dispersion, and samples poured directly into the machine. An analysis of variance (ANOVA) test was run with the dependent factors of treatment (SSC versus non-SSC) nested into particle-size percentage by size fraction and found that the methods were not significantly different (P=0.435). Samples with low SSC must be concentrated in order to meet a minimum concentration level required by the Digisizer. To maintain sample result consistency, all samples were run through the SSC drying methodology prior to LPSA, regardless of sediment concentration.

Load Calculations

The suspended sediment load (SSL) was the product of the suspended sediment concentration (SSC in mg L^{-1}) and discharge Q (in m^3 s^{-1}):

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

where concentration and discharge were continuous over time *t*. This equation was approximated by the discrete sum:

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

with a fixed sampling interval that was shorter than the minimum time over which discharge or concentration could significantly change. Therefore, SSL was calculated for each 10-minute interval having turbidity data. Total event loadings were calculated by summation of the ten minute calculated loadings. When in-stream turbidity exceeded the sensor maximum (1,000 NTU), the autosampler was programmed to collect a water sample every 60 minutes. Suspended sediment loading (SSL) during these high turbidity events was estimated from SSC measured in these hourly samples. Suspended sediment loading was also estimated based on particle-size grouping. This was accomplished by multiplying the flow-weighted average particle size fraction by the total suspended sediment load for those events where particle size analysis was conducted.

In 2005, 10 samples collected from RW-Blw were found to have an SSC of greater than 2,000 mg L^{-1} with a median particle size of greater than 150 μm. These samples were excluded from the analysis as they resulted from the temporary capture of bed load caused by the sampling intake being positioned too close to the bottom of the creek.

OVERVIEW

This section contains a general overview of Rosewood Creek and Third Creek hydrologic parameters and events. Information in this section is organized topically rather than chronologically and is presented to contrast the differences between the two watersheds. Specific event-based results, including water and sediment loadings will be discussed in subsequent sections.

Data collection was initiated at sites above the restoration project (State Route 28; RW-Abv) and on Third Creek (Third) in November 2003 and below the project in August 2004 (Lakeshore; RW-Blw) after completion of the project. This report summarizes data collected through September 2007, and includes 60 hydrologic events including rain, snowmelt, and rain-on-snow events (Table 1). The hydrographs during each of the four post-construction years show a striking year-to-year variability (Figure 5). Water Year (WY) 2004 was dominated by a quick snowmelt season, whereas WY 2005 was dominated by a less intense, but much longer, snowmelt season. Water Year 2006 was dominated by both an intense rain-on-snow event that generated the highest peak flows yet observed in the project as well as the highest peak discharges during snowmelt. In contrast, low snowfall totals resulted in lower runoff during the spring of WY 2007 than in previous years. Peak flows in Rosewood Creek were approximately 5 to 20 percent of those observed from the Third Creek watershed (Table 5).

Turbidity levels in Rosewood Creek were found to be very responsive to small changes in discharge (Figure 5 and Tables 2-4). Rainstorms produced short-lived, but high, turbidity values compared to snowmelt events that had lower turbidity values that persisted for a longer duration. Turbidity values were, in general, higher in Rosewood Creek than in Third Creek because of at least two factors. First, Rosewood Creek rapidly responds to precipitation events because of its small size and the fact that its entire length resides in a low-elevation, urbanized area. Third Creek, in contrast, is primarily a high-elevation watershed with only 10 percent of its areal extent in the urbanized lower elevation. As a result, the yearly Third Creek hydrograph is dominated by high-elevation snowmelt (Figure 6). Second, water flows within Third Creek can be considerably higher than those in Rosewood Creek. Average annual discharge from Third Creek ranged between 0.153 and 0.379 cms, whereas Rosewood Creek ranged from 0.011 to 0.031 cms (Table 5). As a result, urban and surface runoff that enters Third Creek can be significantly diluted, resulting in lower observed turbidity values.

The magnitude and extent of elevated discharge and turbidity varied between the two watersheds primarily due to their differences in elevation. The highest turbidity values observed in both watersheds was during Event 8, a series of thunderstorms that occurred on August 21, 2003. Average daily turbidity quickly exceeded 350 NTU and increased beyond the upper limit of the turbidity sensors (1,000 NTU) at both sites. In contrast, the earlier onset of snowmelt in the lower elevation Rosewood Creek watershed (Figure 4) resulted in higher loadings from Rosewood Creek while flows and sediment loading in the Third Creek watershed were low. Rosewood Creek was also more responsive to winter precipitation that fell as rain in the lower elevations, whereas snowfall at higher elevations did not immediately impact discharge in Third Creek. For example, a low elevation rain-on-snow, high elevation snow event from December 30, 2005 through January 8, 2006 (Event 42) increased discharge and sediment loads only in the lower elevation Rosewood Creek watershed.

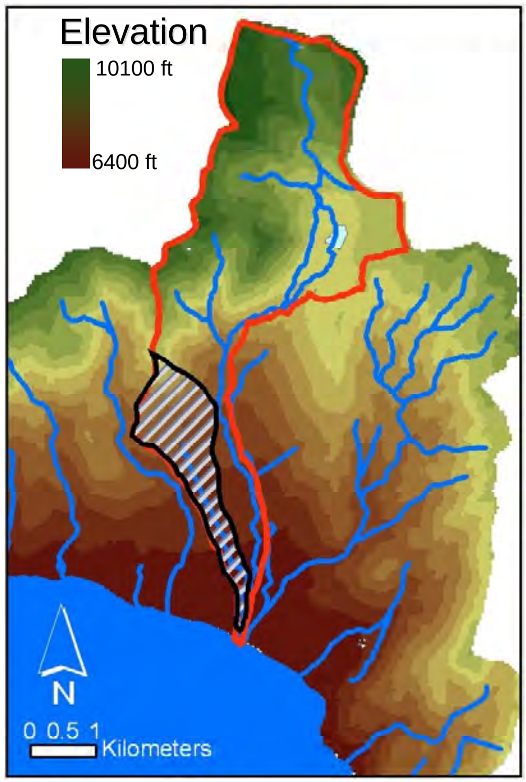

Figure 4. Elevation map of the Third (red outline) and Rosewood (black outline, hatched) creek watersheds.

Summary statistics for SSC, turbidity, EC, and water temperature are presented in Tables 2 through 4. Electrical conductivity was dependent on season, with lower values observed during the snowmelt season when water input to the creeks was dominated by lower-EC water derived by snowmelt. Typical average conductivities ranged from 111 to 253 $\mu S\ cm^{-1}$ in Rosewood Creek to 42 to 127 $\mu S\ cm^{-1}$ in Third Creek. Water temperatures in both creeks were also seasonal, ranging 0.5 to 3.1 ^{o}C during snowmelt and between 13.1 to 15.5 ^{o}C during summer thunderstorms.

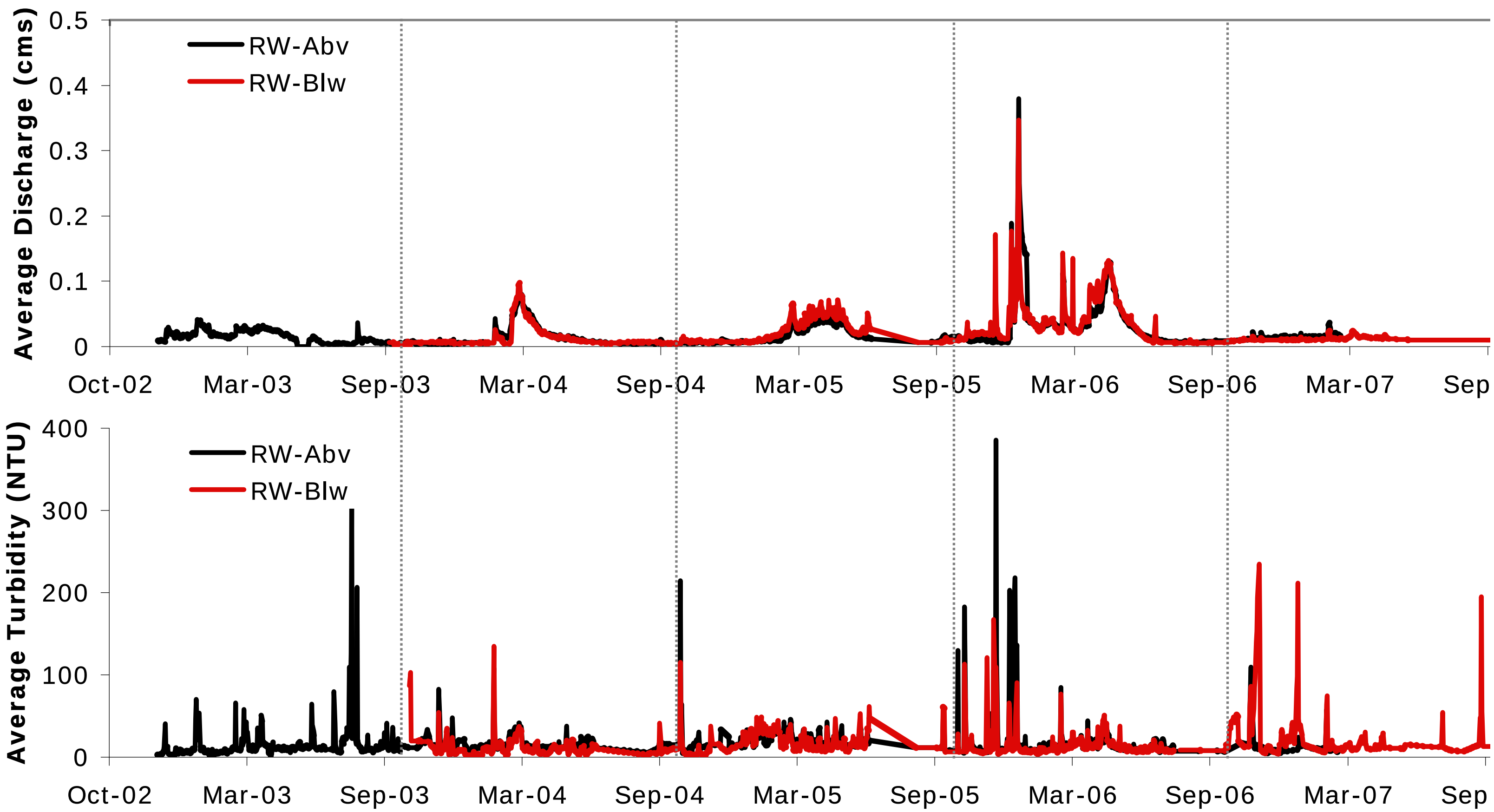

Figure 5. Average daily discharge and average daily turbidity above (RW-Abv) and below (RW-Blw) the restoration project. Dashed vertical lines represent water years.

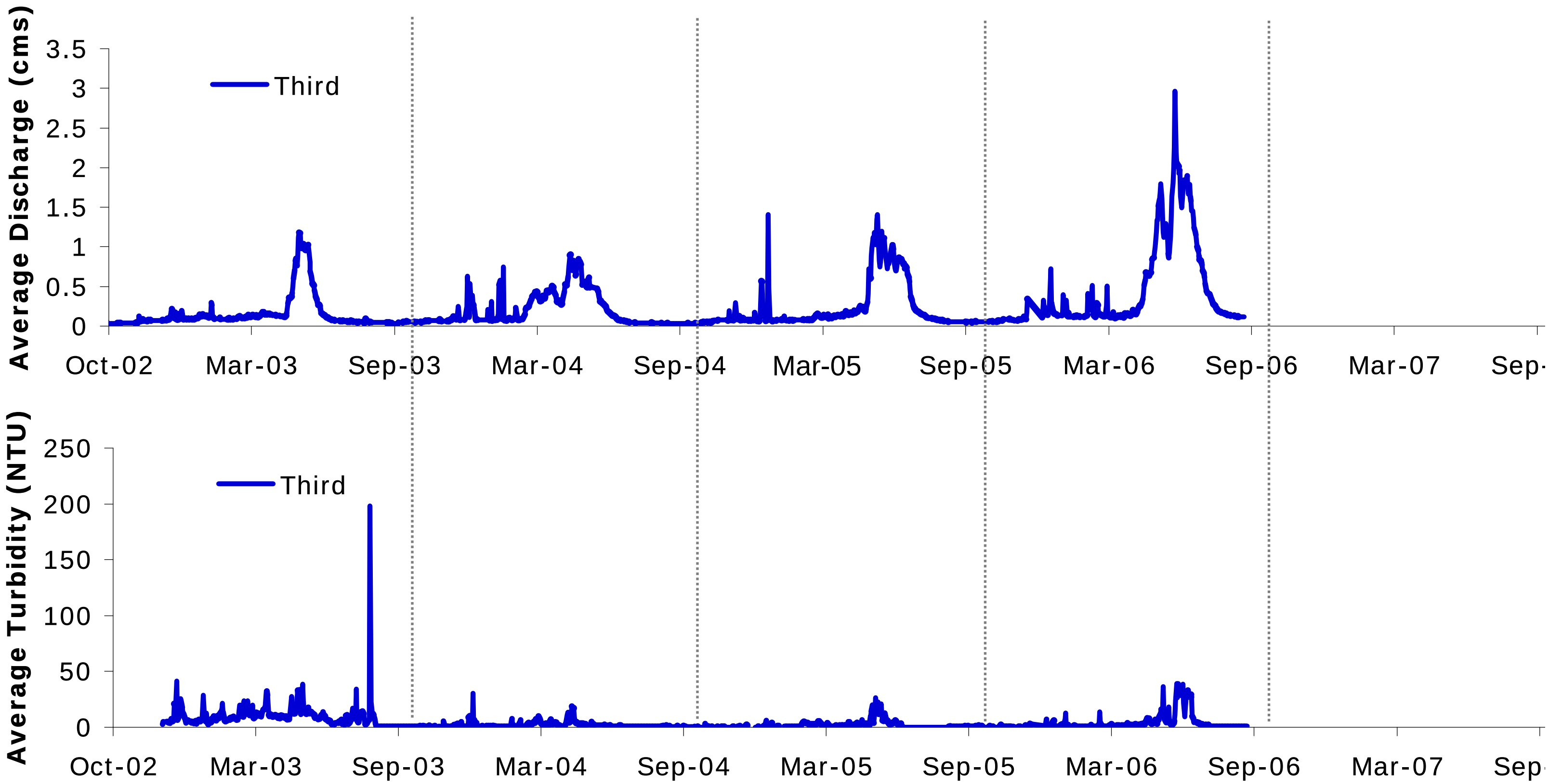

Figure 6. Average daily discharge and average daily turbidity at the Third Creek site.

Table 1. List of hydrologic events (SM = snowmelt; ROS = rain on snow). The water year starts on October 1 and ends on September 30.

Event Number	Event Type	Event Start	Event End	Duration (Days)	Notes
Water Year 2002-2003					
1	SM	1/22/2003 0:00	2/5/2003 15:00	14.6	Mid-winter snowmelt event
2	SM	3/8/2003 0:00	5/24/2003 0:00	77.0	Entire snowmelt season
3	SM	3/8/2003 0:00	4/20/2003 0:00	43.0	Snowmelt, rising limb
4	SM	4/20/2003 0:00	5/24/2003 0:00	34.0	Snowmelt, falling limb
5	ROS	5/3/2003 0:00	5/4/2003 0:00	1.0	
6	SM	5/11/2003 0:00	7/1/2003 0:00	51.0	High-elevation snowmelt (Third Creek)
7	Rain	7/22/2003 19:00	7/24/2003 12:00	1.7	
8	Rain	8/21/2003 7:00	8/27/2003 7:00	6.0	
Water Year 2003-2004					
9	SM	1/20/2004 0:00	2/10/2004 18:00	21.8	Mid-winter snowmelt event
10	ROS	2/16/2004 9:00	2/18/2004 8:00	2.0	
11	ROS	2/26/2004 0:00	2/28/2004 14:00	2.6	
12	SM	3/5/2004 12:00	4/27/2004 0:00	52.5	Entire snowmelt season
13	SM	3/5/2004 12:00	3/9/2004 12:00	4.0	Early snowmelt, rising limb
14	SM	3/13/2004 12:00	3/18/2004 12:00	5.0	Middle snowmelt
15	SM	3/21/2004 12:00	4/27/2004 12:00	37.0	Late snowmelt
16	SM	3/21/2004 19:00	5/20/2004 0:00	59.2	Falling limb of seasonal snowmelt
17	SM	3/2/2004 0:00	5/29/2004 0:00	88.0	High-elevation snowmelt (Third Creek)
18	Rain	5/21/2004 14:00	5/22/2004 6:00	0.7	
19	Rain	5/28/2004 5:00	5/28/2004 10:00	0.2	
20	Rain	6/9/2004 6:00	6/9/2004 22:00	0.7	
21	Rain	9/20/2004 0:00	9/21/2004 15:00	1.6	
Water Year 2004-2005					
22	Rain	10/17/2004 0:00	10/21/2004 9:00	4.4	
23	Rain	11/10/2004 0:00	11/12/2004 0:00	2.0	Mixed rain/snow event
24	ROS	1/25/2005 0:00	1/29/2005 7:00	4.3	
25	SM	2/3/2005 0:00	6/18/2005 0:00	135.0	Entire snowmelt season
26	SM	2/3/2005 0:00	2/25/2005 0:00	22.0	Early snowmelt, rising limb
27	SM	2/25/2005 0:00	3/5/2005 0:00	8.0	Snowmelt, rising limb
28	SM	3/5/2005 0:00	3/19/2005 0:00	14.0	Snowmelt, large pulse event
29	SM	3/19/2005 0:00	4/21/2005 0:00	33.0	Snowmelt, slight rising limb
30	SM	4/21/2005 0:00	5/18/2005 0:00	27.0	Middle snowmelt season
31	SM	5/18/2005 0:00	6/18/2005 0:00	31.0	Late snowmelt season, falling limb
32	SM	3/5/2005 0:00	8/1/2005 0:00	149.0	High-elevation snowmelt (Third Creek)
33	Rain	6/8/2005 2:00	6/10/2005 5:00	2.1	
34	Rain	6/10/2005 6:00	6/11/2005 5:00	1.0	
35	Rain	6/16/2005 16:00	6/17/2005 9:00	0.7	
36	Rain	9/26/2005 18:00	9/28/2005 0:00	1.3	

Table 1. List of hydrologic events (SM = snowmelt; ROS = rain on snow) (continued).

Event Number	Event Type	Event Start	Event End	Duration (Days)	Notes
Water Year 2005-2006					
37	Rain	10/15/2005 7:00	10/15/2005 22:00	0.6	
38	Rain	10/24/2005 18:00	10/25/2005 12:00	0.8	
39	ROS	11/30/2005 17:00	12/3/2005 0:00	2.3	
40	ROS	12/20/2005 21:00	12/25/2005 0:00	4.1	
41	ROS	12/27/2005 0:00	12/30/2005 4:00	3.2	
42	ROS	12/30/2005 6:00	1/8/2006 12:00	9.3	
43	ROS	2/26/2006 21:00	2/28/2006 15:00	1.8	
44	SM	3/21/2006 0:00	6/21/2006 0:00	92.0	Entire snowmelt season
45	SM	4/2/2006 12:00	4/27/2006 16:00	25.2	Snowmelt, rising limb
46	SM	4/27/2006 16:00	7/22/2006 0:00	85.3	Snowmelt, falling limb
47	SM	4/25/2006 0:00	7/14/2006 0:00	80.0	High elevation snowmelt (Third Creek)
48	Rain	6/28/2006 12:00	6/28/2006 22:00	0.4	
Water Year 2006-2007					
49	Rain	10/5/2006 11:00	10/7/2006 4:00	1.7	
50	Rain	11/2/2006 4:00	11/4/2006 1:00	1.9	
51	Rain	11/13/2006 7:00	11/14/2006 19:00	1.5	
52	Rain	11/28/2006 1:00	11/30/2006 22:00	2.9	Mixed rain/snow event
53	ROS	1/3/2007 14:00	1/5/2007 0:00	1.4	
54	ROS	2/8/2007 18:00	2/14/2007 6:00	5.5	
55	SM	2/25/2007 20:00	3/22/2007 14:00	24.8	Entire snowmelt season
56	SM	2/25/2007 20:00	3/12/2007 16:00	14.8	Snowmelt, rising limb
57	SM	3/12/2007 16:00	3/22/2007 14:00	9.9	Snowmelt, falling limb
58	Rain	5/2/2007 12:00	5/3/2007 0:00	0.5	
59	Rain	8/29/2007 1:00	8/31/2007 16:00	2.6	
60	Rain	9/19/2007 23:00	9/22/2007 18:00	2.8	

Table 2. Average (avg), maximum (max), and minimum (min) values for turbidity, EC, water temperature, and discharge during each event at the RW-Abv (State Route 28) site.

Event	Turbidity (NTU)			Water temp (°C)			EC (µS cm^{-1})			Discharge (cms)		
Num.	min	avg	max	min	avg	max	min	avg	max	min	avg	max
1	4	22	435	-0.2	3.1	5.6	152	206	421	0.0142	0.0340	0.0595
2	1	15	448	-0.2	4.7	15.5	--	208	686	--	0.0226	0.0623
3	1	18	448	-0.2	3.7	10.5	149	201	481	--	0.0255	0.0623
4	1	11	109	1.5	5.8	15.5	--	217	686	0.0142	0.0226	0.0340
5	8	18	109	3.5	5.2	8.3	195	251	686	0.0226	0.0255	0.0340
6	0	14	375	2.8	10.2	16.4	--	201	274	--	0.0113	0.0340
7	6	44	588	13.9	15.0	16.9	167	180	251	0.0028	0.0057	0.0226
8	7	45	1,054	10.3	12.7	16.8	104	155	192	0.0028	0.0142	0.2831
9	1	13	45	-0.2	0.9	3.2	88	144	366	0.0057	0.0057	0.0085
10	12	67	460	0.5	2.1	3.2	130	189	293	0.0057	0.0425	0.1331
11	4	11	19	-0.2	0.1	1.2	164	177	210	0.0142	0.0170	0.0198
12	7	19	103	1.6	4.9	12.7	35	180	246	0.0113	0.0425	0.1104
13	8	21	86	2.0	3.1	5.7	182	197	226	0.0113	0.0226	0.0538
14	8	30	86	2.6	4.1	6.9	58	146	237	0.0453	0.0623	0.0906
15	9	15	103	1.6	5.5	12.7	149	191	246	0.0170	0.0396	0.1104
16	9	14	85	1.6	6.4	13.8	144	184	246	0.0113	0.0283	0.0991
17	2	17	478	0.2	5.9	13.8	35	177	270	0.0113	0.0311	0.1104
18	11	53	478	5.6	7.3	9.8	143	151	169	0.0113	0.0198	0.0595
19	14	28	71	7.6	7.8	8.2	144	147	155	0.0142	0.0170	0.0255
20	14	29	126	5.4	6.2	6.9	126	136	140	0.0113	0.0113	0.0226
21	15	19	25	3.2	4.8	7.5	98	115	185	0.0057	0.0085	0.0226
22	1	39	596	0.6	4.3	7.7	89	126	240	0.0057	0.0085	0.0566
23	11	24	327	3.6	4.7	6.3	84	154	409	0.0057	0.0085	0.0311
24	14	28	144	0.3	2.3	3.1	144	180	316	0.0085	0.0085	0.0170
25	7	21	434	-0.2	4.9	15.0	--	185	511	--	0.0255	0.1019
26	13	25	78	0.7	2.6	4.6	150	191	511	0.0085	0.0113	0.0170
27	13	24	145	0.9	2.9	5.0	98	148	275	0.0113	0.0142	0.0311
28	10	26	135	1.3	3.6	6.8	95	171	224	0.0142	0.0283	0.0566
29	9	21	434	-0.2	3.1	8.6	--	139	331	0.0170	0.0340	0.0764
30	10	20	259	2.3	5.8	12.2	112	210	296	--	0.0396	0.1019
31	7	17	159	3.9	8.9	15.0	--	225	287	0.0113	0.0198	0.0453
32	1	20	434	-0.2	5.7	15.0	--	188	331	--	0.0311	0.1019
33	15	33	69	5.8	7.9	10.6	191	208	233	0.0113	0.0170	0.0255
34	13	28	132	7.4	9.0	10.8	206	222	240	0.0170	0.0170	0.0368
35	13	30	75	6.4	7.5	9.3	183	198	213	0.0113	0.0142	0.0226
36	11	55	585	7.3	8.2	9.0	123	142	243	0.0113	0.0142	0.0368
37	8	198	1,052	5.5	6.2	6.8	113	137	194	0.0113	0.0142	0.0396
38	19	170	1,053	7.7	8.3	9.1	108	140	161	0.0113	0.0255	0.0906
39	8	61	317	1.4	2.6	3.7	99	155	257	0.0057	0.0510	0.2435
40	9	57	462	1.5	3.5	5.0	55	156	208	0.0113	0.0934	0.3284
41	9	60	725	2.5	2.9	3.6	98	253	631	0.0311	0.0991	0.1840
42	10	37	622	1.1	2.6	3.9	66	149	538	0.0849	0.2095	0.4926
43	22	69	251	1.1	2.2	3.3	123	156	205	0.0368	0.1076	0.1925
44	1	15	1,053	-0.1	6.2	13.7	--	195	635	0.0113	0.0510	0.1812
45	1	20	226	-0.1	3.6	8.5	141	206	428	0.0311	0.0679	0.1812
46	1	12	1,053	4.0	9.6	14.9	150	185	582	0.0085	0.0340	0.1614
47	1	13	1,053	2.9	9.1	13.9	141	186	582	0.0085	0.0396	0.1812
48	11	35	160	11.5	12.2	13.2	165	193	384	0.0113	0.0198	0.0453
49												
50	24	73	273	4.8	6.1	7.3	95	111	128	0.0113	0.0198	0.0963
51	6	15	189	2.9	5.0	6.0	99	145	220	0.0113	0.0226	0.0425
52	6	8	12	-0.2	0.4	2.2	99	107	228	0.0142	0.0142	0.0170
53	9	20	66	0.2	2.4	3.9	134	195	274	0.0142	0.0198	0.0283
54	1	25	216	0.4	2.5	4.2	76	113	360	0.0170	0.0283	0.0595
55	1	13	53	-0.2	3.3	8.6	98	152	213	0.0113	0.0226	0.0396
56	1	15	53	-0.2	2.4	7.2	98	147	213	0.0113	0.0198	0.0396
57	3	11	46	1.9	4.8	8.6	137	158	186	0.0198	0.0283	0.0396
58	9	15	50	4.0	5.3	6.2	146	155	181	0.0142	0.0170	0.0226
59	22	47	395	11.8	13.1	14.9	143	178	250	0.0057	0.0085	0.0198
60	1	48	934	6.5	8.4	10.2	93	121	230	--	0.0085	0.0566

Table 3. Average (avg), maximum (max), and minimum (min) values for turbidity, EC, water temperature, and discharge during each event at the Lakeshore site, RW-Blw.

Event	Turbidity (NTU)			Water temp (°C)			EC (μS cm⁻¹)			Discharge (cns)		
Num.	min	avg	max	min	avg	max	min	avg	max	min	avg	max
1												
2												
3												
4												
5	Station not in place											
6												
7												
8												
9	2	6	164	0	0	3	140	173	375	0.0057	0.0057	0.0057
10	13	95	579	0	2	3	145	166	292	0.0057	0.0255	0.1585
11	6	13	18	0	0	1	147	153	171	0.0085	0.0113	0.0142
12	2	13	89	1	5	15	--	235	303	0.0085	0.0425	0.1699
13	2	15	68	1	3	6	197	228	280	0.0085	0.0198	0.0368
14	10	23	61	2	4	8	216	239	278	0.0453	0.0736	0.1132
15	3	10	89	1	6	15	--	235	303	0.0170	0.0368	0.1047
16	1	10	76	1	7	17	--	232	303	0.0113	0.0283	0.1019
17	1	12	89	0	6	17	--	226	303	0.0085	0.0311	0.1699
18	11	26	80	6	8	14	187	199	246	0.0113	0.0142	0.0595
19	12	25	47	8	8	11	192	195	209	0.0113	0.0142	0.0226
20	4	14	268	6	7	8	165	172	178	0.0085	0.0113	0.0170
21	2	39	234	2	5	12	108	138	232	0.0057	0.0057	0.0113
22	3	38	588	0	4	8	108	142	256	0.0057	0.0113	0.0538
23	3	11	195	3	5	7	154	204	353	0.0085	0.0085	0.0283
24	19	35	175	0	2	2	172	211	304	0.0085	0.0113	0.0283
25	1	19	846	0	5	18	--	242	654	--	0.0368	0.1472
26	11	34	91	0	2	5	--	227	654	0.0113	0.0170	0.0283
27	5	16	118	0	3	5	225	250	508	0.0198	0.0255	0.0510
28	4	19	467	1	3	8	--	229	278	0.0226	0.0425	0.0934
29	4	15	846	0	3	10	109	242	388	--	0.0453	0.0963
30	5	16	179	2	6	14	--	235	312	0.0340	0.0510	0.1019
31	1	17	151	3	10	18	--	264	358	0.0113	0.0255	0.1472
32	1	17	1,045	0	6	18	--	245	388	--	0.0425	0.1472
33	19	44	151	6	8	15	211	236	295	0.0113	0.0198	0.0453
34	5	20	104	7	10	15	238	260	312	0.0113	0.0283	0.1472
35	13	26	74	6	8	11	216	235	266	0.0255	0.0453	0.0963
36	10	87	457	7	9	12	137	160	268	0.0057	0.0142	0.0538
37	7	37	188	5	6	8	122	152	213	0.0113	0.0170	0.0595
38	11	75	352	8	8	11	134	152	179	0.0113	0.0481	0.1727
39	3	120	1,048	1	2	3	80	165	278	0.0226	0.1076	0.3907
40	7	37	283	1	3	5	73	167	223	0.0255	0.1019	0.3935
41	6	16	64	1	2	3	147	206	386	0.0311	0.0906	0.2774
42	6	24	207	0	2	4	66	216	531	0.0453	0.1217	0.5351
43	17	60	244	0	2	3	117	172	396	0.0311	0.1189	0.2576
44	2	15	655	0	7	17	--	180	673	--	0.0595	0.1727
45	8	22	470	0	4	12	--	234	443	0.0368	0.0906	0.1727
46	2	11	655	3	11	22	--	101	561	--	0.0340	0.1699
47	2	13	655	3	10	20	--	97	561	--	0.0396	0.1727
48	7	33	126	12	13	14	200	226	394	0.0085	0.0198	0.0623
49	17	40	177	5	7	10	115	132	215	0.0085	0.0085	0.0198
50	21	58	293	4	6	8	94	116	176	0.0113	0.0142	0.0538
51	3	24	92	3	5	7	104	135	252	0.0113	0.0142	0.0198
52	4	9	33	-1	0	1	80	103	188	0.0113	0.0113	0.0113
53	23	39	89	0	2	4	125	187	282	0.0113	0.0142	0.0198
54	3	33	224	0	2	5	117	156	326	0.0028	0.0170	0.0510
55	6	11	115	0	3	11	128	170	227	0.0113	0.0142	0.0425
56	6	12	115	0	2	9	128	158	212	0.0113	0.0142	0.0396
57	7	10	40	1	5	11	163	190	227	0.0113	0.0198	0.0425
58	11	11	11	4	6	7	158	169	193	0.0113	0.0113	0.0170
59	8	56	436	12	15	20	162	189	272	0.0113	0.0113	0.0142
60	1	26	587	0	7	12	111	131	215	0.0113	0.0113	0.0595

Table 4. Average (avg), maximum (max), and minimum (min) values for turbidity, EC, water temperature, and discharge during each event at the Third Creek site.

Event	Turbidity (NTU)			Water temp (^oC)			EC (µS cm^{-1})			Discharge (cms)		
Num.	min	avg	max	min	avg	max	min	avg	max	min	avg	max
1	2	19	915	-0.2	2.5	5.0	93	124	221	0.0963	0.1274	0.2123
2	5	16	225	-0.2	3.5	11.3	33	97	285	0.0906	0.1670	0.8889
3	5	16	112	-0.2	2.9	9.2	63	97	138	0.0906	0.1246	0.2293
4	5	16	225	0.2	4.1	11.3	33	97	285	0.1132	0.2180	0.8889
5	9	68	225	2.6	4.6	7.8	109	127	245	0.1331	0.1331	0.1416
6	5	25	348	1.0	7.0	14.6	--	47	126	0.1132	0.5634	1.4665
7	3	23	99	14.3	15.5	17.1	92	100	128	0.0566	0.0708	0.1217
8	6	63	1,048	10.4	13.0	15.4	-6	94	265	0.0453	0.0623	0.2746
9	2	4	9	-0.5	0.5	2.5	43	64	84	0.0651	0.1784	2.3780
10	4	12	42	0.4	1.7	2.6	66	73	91	0.0708	0.1047	0.1529
11	3	4	27	-0.5	-0.2	-0.1	53	68	73	0.0793	0.1614	0.3397
12	4	8	229	0.2	3.3	8.1	43	69	100	0.0878	0.3454	0.5379
13	4	6	10	1.4	2.6	5.5	73	78	86	0.0878	0.1274	0.2293
14	4	7	25	1.7	3.6	6.5	78	85	97	0.2293	0.3114	0.3680
15	4	8	229	0.2	3.3	8.1	43	63	87	0.2293	0.3822	0.5379
16	4	10	229	0.2	3.5	8.9	27	54	87	0.2293	0.5067	1.2456
17	4	9	229	-0.2	3.7	11.4	27	59	100	0.0736	0.4501	1.2456
18	4	5	7	3.9	5.3	8.1	42	43	48	0.5096	0.5804	0.6681
19	13	13	14	6.1	6.2	6.7	42	42	43	0.6228	0.6398	0.6794
20	--	--	--	5.0	5.9	6.9	44	45	47	0.4247	0.4445	0.4530
21	2	3	8	2.8	4.2	6.7	61	66	75	0.0311	0.0340	0.0425
22	1	6	25	-0.1	3.6	7.8	58	70	105	0.0368	0.0481	0.0878
23	1	3	8	2.8	3.9	5.5	65	69	95	0.0736	0.0793	0.0963
24	3	4	5	-0.1	1.7	2.5	0	0	0	0.0736	0.0821	0.2633
25	1	6	175	-0.2	3.2	15.7	--	60	135	0.0651	0.3341	2.7064
26	3	6	17	-0.1	1.9	3.8	0	27	92	0.0651	0.0764	0.0849
27	3	4	10	-0.2	2.1	4.3	78	85	135	0.0651	0.0821	0.0934
28	4	5	16	0.0	2.8	6.3	73	83	96	0.0764	0.1189	0.1755
29	4	6	160	-0.2	2.4	8.3	65	87	128	0.0878	0.1302	0.2378
30	4	8	175	1.1	4.1	9.5	32	69	95	0.1274	0.2406	0.9625
31	1	6	86	0.9	4.6	15.7	--	31	46	0.5379	0.9739	2.7064
32	1	6	293	-0.2	5.9	--	--	60	128	0.0764	0.4162	2.7064
33	4	15	65	2.8	4.5	7.7	34	35	39	0.6511	0.7559	0.8663
34	3	16	63	3.8	5.4	7.4	32	35	39	0.6794	0.8097	0.9625
35	8	10	14	3.4	4.7	6.9	36	36	38	0.8210	0.9257	1.0192
36	9	14	17	7.4	8.4	9.3	72	77	91	0.0510	0.0595	0.0708
37	44	44	44	7.1	7.1	7.1	70	72	77	0.0566	0.0623	0.0708

Table 5. Average monthly and yearly discharge for all sites during the period of observation.

Site	Month	Average Discharge (cms)				
		2003	2004	2005	2006	2007
RW-Abv: Above Rosewood Creek Restoration (State Rte. 28)	1	0.0226	0.0057	0.0085	0.0821	0.0142
	2	0.0198	0.0142	0.0113	0.0396	0.0198
	3	0.0198	0.0481	0.0255	0.0311	0.0226
	4	0.0255	0.0283	0.0396	0.0708	0.0170
	5	0.0198	0.0142	0.0311	0.0566	0.0142
	6	0.0057	0.0085	0.0142	0.0170	0.0085
	7	0.0057	0.0057	0.0057	0.0085	0.0085
	8	0.0085	0.0057	--	0.0085	0.0085
	9	0.0085	0.0057	0.0085	0.0085	0.0085
	10	0.0057	0.0057	0.0142	0.0113	--
	11	0.0057	0.0057	0.0113	0.0142	--
	12	0.0057	0.0057	0.0510	0.0142	--
	Annual	0.0113	0.0142	0.0226	0.0311	--
RW-Blw: Below Rosewood Creek Restoration (Lakeshore)	1	--	0.0057	0.0085	0.0481	--
	2	--	0.0085	0.0170	0.0396	0.0113
	3	--	0.0481	0.0396	0.0368	0.0170
	4	--	0.0255	0.0538	0.0906	0.0142
	5	--	0.0142	0.0425	0.0595	0.0113
	6	--	0.0085	0.0255	0.0170	0.0113
	7	--	0.0057	--	0.0057	0.0113
	8	--	0.0057	0.0057	0.0057	0.0113
	9	--	0.0057	0.0057	0.0057	0.0113
	10	0.0057	0.0085	0.0113	0.0057	--
	11	0.0057	0.0085	0.0198	0.0113	--
	12	0.0057	0.0085	0.0623	0.0113	--
	Annual	0.0057	0.0113	0.0283	0.0283	--
Third: Third Creek	1	0.1076	0.1217	0.1727	0.1614	0.1047
	2	0.1132	0.1557	0.0764	0.1784	0.0991
	3	0.1076	0.2746	0.1161	0.1444	0.1246
	4	0.1416	0.3992	0.1472	0.2321	0.1812
	5	0.4416	0.6766	0.6143	1.0871	0.1982
	6	0.5407	0.2463	0.8804	1.7892	0.0679
	7	0.0764	0.0566	0.2859	0.5605	0.0311
	8	0.0481	0.0396	0.0736	0.1387	0.0255
	9	--	0.0340	0.0510	0.1019	0.0255
	10	0.0538	0.0425	0.0595	0.1047	--
	11	0.0679	0.0934	0.0849	0.0651	--
	12	0.1557	0.1019	0.2378	0.1217	--
	Annual	0.1529	0.1840	0.2321	0.3794	--

Suspended sediment concentrations from Third Creek were more highly variable and had a lower mean SSC value than those from either of the Rosewood Creek sites (Figure 7). It must be noted that these SSC statistics do not describe that average value for a given site, as sampling was purposefully biased towards the collection of samples during elevated suspended sediment conditions. The particle size distribution of these suspended sediment samples is shown aggregrated in Figure 8 and on a sample basis in Figure 9 and Table 6. In general, the particle size distribution was consistent at RW-Abv regardless of event type.

Early post-construction variations in the particle size distribution at RW-Blw were attributed to the delivery of coarser, unconsolidated sediment left within the channel. Particle size distribution within Third Creek was a function of storm type, as high-elevation snowmelt events yielded distributions that were different from those during thunderstorms, and will be discussed later.

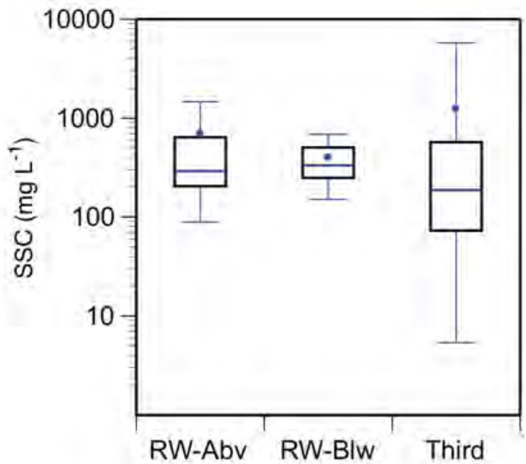

Figure 7. Suspended sediment concentration box plot for the period of record. The top, bottom, and middle line of the box correspond to the 75th, 25th, and 50th percentile (median), respectively. The whiskers extend from the bottom 10th percentile and the top 90th percentile. The filled circle within the box represents the mean for the data range. The number of samples included in this datasets were 141, 124, and 52 for RW-Abv, RW-Blw, and Third, respectively.

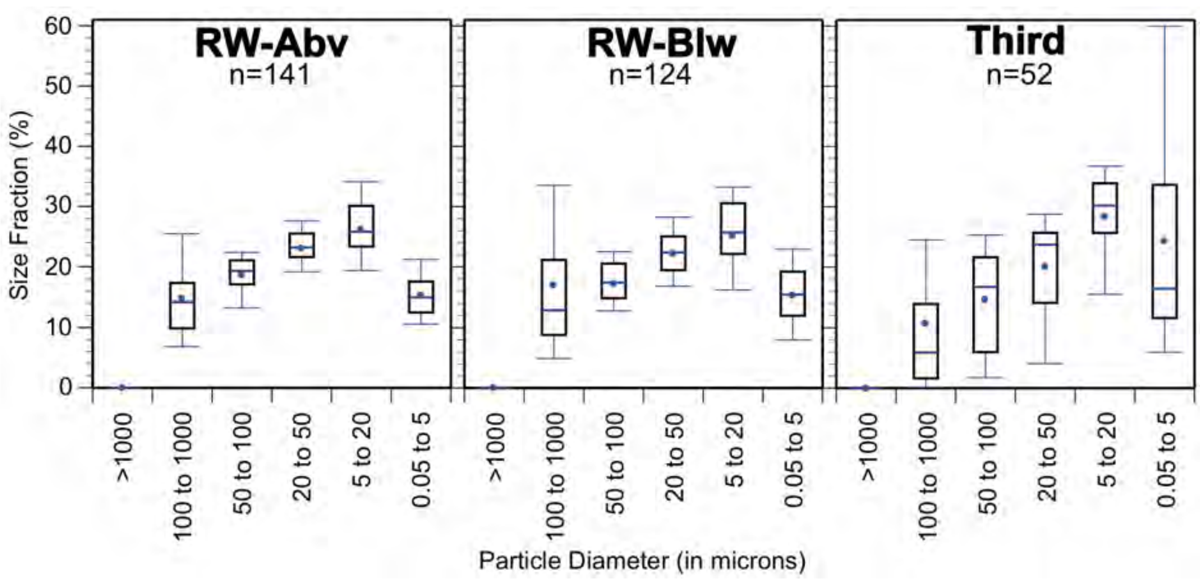

Figure 8. Particle size distribution box plot for all suspended sediment samples by site. See Figure 7 for definition of box plot symbology.

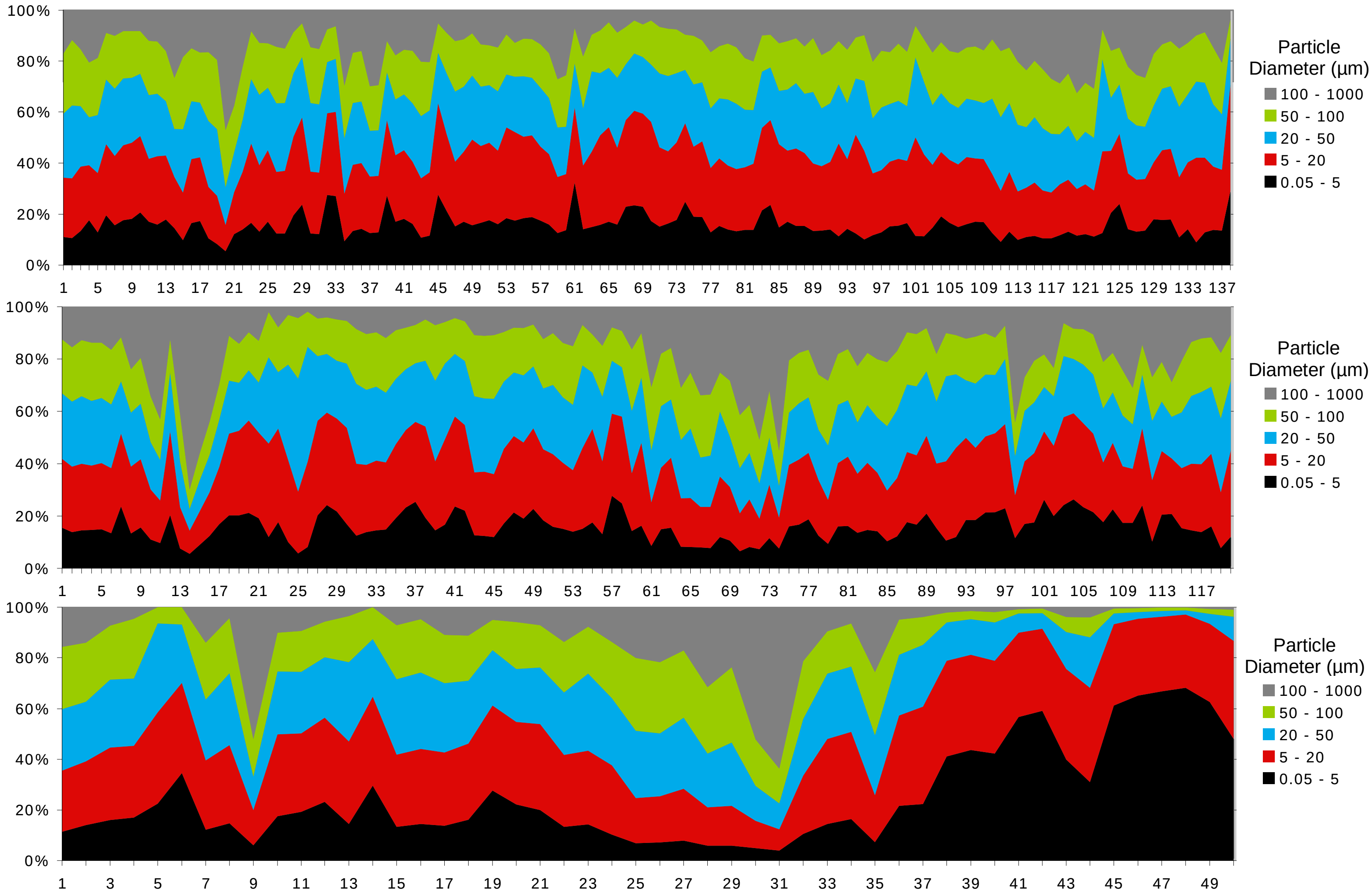

Figure 9. Particle size distribution of suspended sediment samples by site. The x-axis denotes the sample number collected at each site. See Table 6 for event key. Particle size fractionation is denoted by different colors for different size fractions.

Table 6. Sample collection times for samples shown in Figure 9.

Sample	RW-Abv	RW-Blw	Third	Sample	RW-Abv	RW-Blw
1	12/11/02 18:50	12/13/02 16:30	12/13/02 18:10	68	6/9/04 11:00	4/11/05 14:20
2	12/12/02 23:20	12/13/02 17:20	12/13/02 21:40	69	6/9/04 11:00	4/11/05 19:00
3	1/7/03 22:00	12/13/02 19:10	1/3/03 15:50	70	1/25/05 11:20	4/12/05 15:50
4	1/10/03 12:50	12/13/02 21:40	1/3/03 16:40	71	1/25/05 12:20	4/12/05 20:40
5	1/13/03 15:10	12/13/02 22:30	1/4/03 11:20	72	1/25/05 13:10	4/16/05 14:30
6	1/22/03 15:30	12/14/02 0:30	1/4/03 12:20	73	1/25/05 15:00	4/16/05 15:50
7	1/22/03 18:40	12/24/03 9:50	1/8/03 19:30	74	2/28/05 11:30	4/16/05 22:20
8	1/22/03 19:00	3/7/04 14:10	1/8/03 19:50	75	2/28/05 13:30	4/27/05 5:20
9	1/22/03 19:20	3/7/04 15:10	1/12/03 4:20	76	2/28/05 16:10	4/27/05 6:50
10	1/22/03 19:50	3/7/04 17:20	1/22/03 19:00	77	3/8/05 13:00	4/27/05 7:20
11	1/23/03 1:30	3/8/04 15:00	1/22/03 19:40	78	3/9/05 14:20	4/27/05 9:00
12	3/15/03 7:20	3/9/04 16:05	1/22/03 20:00	79	3/10/05 13:50	4/30/05 20:20
13	3/15/03 13:10	3/13/04 13:30	1/22/03 20:30	80	3/10/05 14:40	4/30/05 20:50
14	3/15/03 14:30	3/13/04 14:30	1/22/03 21:40	81	3/10/05 17:50	4/30/05 22:20
15	3/23/03 0:40	3/13/04 15:00	1/23/03 17:20	82	3/11/05 12:57	5/5/05 9:50
16	3/23/03 2:50	3/14/04 17:10	1/23/03 17:50	83	3/28/05 12:20	5/5/05 10:30
17	3/23/03 3:10	3/15/04 15:30	1/23/03 18:30	84	3/28/05 14:50	5/5/05 12:20
18	4/27/03 13:00	3/16/04 15:30	1/23/03 19:20	85	3/31/05 12:50	10/15/05 11:00
19	4/28/03 13:30	3/21/04 2:10	3/15/03 11:00	86	4/1/05 14:10	10/15/05 11:20
20	5/3/03 9:20	3/21/04 2:40	3/15/03 14:30	87	4/1/05 17:10	12/1/05 6:20
21	5/3/03 10:30	3/21/04 3:40	3/15/03 15:40	88	4/2/05 13:40	12/1/05 7:50
22	5/3/03 11:10	5/27/04 7:50	4/27/03 11:00	89	4/2/05 17:10	12/1/05 10:40
23	6/23/03 13:10	5/27/04 8:40	4/27/03 12:00	90	4/6/05 16:50	12/1/05 19:30
24	6/23/03 15:00	5/27/04 12:20	5/13/03 13:10	91	4/6/05 18:40	12/21/05 2:30
25	6/23/03 17:10	5/27/04 18:40	5/13/03 19:30	92	4/11/05 12:30	12/21/05 2:50
26	7/22/03 17:40	5/27/04 18:40	5/14/03 2:10	93	4/11/05 14:50	12/21/05 16:40
27	7/22/03 17:40	6/9/04 9:40	5/14/03 18:50	94	4/12/05 13:20	12/21/05 17:30
28	7/22/03 18:30	6/9/04 10:10	5/21/03 6:20	95	4/12/05 21:40	12/21/05 18:00
29	7/22/03 19:10	6/9/04 11:40	5/21/03 18:00	96	4/16/05 14:30	12/21/05 18:30
30	7/23/03 17:10	10/19/04 11:30	5/29/03 20:10	97	4/16/05 15:40	12/21/05 18:50
31	7/23/03 17:10	10/19/04 12:00	5/30/03 18:00	98	4/16/05 18:50	12/28/05 12:30
32	7/23/03 17:50	10/19/04 14:10	6/26/03 13:10	99	4/17/05 14:00	12/28/05 13:20
33	7/23/03 18:20	10/19/04 17:20	6/26/03 13:30	100	4/17/05 18:30	12/28/05 18:50
34	8/21/03 13:10	10/19/04 20:10	6/26/03 13:50	101	4/30/05 10:20	12/30/05 12:00
35	8/21/03 13:50	11/10/04 19:20	7/22/03 19:20	102	4/30/05 11:55	12/30/05 17:10
36	8/21/03 13:50	11/10/04 19:40	7/22/03 19:50	103	4/30/05 20:10	12/31/05 1:50
37	8/21/03 15:20	11/10/04 19:50	7/22/03 20:50	104	4/30/05 21:00	12/31/05 5:40
38	8/21/03 15:20	1/25/05 11:50	8/21/03 17:50	105	4/30/05 22:10	12/31/05 8:00
39	8/21/03 16:20	1/25/05 13:20	8/21/03 18:20	106	5/5/05 10:00	12/31/05 17:30
40	8/21/03 16:50	1/25/05 13:50	8/21/03 18:50	107	5/8/05 13:10	2/27/06 8:20
41	8/21/03 16:50	1/25/05 14:10	8/21/03 19:10	108	5/8/05 13:40	2/27/06 8:40
42	8/21/03 17:30	1/25/05 15:30	8/21/03 19:10	109	5/8/05 14:10	2/27/06 10:30
43	8/21/03 19:40	2/10/05 17:50	8/21/03 20:50	110	9/27/05 1:40	2/27/06 14:00
44	8/21/03 19:40	2/12/05 15:00	8/21/03 20:50	111	12/1/05 5:00	2/27/06 15:00
45	12/24/03 8:50	2/16/05 12:50	8/21/03 23:30	112	12/1/05 7:30	4/3/06 1:50
46	2/16/04 12:00	2/26/05 15:50	8/22/03 0:00	113	12/1/05 9:30	4/3/06 2:40
47	2/16/04 13:30	2/28/05 13:30	8/22/03 0:30	114	12/1/05 18:50	4/3/06 6:20
48	2/16/04 17:40	2/28/05 14:40	8/22/03 0:30	115	12/21/05 17:40	4/27/06 16:10
49	3/7/04 12:40	2/28/05 14:50	8/22/03 1:00	116	12/21/05 18:50	2/9/07 11:45
50	3/7/04 14:20	3/10/05 14:20	8/22/03 2:00	117	12/21/05 19:50	2/10/07 11:50
51	3/7/04 17:10	3/10/05 15:20	--	118	12/22/05 6:20	2/10/07 13:00
52	3/8/04 14:00	3/10/05 17:30	--	119	12/30/05 15:10	3/13/07 16:20
53	3/10/04 12:20	3/10/05 20:30	--	120	12/30/05 16:20	3/13/07 20:00
54	3/10/04 12:40	3/11/05 10:33	--	121	12/30/05 22:50	--
55	3/10/04 13:10	3/19/05 15:30	--	122	12/31/05 1:40	--
56	3/13/04 13:10	3/19/05 16:30	--	123	4/3/06 1:00	--
57	3/13/04 13:30	3/19/05 17:40	--	124	4/3/06 2:10	--
58	3/13/04 13:50	3/20/05 17:10	--	125	4/3/06 3:10	--
59	3/16/04 15:30	3/20/05 17:20	--	126	4/25/06 17:00	--
60	3/16/04 15:30	3/20/05 18:30	--	127	4/25/06 19:00	--
61	3/16/04 15:30	3/31/05 14:10	--	128	4/25/06 19:20	--
62	3/24/04 18:30	4/1/05 14:50	--	129	4/25/06 19:40	--
63	5/27/04 10:00	4/1/05 15:10	--	130	2/9/07 13:35	--
64	5/27/04 12:20	4/6/05 15:20	--	131	2/9/07 13:40	--
65	5/27/04 18:40	4/6/05 23:00	--	132	2/10/07 11:10	--
66	6/9/04 9:10	4/10/05 13:50	--	133	2/10/07 11:50	--
67	6/9/04 9:50	4/10/05 15:50	--	134	3/13/07 15:50	--
				135	8/31/07 13:15	--

ROSEWOOD AND THIRD CREEKS: PRE-PROJECT MONITORING

The importance of the suspended sediment contribution from Rosewood Creek to Third Creek differed during the year, dependent on the differences of the spatial distribution and elevations of the two watersheds. The Rosewood Creek watershed is a low-elevation, urbanized watershed that responds rapidly to low-elevation/lake level snowmelt and storm events. Forty-five percent of the 2.3 km^2 watershed lies below Highway 431 (at an elevation of 2,182 m). In comparison, the Third Creek watershed is larger, with a higher mean elevation, and responds primarily to hydrologic events that occur at higher elevations. Only 10 percent of 13.3 km^2 watershed lies below Highway 431. Therefore, hydrologic events that target low-elevation areas will impact Rosewood Creek, whereas only high-elevation events will impact Third Creek.

The objective of pre-project monitoring was to establish background data for Rosewood Creek prior to construction, and to estimate the contribution of flow and sediment from Rosewood Creek into Third Creek. Prior to construction, the RW-Abv site was located just upstream of Rosewood's confluence with Third Creek, just south of State Route 28. The Third Creek site (Third) was 900 m downstream of this confluence.

There were four primary events during pre-project monitoring, including two snowmelt (Events 2 and 6 in Table 1) and two rain events (Events 7 and 8). The two snowmelt events were partially overlapping periods dominated by low-elevation (Event 2) or high-elevation (Event 3) snowmelt. The 68,755 kg of suspended sediment delivered by Rosewood Creek during low elevation snowmelt comprised 47 percent of that delivered by the Third Creek watershed during snowmelt. The difference in water loads was more disparate – total water loads for Third Creek were 14.8 times greater than the 159 x 10^6 L of water from delivered by Rosewood Creek. This resulted in higher average snowmelt SSC (432 mg L^{-1}) and sediment loadings (893 kg day^{-1}) for Rosewood Creek (Event 2) compared to Third Creek (63 mg L^{-1} and 2,872 kg day^{-1}, respectively) (Event 6).

Construction of the restoration project was completed in early July 2003. Water was released into the new channel at the diversion on July 7, but water flow was not detected at the bottom end of the new channel until a minor rainstorm on July 22. After the event, the leading edge of the wetting front retreated upstream until the intense thunderstorms of August 21 resulted in sustained water discharge throughout the channel length. Once water was diverted into Rosewood Creek, the existing monitoring site on Third Creek no longer reflected water and sediment inputs from Rosewood Creek, as the new confluence of these streams was just downstream of the Third monitoring site.

Rain events 7 and 8 occurred during the summer of 2003, as the restoration project was being completed and as the monitoring site at the lower end of the restoration (RW-Blw) was being installed. Therefore, although some water actually traveled down the restored creek, the discussion below only compares the RW-Abv and Third Creek, to be consistent with the previous discussion of snowmelt. Event 7 was the smaller of the two thunderstorms, yielding nearly 2.3 centimeters of rain on July 22 and 23, 2003 (as measured below Tyrol Village, online at http://www.inclinecreek.dri.edu). Of the total 1,139 kg of suspended sediment entering the lake, 41 percent was delivered from the Rosewood Creek watershed with the remaining from within the Third Creek watershed. Suspended sediment delivery by Rosewood Creek was flashy, characterized by a high peak loading (165 kg $hour^{-1}$, 662 NTU) and the quick return to near baseline levels. In contrast, Third Creek was characterized by much lower peak loadings (71 kg $hour^{-1}$, 81 NTU), but suspended solids levels within the creek remained elevated above background levels for over 20 hours after the event.

The largest summer thunderstorms during the period of record occurred on August 21, 2003 (Event 8). This event had two large downpours, one in the morning (5:40 to 8:50) and one in the evening (15:10 to 17:00) that produced 0.79 cm and 0.89 cm of precipitation, respectively. The maximum rainfall intensity observed was 0.41 cm in 10 minutes during the evening storm, a factor of three times greater than during the morning storm. This rainfall intensity coupled with the wet antecedent conditions from the earlier storms resulted in significantly higher discharges and greater sediment loads. Overall, the total suspended sediment delivered by Rosewood Creek (13,003 kg) was approximately half that delivered by Third Creek (22,364 kg). However, Third Creek also experienced an additional pulse of suspended sediment that peaked about midnight on August 22. This sediment pulse delivered an additional 6,469 kg of suspended sediment that originated from above Highway 431, as the sediment pulse was also observed by in-stream turbidity meters located just below the highway at the Incline Village Mountain Golf Course.

The particle size distributions of suspended sediment at RW-Abv and Third during this event were dissimilar. Suspended sediment less than 20 μm in diameter comprised nearly 80 percent of the samples collected at Third, but comprised only about 35 percent of the samples collected at RW-Abv (Figure 10). The particle size distribution of RW-Abv samples was slightly finer near peak suspended sediment loading and was consistent with the particle size distribution observed in other events (Figure 9). In contrast, the particle size distribution of suspended sediment at Third Creek was much finer in composition than samples collected at other times during the year. Visual assessment after the event suggested that slope failures from the steep slopes of the Mountain Golf Course and from erosion of the turfless Championship Golf Course that was under renovation contributed to Third Creek suspended sediment loads.

The particle size of suspended sediment from the overnight turbidity pulse in Third Creek had a slightly finer distribution than samples collected during the evening event. The finer particle size was consistent with the finer soil textures found in the volcanic-derived soils of the upper Third Creek watershed. This overnight suspended sediment pulse was not associated with an obvious inflow of water to the creek, such as in conjunction with a thunderstorm or release of water from Incline Lake, as the hydrograph did not significantly change. In total, this event delivered significantly more fine sediment (< 20 μm) to the lake than that from Rosewood Creek (Figure 11).

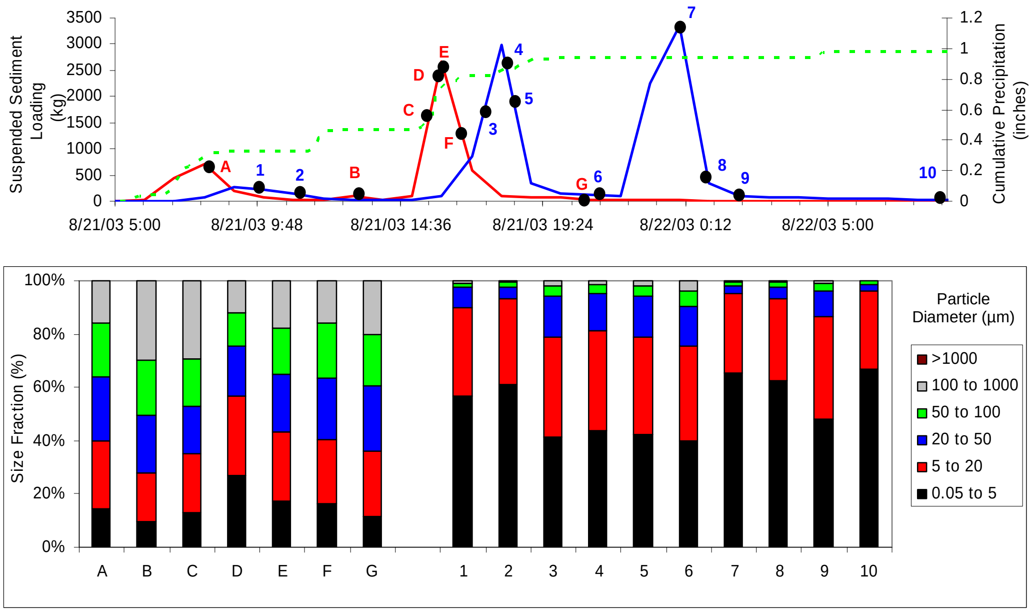

Figure 10. Particle size distribution for water samples collected at RW-Abv and Third during the August 21, 2003, thunderstorms. The top graph shows the suspended sediment loading at RW-Abv (red line) and Third (blue line), and the cumulative precipitation measured below Tyrol Village (dotted green line). The particle size distribution of samples collected at RW-Abv (A-G) and Third (1-10) are shown in the lower graph.

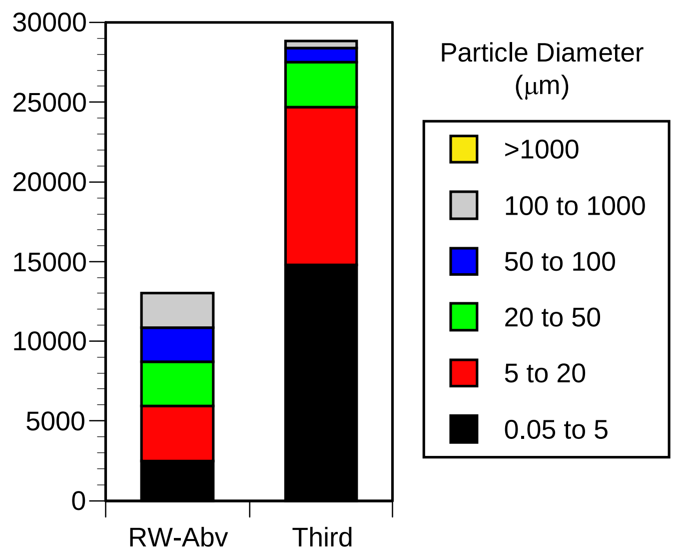

Figure 11. Total suspended sediment loading, by particle size during the August 21, 2003 thunderstorms (Event 8).

TURBIDITY SURROGATE RELATIONSHIPS

Development of Surrogate Relationships

The estimation of suspended sediment loading within a stream requires the continuous monitoring of suspended sediment or some parameter related to suspended sediment. The continuous monitoring of SSC is impractical because discrete water samples must be collected for each SSC measurement. A more reasonable approach is to continuously monitor a surrogate, a parameter that is closely related to SSC (Leopold and Maddock, 1953). Historically, water discharge was used as a surrogate for continuous SSC estimates, as increased sediment loadings are generally correlated with increased water discharge. However, discharge-based estimates for SSC loadings have been found to generally underestimate actual suspended sediment loads, especially in rivers that exhibit strong hysteresis between sediment load and discharge. Despite some challenges, turbidity has recently become the parameter of choice as a SSC surrogate (Gippel, 1995; Lewis, 1996).

Turbidity is a specific class of light 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 can be comprised of particles having many different shapes and sizes, particles of both organic and inorganic composition, and be composed of compounds that may absorb light. A wide variety of techniques may be utilized by sensor manufacturers to measure turbidity, with each approach having a different sensitivity to the aforementioned factors. This can result in two properly calibrated sensors reporting different turbidity values for the same natural water sample. An in-depth discussion of turbidity and other measurements of optical properties of water relevant to Lake Tahoe can be found in Taylor *et al*. (2004).

Despite the limitations described above, turbidity is an extremely useful and easily measured surrogate for SSC. A relationship between SSC and the turbidity surrogate must be derived for each site because of differences in water and sediment composition, differences in how the sensors are installed at each site, and intra- and intersensor differences from manufacturing and sensor approach. For this project, turbidity was measured using an OBS-3 turbidity sensor through September 2007.

To predict SSC from turbidity, water samples analyzed for SSC were collected using a vacuum-assisted autosampler and compared against in-stream turbidity (Figure 12). A series of regression models were created between discrete SSC samples and turbidity that were then used to estimate continuous SSC concentration based on continuous turbidity readings.

The regression models correlating turbidity and SSC took the linear form:

$$SSC = b \times Turbidity + c$$

where b was the slope coefficient and c was the intercept. Regression models for the Rosewood sites are presented in Table 7. The original objective was to develop a single site-specific regression model by aggregating all the samples collected at a given site. To support this, the sampling scheme was tuned to the collection of fewer elevated turbidity samples per event, relying on the aggregated population built over time. The correlation coefficient (R^2) of the regression models using this approach was 0.70 at RW-Abv (regression 1A, Table 7), but was less than 0.15 at RW-Blw (regression 2B). The low predictive ability of the model at RW-Blw was caused by the temporal changes that occurred within the project as the creek and adjacent riparian zone recovered from the disturbance of construction and the planted vegetation matured over time.

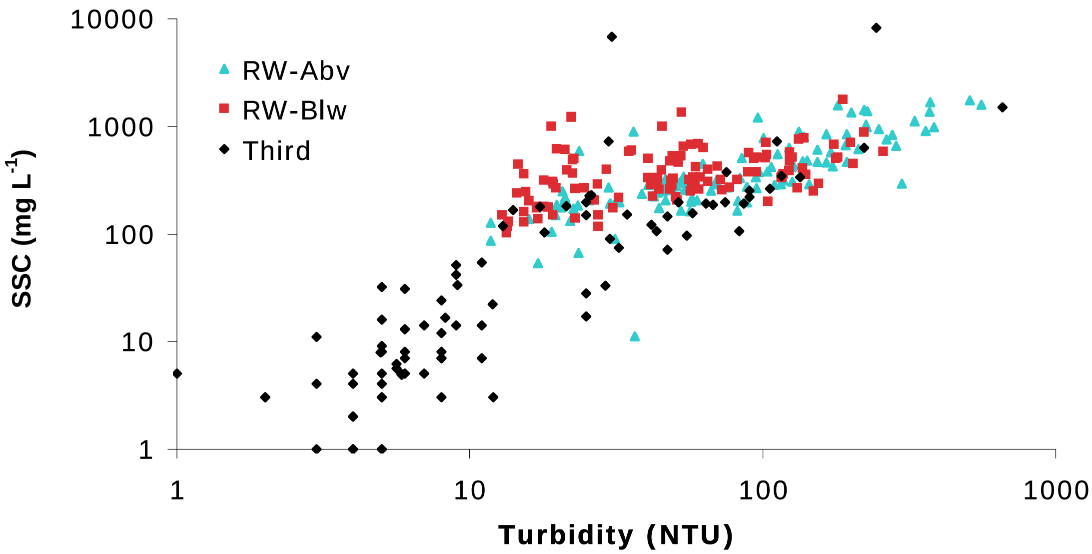

Figure 12. Comparison of SSC from discrete water samples and in-stream turbidity for all sites. See Appendix A for tabular form of this data.

To test this hypothesis, supplementary regressions were also developed by splitting the post-restoration time-period in half (regressions 3 to 5 in Table 7). This improved the correlation coefficient for RW-Blw to 0.37 for WYs 2005 to 2007 (regression 5B), but did not improve WYs 2003 to 2005. This supported the hypothesis and indicated that suspended sediment delivery at RW-Blw immediately after construction was significantly altered and not as predictable as at the RW-Abv site that was not impacted by construction (regression 3A).

For greater temporal resolution, regression models were also constructed on a yearly basis for both sites (regressions 6 to 10). For RW-Abv, this produced models with correlation coefficients from 0.63 to 0.90. For RW-Blw, WY 2003 to 2004 had a higher correlation coefficient, WY 2004 to 2005 remained poor, and WYs 2005 to 2007 correlation coefficients remained unchanged. Further investigation revealed that dividing the season into rising limb of the snowmelt season (regression 11B derived from samples collected during Event 27) from the remainder of the water year (regression 13B) produced models with somewhat better correlation coefficients. The regression model specific to the intervening period (regression 12B) did not improve, however.

Table 7. Turbidity regression equations for RW-Abv and RW-Blw. See text for definition of regression equations.

Period		Reg	Site A: Above Restoration (Hwy 28)					Reg	Site B: Below Restoration (Lakeshore)				
Start	End	No.	b	c	adj. R^2	p-value	n	No.	b	c	adj. R^2	p-value	n
All Data													
11/1/2002	10/1/2007	**1A**	3.6442	93.1775	0.70	<0.0001	121						
10/1/2003	10/1/2007							**2B**	1.9141	283.0743	0.15	0.00001	114
Two-year Periods													
11/1/2002	10/1/2005	**3A**	6.7883	-228.1861	0.76	<0.0001	98						
10/1/2003	10/1/2005							**4B**	0.922	343.568	0.01	0.2100	77
10/1/2005	10/1/2007	**5A**	5.090	-2.038	0.68	<0.0001	26	**5B**	2.85	166.201	0.37	<0.0001	37
Yearly Periods													
10/1/2002	10/1/2003	**6A**	3.2052	187.2073	0.64	<0.0001	30	**6B**					
10/1/2003	10/1/2004	**7A**	2.0892	116.1005	0.89	<0.0001	25	**7B**	8.9900	36.1080	0.25	0.0097	22
10/1/2004	10/1/2005	**8A**	2.1983	144.6535	0.67	<0.0001	40	**8B**	0.1633	393.6575	-0.02	0.8074	55
10/1/2005	10/1/2006	**9A**	4.6930	132.2040	0.63	<0.0001	20	**9B**	2.9960	164.3828	0.37	0.0001	32
10/1/2006	10/1/2007	**10A**	2.4277	44.7954	0.90	0.00263	6	**10B**	1.6578	191.3764	0.37	0.1630	5
Multiple Event Based Periods													
2/25/2005	3/19/2005							**11B**	2.3386	197.6306	0.39	0.0424	9
3/19/2005	4/21/2005							**12B**	2.082	316.597	<0.01	0.4127	18
4/21/2005	10/1/2005							**13B**	2.002	266.648	0.15	0.1422	10
Event Based													
3/21/2004	5/28/2004	**14A**	10.331	-21.869	0.15	0.3400	4	**14B**	10.029	-14.082	0.42	0.0700	7
6/9/2004	6/9/2004	**15A**	1.115	143.107	0.33	0.3940	3	**15B**	3.341	81.548	1.00	0.0040	3
10/19/2004	10/21/2004							**16B**	3.4	133.776	0.07	0.3401	5
1/25/2005	1/29/2005	**17A**	0.359	247.642	<0.01	0.8350	4	**17B**	0.629	220.699	<0.01	0.4530	5
1/1/2005	6/1/2005	**18A**	2.015	155.125	0.45	<0.0001	39	**18B**	-4.423	901.33	0.00	0.6460	47
2/3/2005	2/25/2005							**19B**	0.913	552.96	<0.01	0.9129	3
2/3/2005	6/18/2005	**20A**	2.575	129.274	0.61	<0.0001	35	**20B**	0.205	414.793	<0.01	0.8570	42
2/25/2005	3/5/2005	**21A**	1.9906	176.7232	0.93	0.1211	3	**21B**	1.443	226.926	0.42	0.2183	4
3/5/2005	3/19/2005	**22A**	1.448	225.214	0.03	0.3400	6	**22B**	2.586	210.25	0.41	0.1480	5
3/19/2005	4/21/2005	**23A**	3.204	106.725	0.52	0.0005	18	**23B**	0.3479	436.0957	<0.01	0.9371	20
4/21/2005	5/18/2005	**24A**	3.309	37.279	0.90	<0.0001	8	**24B**	2.002	266.648	0.16	0.1420	10
11/30/2005	12/3/2005	**25A**	9.715	-913.274	0.77	0.0800	4	**25B**	5.163	-255.536	1.00	0.0010	4
12/20/2005	12/25/2005	**26A**	-0.206	1345.3	<0.01	0.9650	4	**26B**	2.302	103.805	0.88	0.0010	7
12/27/2005	12/30/2005							**27B**	1.999	185.511	0.52	0.0002	20
12/30/2005	1/8/2006	**28A**	4.999	354.351	0.71	0.1030	4	**28B**	1.007	276.511	0.06	0.3200	6
4/2/2006	4/28/2006	**29A**	1.491	575.189	<0.01	0.4540	7	**29B**	3.733	145.642	0.59	0.3000	3
1/1/2007	10/1/2007	**30A**	2.428	44.795	0.90	0.0030	6	**30B**	1.658	191.376	0.37	0.1630	4

Suspended sediment loadings reported below and in Table 8 were based on the yearly regression models (regressions 6 through 10) with the exception that the last half of WY 2004 to 2005 at RW-Blw were based on regressions 11B to 13B, discussed above. For comparison, Table 7 also provides event-specific models (regressions 14 to 30). In many cases, particularly at RW-Blw, event-based regressions yielded models with higher correlation coefficients, but not in all cases. Event-based regressions were not used for two reasons. First, the sampling of suspended sediment was not optimized for event-based sampling to reduce the cost of analysis. Furthermore, the data collected indicate that this approach was not suitable for small creeks like Rosewood, whose sediment sources appeared to be variable and highly responsive to urban runoff. Aggregate models, i.e.—inclusive of the entire sampling period, failed to capture the change in relationship between turbidity and SSC over time and were also potentially influenced by how the turbidity sensors themselves perceived temporal changes in water composition and particle sediment size and shape. Another confounding factor for the aggregated regression models was the change in water quality entering the restoration project, a result of the decreased number and extent of short-term, elevated turbidity events after WY 2002 to 2003. The most likely explanation for this trend was the construction of treatment projects higher in the watershed that affected the volume, timing, and sediment loads delivered by urban runoff to the creek. Two examples that directly impacted Rosewood Creek were the installation of curbs, gutters, and a detention basin near Harold Drive and the installation of curbs, gutters, and treatment vaults installed along State Route 28. As a result, the current sampling scheme is now optimized to collect additional samples for any given event to facilitate the estimation of loads on an event basis.

Each of the regression models employed for loading calculations is presented in Figure 13. For RW-Abv, equation 9A had the steepest slope, which was heavily influenced by three large rain-on-snow events (Events 40, 41, and 42) and the largest snowmelt season (Event 44) observed. The larger water volumes and water velocities associated with these events contributed to an increased delivery of suspended sediment, potentially, from sources that may not have been active during lower flows. The contribution of these variable source areas under higher flows can result in substantial changes in water chemistry and suspended sediment composition that affect the turbidity/SSC surrogate relationship. For example, Events 40 and 41 appeared to have different source areas. Relative to Event 40, the average water temperature was 0.6 ^{o}C colder and average EC was 97 µS cm^{-1} greater (Table 2) than during Event 41, suggesting water may have sourced from a slightly higher and more urbanized location in the watershed. For RW-Blw, the regressions appear to be approaching equilibrium over time as the slope of the regression model decreases over time. During the first post-construction year (equation 7B), the slope was very steep indicating a much greater concentration of suspended sediment per unit of turbidity relative to subsequent years. Equation 8B, derived during WY 2004 to 2005, does not fit this trend, as the variability in suspended sediment transport during this time was not readily predictable (*p*-value of 0.8074). The 2005 snowmelt season had an unusually large low-elevation snow pack that resulted in moderate discharge that was sustained throughout the snowmelt season (Figure 14). The underlying causes for the poor relationship between turbidity and SSC were unclear, but may be caused by the interplay between sustained water discharges and the instability of sediment sources within the restoration.

Table 8. Suspended sediment and water loadings by event. RW-Abv is above the diversion, whereas RW-Bdiv is below the diversion. Discharge at RW-Bdiv was estimated (see methods) prior to Event 47 and measured directly after Event 47. See Appendix B for a discussion of the 95% prediction intervals associated with this data.

Event Numbe	Event Type	Event Start	Event End	Linear	Total Suspended Sediment Load (kg event^{-1})				Water Load (10^6 L event^{-1})			
				RW-Abv	RW-Abv	RW-Bdiv	RW-Blw	Third	RW-Abv	RW-Bdiv	RW-Blw	Third
1	SM	1/22/2003	2/5/2003	11,090	18,040	--	--	13,115	41.0	--	--	3,325.0
2	SM	3/8/2003	5/24/2003	38,186	68,755	--	--	51,817	158.8	--	--	41,235.0
3	SM	3/8/2003	4/20/2003	23,046	39,443	--	--	17,935	91.0	--	--	14,444.0
4	SM	4/20/2003	5/24/2003	15,140	29,320	--	--	33,882	67.8	--	--	26,791.0
5	ROS	5/3/2003	5/4/2003	541	940	--	--	3,460	2.2	--	--	190.2
6	SM	5/11/2003	7/1/2003	10,395	19,226	--	--	146,472	44.2	--	--	91,714.0
7	Rain	7/22/2003	7/24/2003	351	467	--	--	672	0.9	--	--	338.5
8	Rain	8/21/2003	8/27/2003	6,827	13,003	--	--	28,833	7.8	--	--	23,489.0
9	SM	1/20/2004	2/10/2004	1,554	1,804	1,554	979	1,471	10.9	10.9	10.7	239.4
10	ROS	2/16/2004	2/18/2004	2,610	2,711	2,276	6,464	529	7.0	6.5	4.4	184.3
11	ROS	2/26/2004	2/28/2004	524	616	524	362	222	3.7	3.7	2.3	293.1
12	SM	3/5/2004	4/27/2004	31,865	34,758	29,542	39,807	17,842	194.3	181.7	194.1	8,165.0
13	SM	3/5/2004	3/9/2004	1,385	1,490	1,375	1,307	382	8.1	8.1	6.6	141.8
14	SM	3/13/2004	3/18/2004	5,023	5,223	4,463	8,102	1,502	27.2	24.3	31.3	739.5
15	SM	3/21/2004	4/27/2004	18,988	21,350	17,905	17,875	14,898	124.2	117.8	114.2	6,064.0
16	SM	3/21/2004	5/20/2004	22,502	25,581	21,523	20,394	51,890	150.9	144.9	139.7	22,689.0
17	SM	3/2/2004	5/29/2004	38,399	21,675	36,038	28,160	60,984	118.1	226.4	123.0	26,642.0
18	Rain	5/21/2004	5/22/2004	348	371	337	295	229	1.1	1.1	0.8	83.6
19	Rain	5/28/2004	5/28/2004	56	60	56	72	200	0.3	0.3	0.3	40.8
20	Rain	6/9/2004	6/9/2004	134	141	134	113	18	0.7	0.7	0.6	49.6
21	Rain	9/20/2004	9/21/2004	213	237	213	327	9	1.4	1.4	0.7	3.4
22	Rain	10/17/2004	10/21/2004	1,050	1,230	1,037	1,699	47	3.2	3.2	4.2	36.1
23	Rain	11/10/2004	11/12/2004	315	318	315	644	25	1.5	1.5	1.6	5.1
24	ROS	1/25/2005	1/29/2005	763	768	763	1,563	147	3.7	3.6	3.9	20.5
25	SM	2/3/2005	6/18/2005	59,523	60,003	58,655	168,401	58,638	306.2	302.9	424.4	64,754.0
26	SM	2/3/2005	2/25/2005	3,771	3,798	3,771	11,890	614	18.9	18.9	29.8	366.0
27	SM	2/25/2005	3/5/2005	2,162	2,178	2,162	4,386	204	10.6	10.6	18.3	151.7
28	SM	3/5/2005	3/19/2005	7,268	7,314	7,196	13,421	895	35.0	34.7	53.0	516.4
29	SM	3/19/2005	4/21/2005	18,924	19,075	18,559	46,170	3,167	97.1	95.5	131.7	751.8
30	SM	4/21/2005	5/18/2005	17,870	18,025	17,440	36,550	9,877	92.3	90.7	121.4	6,185.1
31	SM	5/18/2005	6/18/2005	9,528	9,626	9,527	21,155	43,881	52.4	52.4	70.4	56,783.0
32	SM	3/5/2005	8/1/2005	54,545	54,980	53,677	118,015	67,179	281.6	278.3	388.9	65,099.0
33	Rain	6/8/2005	6/10/2005	711	716	711	1,365	1,341	3.3	3.2	3.9	561.4
34	Rain	6/10/2005	6/11/2005	318	321	318	801	324	1.5	1.5	2.5	304.1
35	Rain	6/16/2005	6/17/2005	188	190	188	936	994	0.9	0.9	2.9	189.9
36	Rain	9/26/2005	9/28/2005	535	541	535	798	21	1.6	1.6	1.5	9.8
37	Rain	10/15/2005	10/15/2005	369	1,462	369	307	--	0.8	0.8	0.9	3.3
38	Rain	10/24/2005	10/25/2005	1,258	1,969	1,146	1,657	--	1.7	1.6	3.2	21.2
39	ROS	11/30/2005	12/3/2005	6,979	7,436	5,264	16,984	--	10.2	8.3	21.5	54.1
40	ROS	12/20/2005	12/25/2005	21,878	31,300	13,985	13,503	--	33.2	24.2	36.8	618.9
41	ROS	12/27/2005	12/30/2005	13,527	18,837	10,218	5,744	--	26.9	21.3	25.2	64.4
42	ROS	12/30/2005	1/8/2006	64,905	92,722	35,721	32,166	--	167.2	101.9	97.7	1,134.9
43	ROS	2/26/2006	2/28/2006	7,605	9,453	5,819	6,845	--	16.3	12.6	18.1	915.9
44	SM	3/21/2006	6/21/2006	87,775	177,955	77,417	103,016	--	402.8	361.0	463.4	311,698.0
45	SM	4/2/2006	4/27/2006	34,719	65,683	29,990	45,969	--	145.2	127.5	194.7	1,459.5
46	SM	4/27/2006	7/22/2006	51,293	109,499	46,500	53,517	--	251.7	231.8	252.3	355,574.0
47	SM	4/25/2006	7/14/2006	58,256	119,529	51,476	60,300	--	271.4	245.2	276.0	355,812.0
48	Rain	6/28/2006	6/28/2006	262	372	294	1,092	--	0.7	0.8	3.5	414.8
49	Rain	10/5/2006	10/7/2006	--	--	--	363	--	--	--	1.4	--
50	Rain	11/2/2006	11/4/2006	940	1,053	976	749	--	3.4	3.8	2.3	--
51	Rain	11/13/2006	11/14/2006	241	392	276	401	--	2.8	3.3	1.7	--
52	Rain	11/28/2006	11/30/2006	218	473	352	520	--	3.4	5.5	2.5	--
53	ROS	1/3/2007	1/5/2007	235	327	235	414	--	2.3	2.3	1.6	--
54	ROS	2/8/2007	2/14/2007	1,632	2,117	1,785	2,137	--	13.2	14.5	7.9	--
55	SM	2/25/2007	3/22/2007	3,739	6,603	5,504	6,992	--	48.5	71.1	33.1	--
56	SM	2/25/2007	3/12/2007	1,993	3,329	3,646	3,683	--	24.5	45.5	17.3	--
57	SM	3/12/2007	3/22/2007	1,746	3,277	1,858	3,316	--	24.1	25.6	15.8	--
58	Rain	5/2/2007	5/3/2007	61	101	63	115	--	0.7	0.8	0.5	--
59	Rain	8/29/2007	8/31/2007	346	413	291	655	--	2.0	1.8	2.3	--
60	Rain	9/19/2007	9/22/2007	653	2,438	649	769	--	2.2	2.9	2.8	--

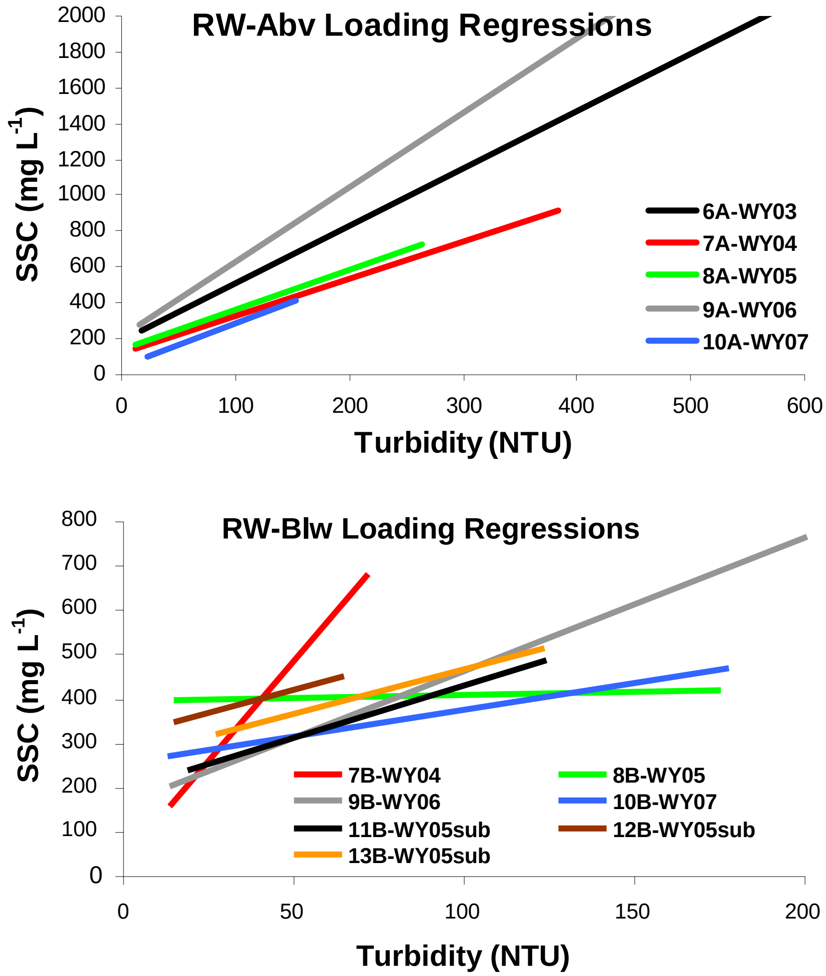

Figure 13. Visual comparison of regression models used (Table 7) to estimate suspended sediment loading from RW-Abv (top) and RW-Blw (bottom).

Third Creek was not the primary focus for this study, thus only a single regression model was constructed:

$$Log(SSC) = 1.3907 \times Log(Turbidity) - 0.1522 \text{ (R}^2\text{=0.74, } p\text{-value} \leq 0.0001\text{, n=89)}$$

This relationship was developed using suspended sediment samples collected by DRI and the USGS and paired with DRI in-stream turbidity measurements. The two SSC data sets complemented each other, as the bulk of the USGS data was collected under lower turbidity and discharge conditions. The 43 SSC samples collected by DRI during hydrologic events averaged 558 mg L^{-1}, whereas the average from USGS samples collected primarily during routine monitoring was 17 mg L^{-1}. This single, aggregated turbidity surrogate approach should only be considered as a coarse estimate of sediment loading because it was derived without incorporating high-turbidity events in WYs 2004 to 2007. Therefore, it is likely that these coarse estimates underestimate suspended sediment loads delivered by Third Creek.

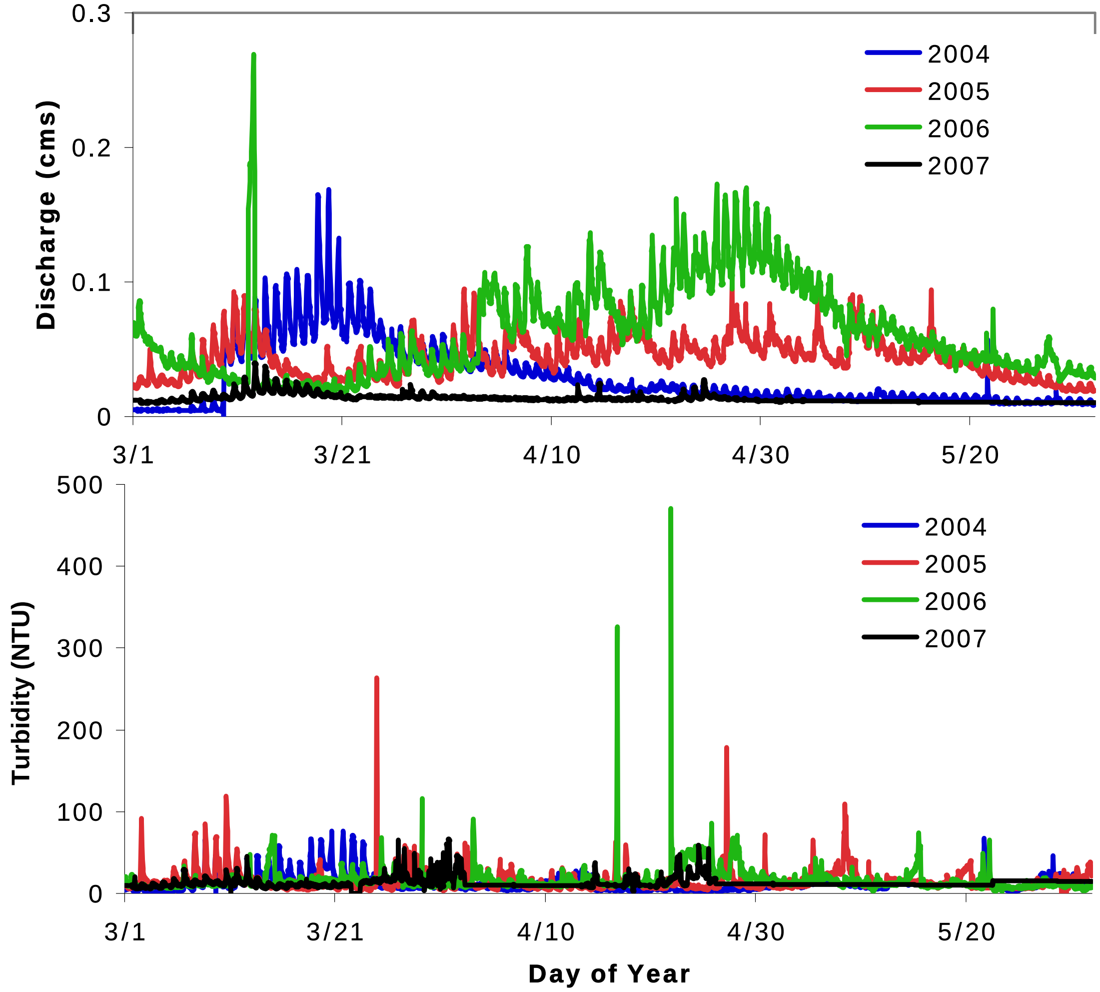

Figure 14. Comparison of average hourly discharge and turbidity during snowmelt at RW-Blw.

The slope of the regression curve for a particular water year may be very shallow or very steep, further prejudicing the loading calculation higher or lower (Figure 14). Event data were used in place of yearly data when there was weak correlation between SSC and turbidity, such as WY 2005 at RW-Blw. For further discussion of turbidity as a surrogate, sediment loadings, and associated errors see Appendix B.

RAIN EVENTS

There were 20 rain events that occurred after the construction of the restoration project through WY 2007 (Figure 15). On Rosewood Creek, these events delivered from 60 to 13,000 kg of suspended sediment in conjunction with 0.3 x 10^6 to 7.8 x 10^6 L of water per event. Rain events were variable in length ranging from six hours to six days. Longer events were either comprised of several days of smaller rainstorms or by a single, intense rainstorm that resulted in higher discharges lasting for several days after the event. Nine of the rainstorms resulted in elevated hydrographs of less than one day, five lasted from one to two days, and seven lasted for greater than two days. Of these events, four are discussed in more detail below. Three of these, Events 37, 38, and 48 had the greatest daily sediment loads of all rain events, but the timing of each differed in how the loads were delivered. The fourth event (Event 22) delivered a large total sediment load but had low daily intensities because the hydrograph was elevated for a longer time.

The largest of these rain events, Event 38 on October 24, 2005 (Figure 16), was the largest post-construction rain event, delivering 2,118 kg of suspended sediment from Rosewood into Third Creek. All post-construction rain events were relatively mild, and were dwarfed by the preconstruction thunderstorms in August 2003 (Event 8, discussed previously) and by a rain-on-snow event that started on December 30, 2005 (Event 42, discussed below). For comparison, suspended sediment delivery during Event 38 was only 16 and 2 percent of that delivered by preconstruction Event 8 or by rain-on-snow Event 42, respectively. Event 38 was subject to substantial surface runoff within the project area as total water loading increased 87 percent between RW-Abv and RW-Blw. Large inputs of water within the project area such as during this event inhibit the ability to assess how effective the project was at reducing sediment loads, because the SSC contributed by surface runoff was unknown. In this case, the 10 percent increase in suspended sediment loads between RW-Abv and RW-Blw was attributed to overland flow.

The second largest post-construction rain event, Event 22 (Figure 17), was comprised of a series of rain events that started on October 17, 2004, and elevated the hydrograph for nearly 4.5 days. Despite delivering 1,699 kg of suspended sediment, it ranked eleventh out of the 20 events for daily loading (388 kg day^{-1}). Lower daily loadings were caused by the low erosive power of this event since precipitation intensities were low, about 2.5 mm per hour, and because lake-level rain changed to snow after six hours. This event delivered only about a quarter of the water delivered by Event 38.

The third event (Event 48, Figure 16), in comparison, had moderate total suspended sediment loads but had the third highest daily sediment loads. This was a short-duration event of 10 hours that occurred on June 28, 2006. Lake-level rain substantially increased the total volume of water exiting (RW-Blw) the project by five-fold relative to that entering (RW-Abv). Yet, suspended sediment yields were attenuated at RW-Blw. The opposite was observed during rain Events 33 to 35 occurring from June 8 through June 17, 2005. Relative to RW-Abv, these events had between a 21 to 122 percent increase in water volume, resulting in an increase of 91 to 397 percent of total suspended sediment load.

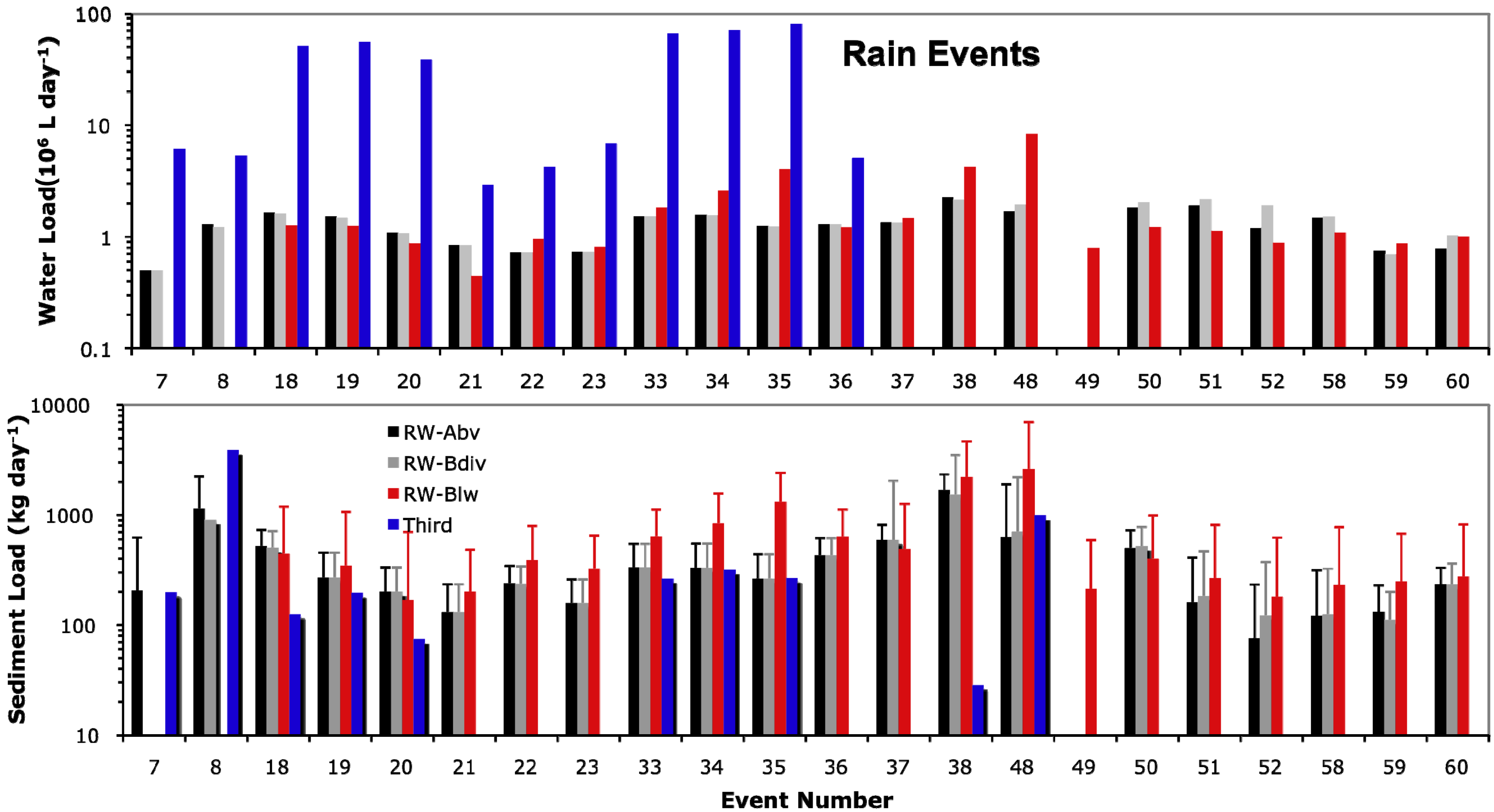

Figure 15. Average daily water loading (above) and suspended sediment loading with error bars (below) for all rain events. RW-Abv reflects conditions above the diversion structure whereas RW-Bdiv estimates conditions below the structure on Rosewood Creek. Error bars are the standard error of measurements. See the section on methods for additional discussion of how RW-Bdiv was calculated.

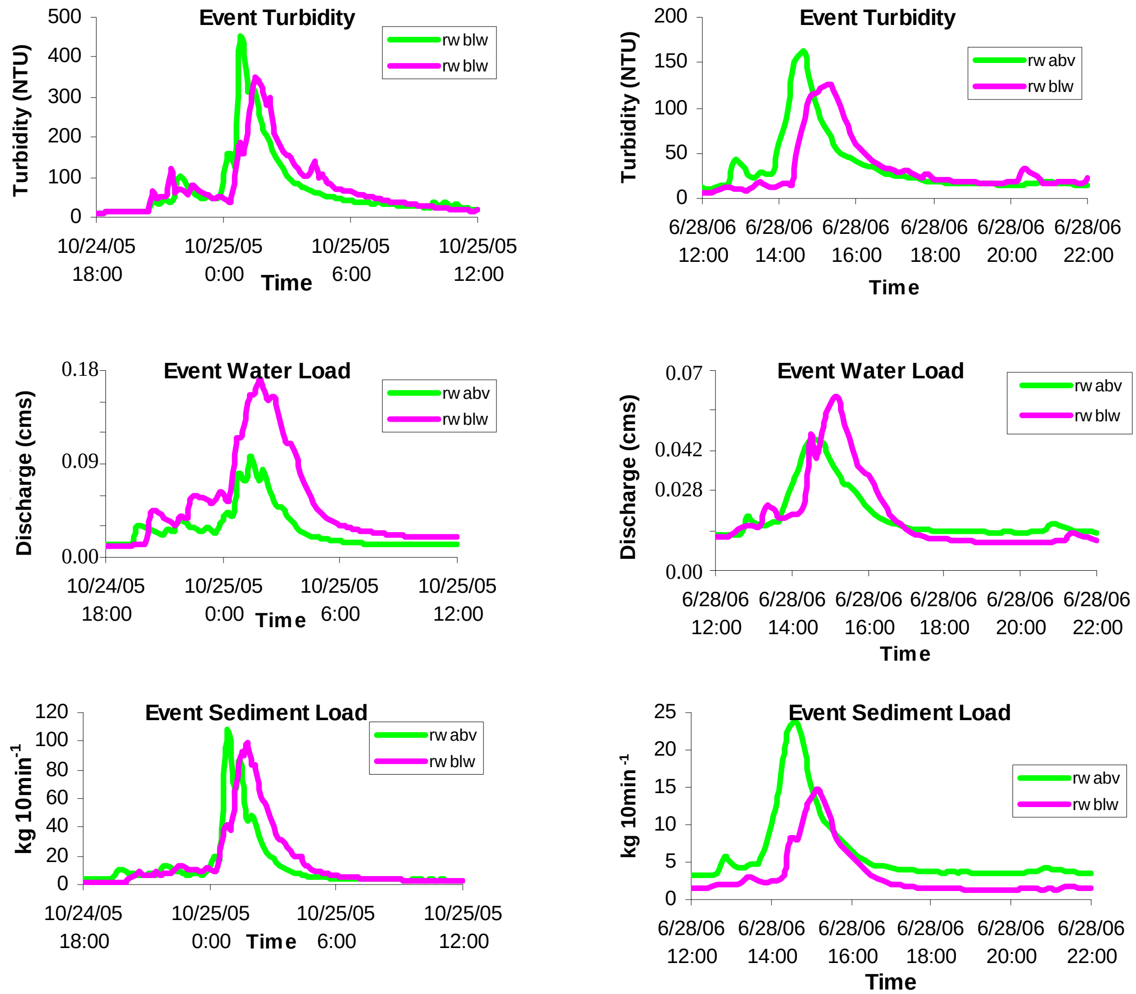

Figure 16. Turbidity, water load, and sediment load during Event 38 (October 24, 2005) and Event 48 (June 28, 2006).

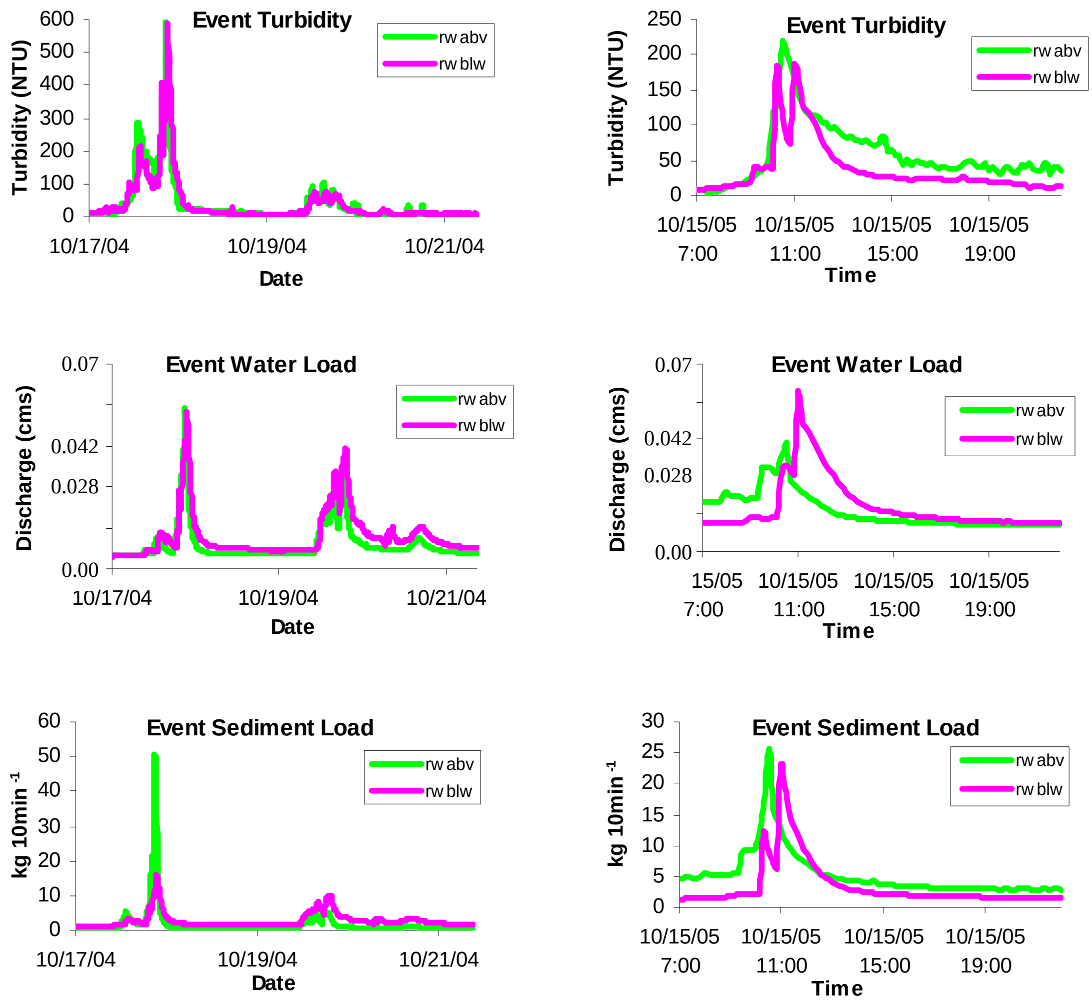

Figure 17. Turbidity, water load, and sediment load during Event 22 (October 17, 2004) and Event 37 (October 15, 2005).

The last event, Event 37 (Figure 17), had the third highest suspended sediment loads within the restoration project during a post-construction rain event. It was primarily a middle elevation event, resulting in nearly all the water exiting to Third Creek having traveled though the entire length of the project. Therefore, elevated turbidity values entering the project at RW-Abv primarily drove sediment loading during this event. Water loads and velocities were relatively low, suggesting that continued mobilization of suspended sediment may have diminished. Conversely, large suspended sediment reductions were observed during rain Events 50 and 60 that had higher water loads through the project. In the case of Event 50, a 29-percent reduction in sediment load occurred with a 39-percent reduction in water loading as the event passed through the restoration area. For Event 60, sediment loads decreased 47 percent. These events (37, 50, and 60) occurred in September or October of their respective year when evapotranspiration demands and plant growth were the highest. When all mid-elevational rain events were considered, the ability of the restoration project to reduce suspended sediment loads decreased as the total water loads fell below 1.5×10^6 L.

RAIN-ON-SNOW EVENTS

Rain-on-snow events (Figure 18) were dominated by a series of rainfall events between November 30, 2005, and February 28, 2006 (Events 39 to 43). These events were primarily rain at the lower and middle elevations and a rain/snow mixture in the upper elevations. Of these, Event 42, which started on 2006 New Year's Eve day, dominated suspended sediment and yield loads, delivering 32,166 kg of sediment and 209 x 10^6 L of water to Third Creek. Events 40 and 41, occurring up to 10 days earlier, delivered a total of another 41,582 kg and 132 x 10^6 L of water. Event 42 produced the maximum peak discharges observed on Rosewood Creek: 0.49 cms at RW-Abv, 0.22 cms estimated at RW-Bdiv, and 0.54 cms at RW-Blw. Under peak flows, the diversion structure can transfer about half of the incoming flow into Third Creek, resulting in lower water volumes at RW-Bdiv than at RW-Abv (see the methods section for additional details).

On average, Events 40 to 42 (Figure 19) had similar daily sediment loadings of 5,830 kg day^{-1} at RW-Bdiv, with the restoration project reducing loads between 33 and 73 percent. Looking at all rain-on-snow events during this study, the average median particle size increased at RW-Blw for Event 54, remained the same during Events 24 and 53, and increased from 34 to 77 percent during Events 5, 39, 40, and 42 (Figure 20). The median particle diameter dropped from about 47 µm to 18 µm during the two largest events (Events 40 and 42) and from 40 µm down to 25 to 30 µm for two smaller events (Events 5 and 39). In contrast to these trends at RW-Blw, the particle size of suspended sediment at RW-Abv typically remained at 40 µm. This shift to smaller median particle diameters can be explained by two mechanisms. First, inflow of surface runoff to the creek is typically comprised of a greater concentration of finer particles during storms with low erosive potentials, such as rain-on-snow events. If there was a significant inflow of surface runoff within the restoration project, then the median particle diameter of sediment at RW-blw would decrease due to the ability of lower energy overland flow to only keep finer diameter particles entrained in flow. Second, a shift towards finer particle diameters exiting the restoration project can be explained by proper functioning of the flood-spreading basins to drop out the coarser sediment sizes. Both processes apparently occurred. The former mechanism could explain the enrichment of fine particles during Events 39 and 40, when surface inflows within the project contributed 34 and 61 percent of the total water exiting the project. In contrast, the latter mechanism could explain Event 42, when the volume of water exiting the project was slightly (<5%) lower than that entering the project. Other events such as Events 24, 53, and 54 had minor changes in median particle diameter associated with near balanced or decreased net water volumes through the project.

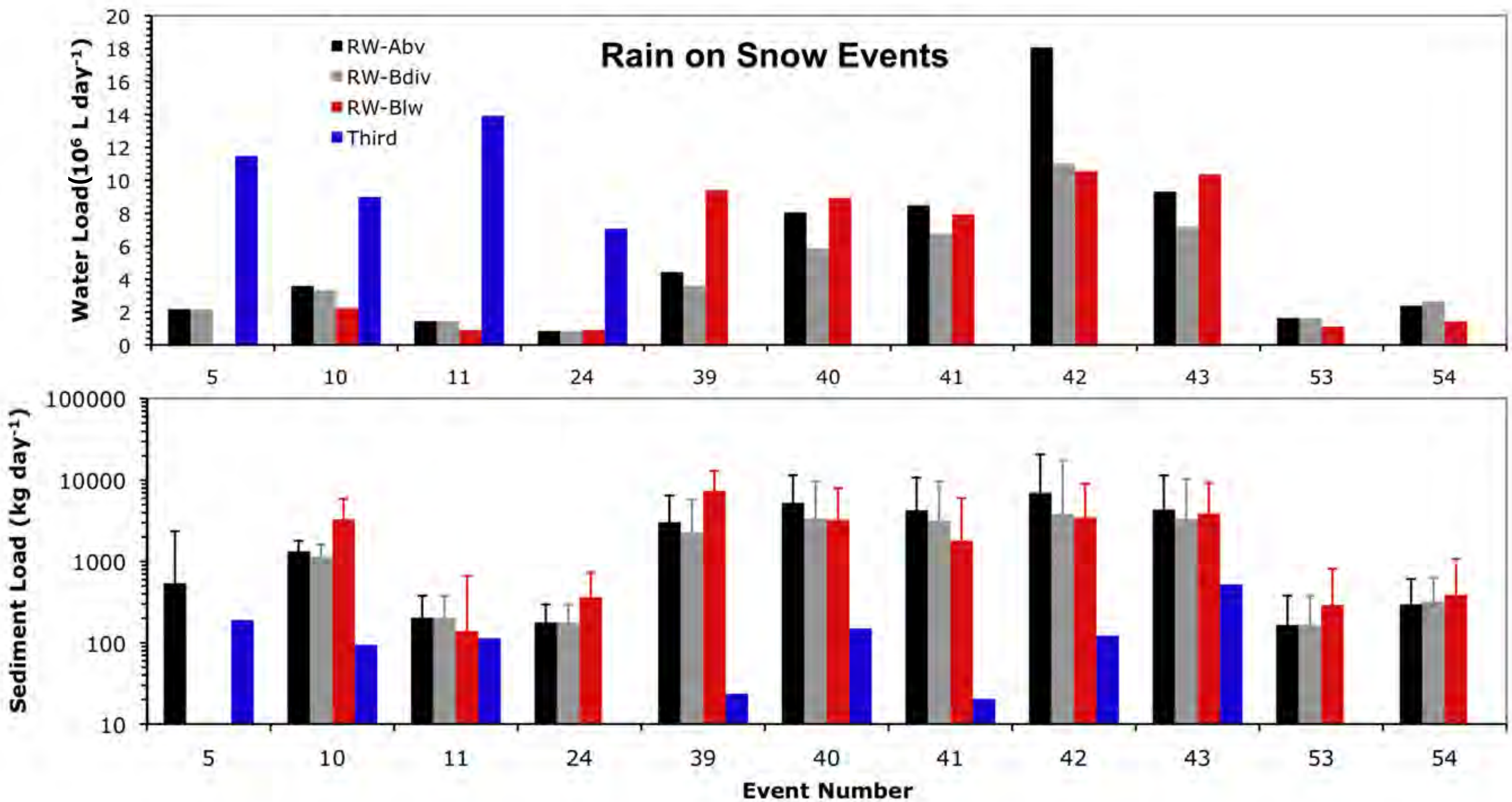

Figure 18. Daily water loading (above) and suspended sediment loading (below) for all rain-on-snow events. RW-Abv reflects conditions above the diversion structure, whereas RW-Bdiv estimates conditions below the structure on Rosewood Creek. See the methods section for additional discussion of how RW-Bdiv was calculated. Error bars are the standard error of measurements.

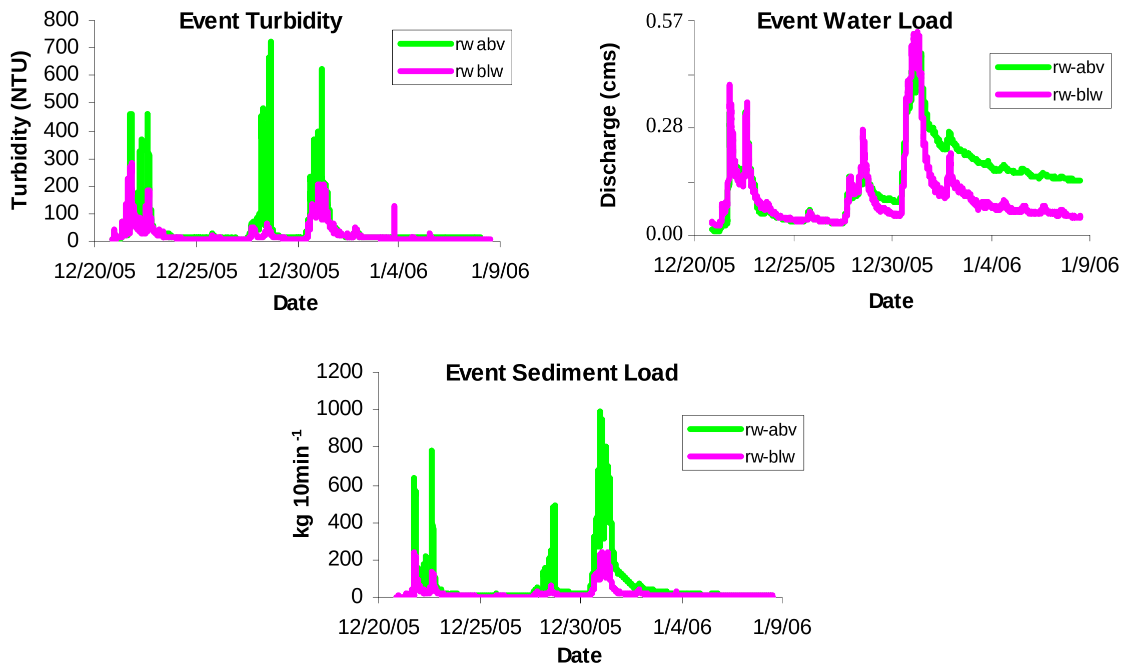

Figure 19. Turbidity, water load, and sediment load during Events 40, 41, and 42 (December 2005 through January 2006).

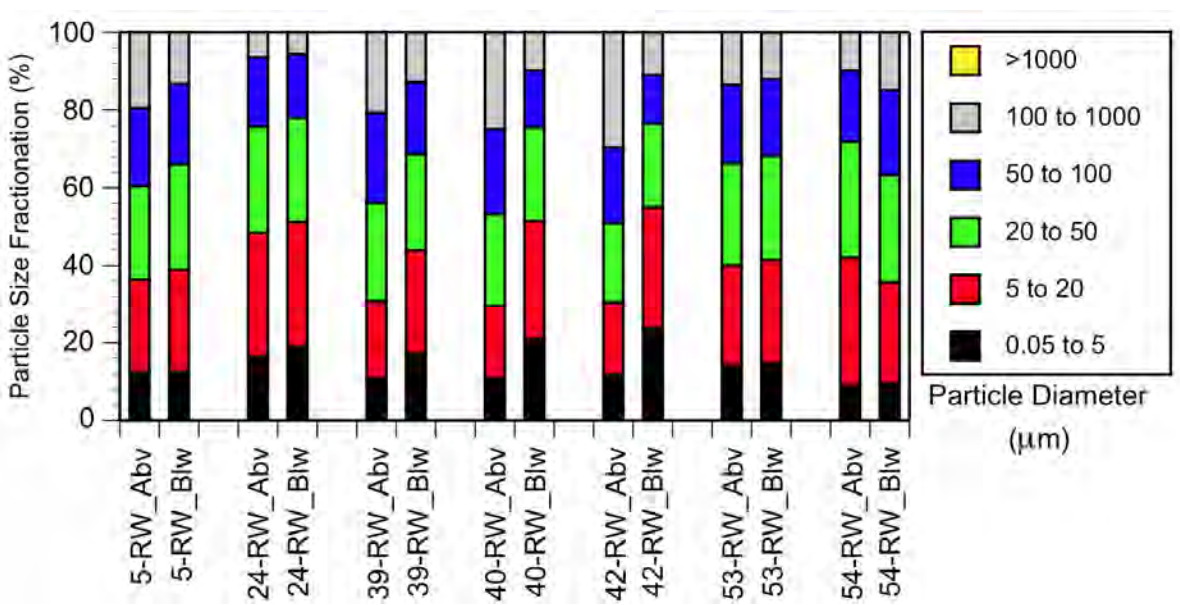

Figure 20. Particle size distributions for rain-on-snow events.

SNOWMELT EVENTS

Snowmelt events varied in their production of suspended sediment and water, varying in duration between 25 and 135 days. The largest snowmelt season observed was in 2006, delivering 177,955 kg of sediment and 402.8 x 10^6 L of water at RW-Abv. The lowest productive year was during the 2007 snowmelt season that delivered only 6,603 kg of sediment and 48.5 x 10^6 L of water. Low elevation surface runoff was an important contributor to flows within the project in years when there was a significant snow depth at or near lake level. For example, the volume of water exiting the restoration project (RW-Blw) was 40 percent greater than water entering the project (RW-Bdiv) in WY 2004 to 2005. In contrast, when snow depths in the lower elevations were low, the majority of streamflow came from the upper elevations and traveled through the project. In WY 2003 to 2004, for example, stream water volumes during snowmelt increased by only seven percent at the lower end of the restoration project. In the extreme case of WY 2006 to 2007, when there was very little seasonal snow accumulation at low elevations, water flows dropped substantially through the restoration project.

Daily suspended sediment loadings during snowmelt were driven by total water loads at RW-Blw (Figure 21). Suspended sediment loads for the large snowmelt years of 2005 and 2006 ranged from 424 and 463 kg day^{-1}, respectively. Conversely, the low snow year of 2007 produced just 33 kg day^{-1}.

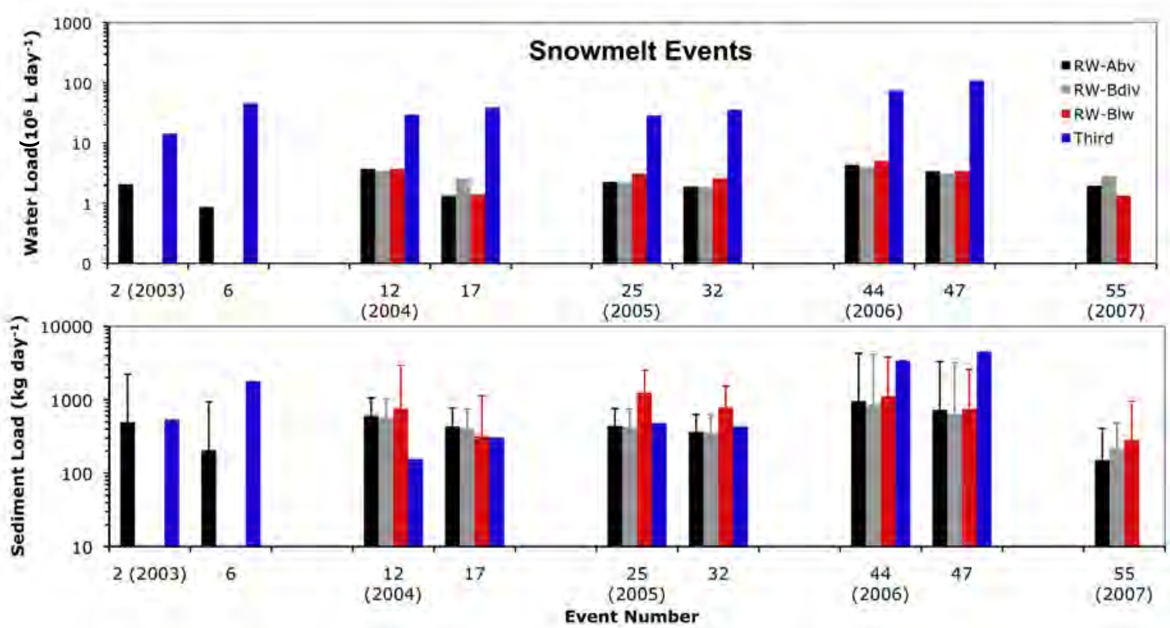

Figure 21. Daily water and sediment loads during each snowmelt period. Error bars are the standard error of measurements.

The flow-weighted particle size distribution and the mean particle diameter (MPD) during snowmelt varied between sites and from year to year (Figure 22). At RW-Abv, the MPD and size distribution were similar from WYs 2002 through 2005 although the MPD increased from 48 to 59 µm in 2006. This 2006 snowmelt season was characterized by the highest sustained water flows (see Figure 14) and velocities that would have been capable of mobilizing and carrying a greater load of coarser sediment, such as that from the slope failure and head cut located about 30 m upstream of State Route 28. Snowmelt during 2004 reached the same peak snowmelt discharge but flows were not elevated at that level for the same length of time that they were elevated in 2006. At RW-Blw, suspended sediment samples showed a marked increase in coarser size fractions and MPD during the first post-construction snowmelt season in 2004 but then decreased over time, as discussed below.

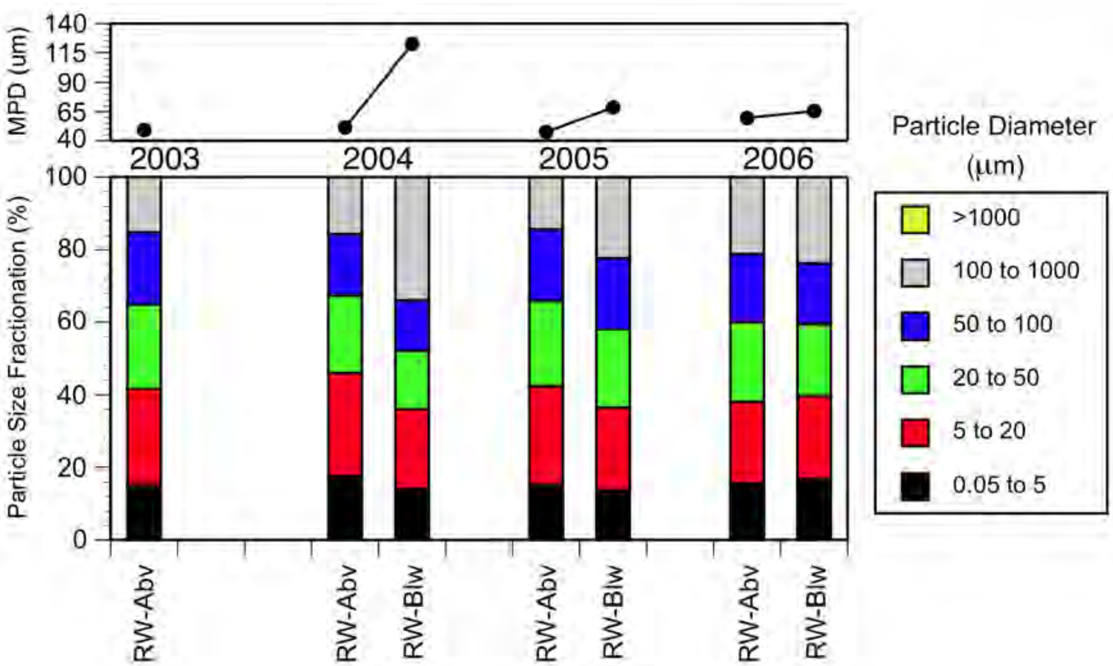

Figure 22. Flow-weighted average particle size fractionation (bottom) and mean particle diameter (MPD, top) for samples collected during snowmelt events. The analysis of particle size samples was biased towards the higher SSC samples that comprised the bulk of the suspended sediment load. Data from 2007 were not collected because of the low volume of sediment transported during unusually low runoff volumes.

First Snowmelt Season after Construction

Two factors contributing to the observed coarser MPD at the bottom of the restoration zone were the: (a) presence of unconsolidated materials remaining in the channel from project construction; (b) the erosion and subsequent deposition of coarser sediments within the project during its first heavy thunderstorms (Event 8) earlier in the water year. The temporary storage of coarser sediment originally mobilized from upstream sources was routinely noted on the creek's bed at RW-Abv as the steeper creek slopes above State Route 28 transitioned into the shallower slopes in the restoration project. The presence of these sediment sources resulted in 23 percent more sediment exiting the project at RW-Blw than entering the project at RW-Abv. This translated into a loading of 221 kg day^{-1} of suspended solids from sources within the restoration project and comprised nearly 20 percent of the suspended sediment delivered to Third Creek during this water year. In addition, these readily available sediment sources resulted in elevated turbidity levels at lower flows and contributed to the large range observed between discharge and suspended sediment loading below the project compared to that observed above the project (Figure 23). The delivery of this coarse sediment out of the project was only observed during the first post-construction snowmelt season.

Hysteresis curves can be used to observe trends in suspended sediment within and between different events. In this context, hysteresis describes the phenomenon whereby a given parameter (SSC) is observed to have a different relationship with discharge during the rising limb of an event hydrograph compared to the falling limb. Hysteresis curves are presented for a subset of this snowmelt season (Event 12) in Figure 24. The greater "stacking" of the lines parallel to the x-axis at RW-Blw indicates that hysteresis was more prevalent at this site. Sites subject to greater levels of hysteresis indicate poor correlation between discharge and SSC.

Hysteresis curves also provide insight as to sediment sources. The ability of a stream to carry suspended sediment depends on the energy of the water (e.g., velocity) and on the availability of a sediment source. When both energy and a sediment source are present, SSC will be elevated. However, if the sediment source becomes depleted, then SSC will decrease even with elevated discharge. To complicate matters, not only may there be several different sediment sources, but some sediment sources may not become active until after a certain energy level or a specific stage threshold is exceeded. For example, SSC during Event 12 had a unimodal distribution at RW-Abv, as SSC was elevated only between 0.03 and 0.05 cms (Figure 24). The mean particle size diameter (35 to 53 μm) observed during snowmelt was consistent with the mean diameters of suspended sediment collected during other events, as previously shown. In contrast, estimated SSC at RW-Blw had a bimodal distribution, with elevated SSC between 0.014 and 0.025 cms, and above 0.09 cfs. Particle size during snowmelt increased in mean diameter during early snowmelt, ranging from 39 μm, for samples collected at 0.20 cms, and 127 μm at 0.28 cms, to 331 μm at 0.09 cfs on March 14, 2004. These coarser sediments were subsequently depleted, as the mean particle diameter decreased in samples collected after March 16, despite discharge remaining elevated.

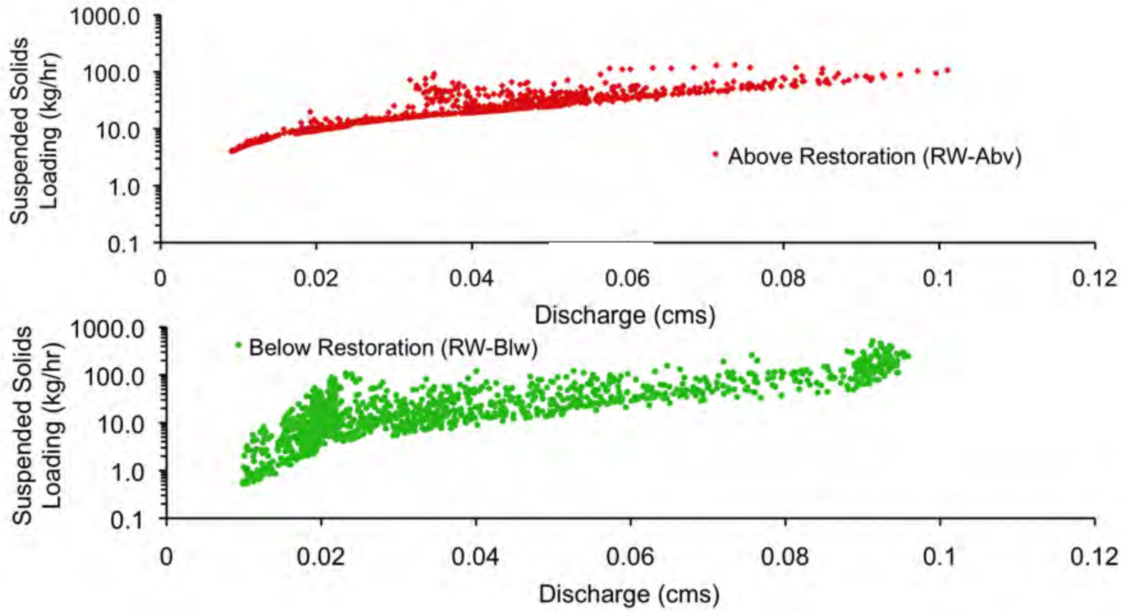

Figure 23. Discharge versus suspended solids loading relationships at both Rosewood Creek sites during 2004 low-elevation snowmelt (Event 12). Each 10-minute measurement during this time period is represented by a point on these plots.

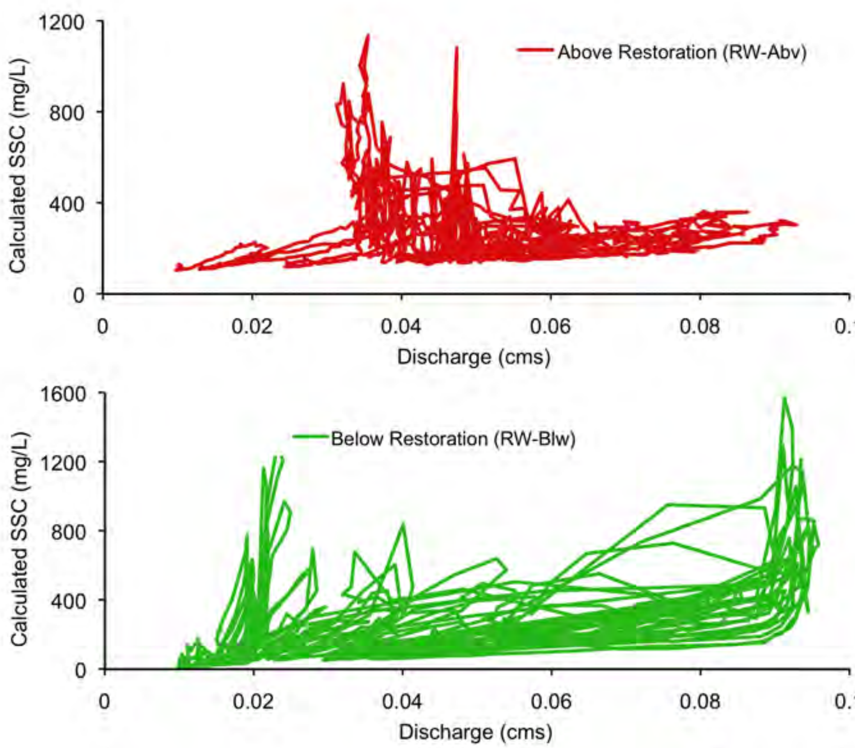

Figure 24. Hysteresis relationship at both Rosewood Creek sites between March 9 and March 16, 2004. The data in this graph are a subset of those presented in Figure 23, and use lines rather than points to show changes through time.

Spatial Investigation of Discharge

Additional investigations were conducted to determine the sources of water entering Rosewood Creek near or in the restoration project. These sources included: 1) streamflow from the middle reach of Rosewood Creek; 2) surface runoff of melting snow entering the stream within the restoration zone; 3) outflow from the drains under the baseball fields at the upper extent of the restoration project; 4) runoff from Northwood Blvd., the Championship Golf Course, State Route 28, and associated best management practice (BMP) projects traveling as surface runoff and entering Rosewood Creek just upstream of the diversion; and 5) overflow from the Incline Way detention basin into Rosewood Creek. The ability of the flood-spreading zones to reduce water velocity and to drop out suspended sediment, and thus reduce suspended sediment loading, may depend on where and when these sources of water are actively contributing. For example, instantaneous measurements taken on March 9, 2004, indicated that 38 percent of the discharge at RW-Blw was sourced from the outfall of the baseball field and from overland flow originating from Northwood Blvd. and State Route 28. Outflows from the baseball field ceased within a week.

<u>2006</u>

In 2006, water sources to the creek were investigated using instantaneous discharge measurements taken at several sites during snowmelt (Figure 25 and Table 9). These data indicate that several of the water sources mentioned above contributed to flows within Rosewood Creek and that the flood-spreading basins are capable of reducing the downstream flow of water. Measurements show that flows within Rosewood Creek increased from 50 to nearly 70 percent between RW-Abv (point A in Figure 25) and the diversion (point B) during both a rain-on-snow (red) and snowmelt (yellow) event. The source of this water was surface runoff from State Route 28 and overflow from a detention basin fed from runoff from both the Championship Golf Course and Northwoods Blvd. This water flowed through a culvert under State Route 28 and traveled as overland flow until it entered Rosewood Creek just above the diversion. Visual observations indicated that this slow-moving surface runoff carried little suspended sediment and would dilute the existing suspended sediment concentration when it entered the creek just upstream of the diversion.

Snowmelt from the baseball field near the diversion was also found to augment flows within the creek, as tile drains under the field discharged directly into Rosewood Creek above Point D. Measurements taken above and below one of the in-stream flood-spreading basins installed as part of the restoration project suggest that it was more effective at reducing flows during snowmelt than during the rain-on-snow event. The creek was designed to flood within this basin and reduce sediment and water loads by increasing the surface area, reducing water velocities, and increasing infiltration. It appears that the slower water velocities during snowmelt promote a greater efficiency than faster water velocities during the rain-on-snow event. Finally, both the snowmelt and rain-on-snow events exhibited an increase in discharge between points D and E, likely from surface runoff. These results, however, are based on a few manually collected instantaneous measurements that present a snapshot of flow conditions only during the days on which the data were collected.

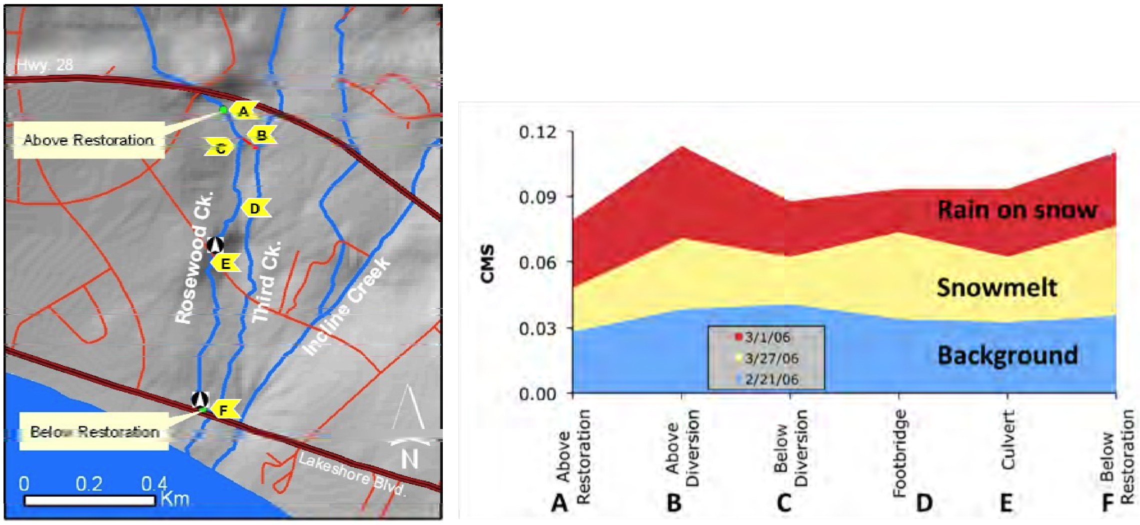

Figure 25. Water sources to the lower reach of Rosewood Creek on three days during the 2006 snowmelt season.

Table 9. Latitude and longitude of sites in the lower Rosewood Creek restoration project. Site letters refer to the sites as presented in Figures 26 and 27. Coordinate datum is NAD27 CONUS.

Site	Site	Latitude	Longitude
RW-Abv	A	39.24833	119.94464
RW-Above Diversion	B	39.24771	119.94432
RW-Below Diversion	C	39.24771	119.9448
RW-Above Footbridge	D	39.24598	119.94472
RW-Above Spreading	E	39.24491	119.94559
RW-Below Spreading	G	39.24386	119.94558
RW-Above Spreading II	H	39.24058	119.94635
RW-Blw	F	39.24025	119.94613

2007

Starting in June 2006, automated stage loggers were added at several locations along the creek to improve the ability to assess the contribution of these water sources and the ability of the flood-spreading basins to affect water loadings. These sensors were placed at strategic locations at the top and bottom of channel reaches (Figure 26) that were thought to be gaining surface runoff or losing flow by water infiltration within the flood-spreading basins. Only natural check structures were used; no flumes or weirs were employed. Rating curves were developed for each location.

Five different events were observed during snowmelt (I-V in Figure 27). During the first snowmelt peak (I), there was a net loss of approximately 0.01 cms of water from below the diversion structure to just below the upper spreading zone (E). Just after this peak,

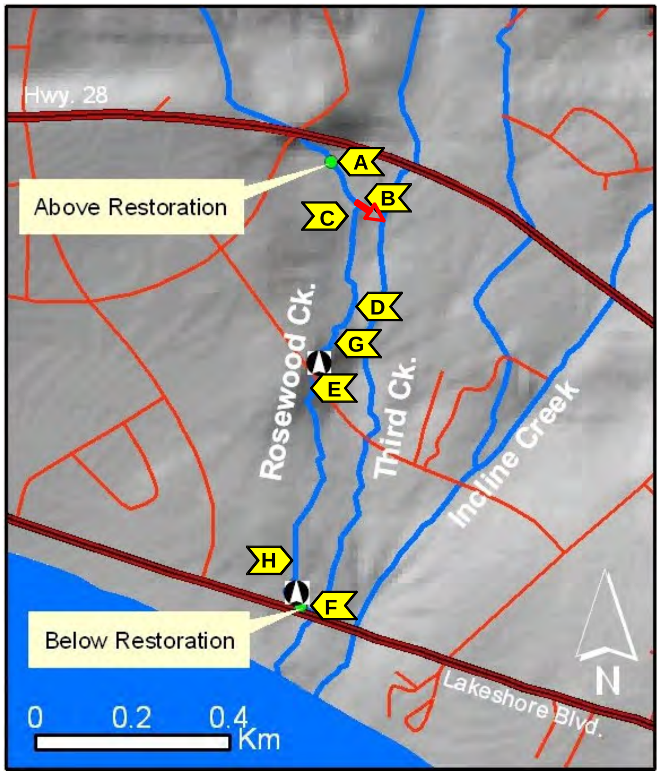

Figure 26. Location of stage monitoring sites within the restoration project starting in June 2006. Sites A-F are the same as in Figure 27.

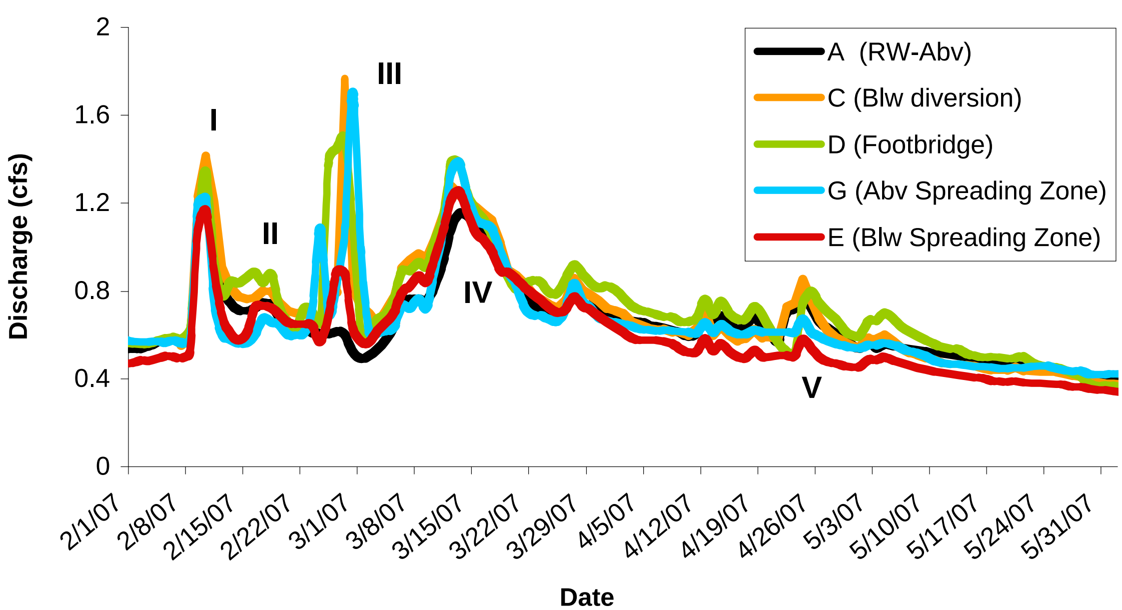

Figure 27. Snowmelt-driven discharge at several sites within the restoration project during spring 2007. See Figure 28 for locations. Data from sites B, F, and RW-Blw were omitted for clarity.

discharge between the diversion structure and the footbridge remained slightly elevated, suggesting runoff from the baseball field (II). Discharge within the creek increased again between February 23 and March 3, 2007 (III). This peak was caused by an increase in surface runoff from Northwood Blvd., the Championship Golf Course, and State Route 28 due to an increase in discharge below the diversion structure (C); discharge remained steady at RW-Abv (A). This surface runoff accounted for 6.2×10^6 L of water, or 33 percent of the flows measured below the diversion structure. Further down the drainage, the flood-spreading zone (G-E) captured 5.5×10^6 L of water, reducing flows by 26 percent. During this nine-day period, this single flood-spreading basin was also the source of nearly 90 percent of the water delivered into the restoration project by surface runoff. A week later, discharge increased again, this time because of snowmelt from higher elevation in the watershed, as nearly all the flow was delivered through RW-Abv. The last peak (V) between April 22 and 29, 2007, also came from higher elevations. Overall, the project dropped the water load from 66.7×10^6 L below the diversion to 58.0×10^6 L, a drop of 13 percent. Trends in these data were difficult to discern, as 2007 was a very poor water year, with average monthly discharges 57 to 78 percent lower than the previous years. It is likely that suspended sediment and water yields would be further reduced in years with higher flows that are capable of fully saturating the engineered flood-spreading zones.

SPATIAL SURVEYS OF BANK, BED, AND SUSPENDED SEDIMENT

The loading of water and suspended sediments by Rosewood Creek was affected by a multitude of natural and anthropogenic factors that were spatially and temporally variable. The ability of the restoration project to reduce suspended sediment loading will be partly determined by the timing, amount, and particle size distribution of sediment entering the project. Sources of water and sediment may change yearly, as upstream BMPs are completed, mature, or fail. For example, road runoff BMP projects were completed on Village Blvd. and State Route 28 during this project by Washoe County and the Nevada Department of Transportation, respectively. Projects such as these may redirect and concentrate inflows into Rosewood Creek that could increase suspended sediment loadings entering the restoration project and accelerate localized bank erosion. Although the temporal variability in sediment entering the project was addressed by long-term data collection at the above restoration monitoring site (RW-Abv), greater detail was desired on potential upstream sources of suspended sediment. This was addressed by conducting a survey of bank erosion potentials.

Bank erosion surveys were conducted by students enrolled in the Hydrologic Sciences Field Methods class at the University of Nevada, Reno. Each reconnaissance survey included an estimation of bank erosion potential using Rosgen's Bank Erosion Hazard Index (BEHI) and the collection of bed, bank, and suspended sediment grab samples for particle size analysis. To obtain a greater number of sampling sites, the location of half the sites differed between the 2003 and 2004 surveys (Figure 28 and Table 10).

Figure 28. Map showing the locations of the bank erosion study sites. Green circles denote sites visited in the 2003 survey, and yellow circles denote sites visited in the 2004 survey.

Table 10. Location, year sampled, and description of bank erosion hazard index (BEHI) sites.

Site	Creek	Year Sampled	Description
1	Rosewood	2003	Very small creek width, above State Route 431.
2	Rosewood	2004	Northeast of the condos, very incised channel.
3	Rosewood	2003, 2004	Dense, relatively flat riparian area above Northwood Blvd.
4	Rosewood	2003, 2004	Headcut north of State Route 28.
5	Rosewood	2003, 2004	Autosampler site RW-abv.
6	Third	2003	Riparian area in golf course above State Route 28.
7	Third	2003	Incised channel below the confluence of Rosewood Creek.
8	Third	2003, 2004	Autosampler site, above Rosewood confluence in 2004.
9	Third	2004	Park-like area south of Lakeshore Blvd., below Rosewood confluence.

Rosgen's BEHI method was chosen because it has been previously used in the Incline Village area (Swanson, 2000). The BEHI method is subjective, and will vary between surveyors. At least one of the Field Methods class instructors (R. Susfalk and S. Tyler) were present at each location in an effort to maintain continuity between groups and years. Sites that were visited in both years did not necessarily assess the exact same stream reach. An effort was made to find the "worst" stream sections for analysis in 2003, whereas an effort was made to find representative stream sections in 2004.

In general, the bank erosion hazard indices at sites visited on Rosewood and Third creeks were generally high, as both creeks were typically incised, with steep, coarse-grained banks (Table 11). The BEHI method was unable to resolve finer-scale differences present among Rosewood and Third creek sites due to its need to generalize bank erosion across different stream types from different geographical areas across the country.

Table 11. Date, location, and BEHI results.

		Location (NAD27 CONUS)		
Site	Date	Latitude	Longitude	Bank Erosion Hazard Index
Rosewood Creek				
1	5/1/2003	39^o 16' 1.7"	119^o 57' 11.3"	High
2	4/16/2004	n/a	n/a	High
3a*	5/1/2003	39^o 15' 13.2"	119^o 56' 49.9"	High
3b	4/16/2004	n/a	n/a	Low
4	5/1/2003	39^o 14' 59.0"	119^o 56' 45.2"	High
4	4/16/2004	39^o 14' 59.0"	119^o 56' 45.2"	High
5	5/1/2003	39^o 16' 24.4"	119^o 55' 55.9"	High
5	4/16/2004	39^o 16' 24.4"	119^o 55' 55.9"	High
Third Creek				
6	5/3/2003	39^o 14' 58.7"	119^o 56' 21.4"	High
7	5/3/2003	39^o 14' 50.0"	119^o 56' 35.4"	Very high
8	5/3/2003	39^o 14' 25.6"	119^o 56' 40.7"	Moderate
8	4/16/2004	39^o 14' 25.6"	119^o 56' 40.7"	High
9	4/16/2004	n/a	n/a	Moderate

*Sites 3a and 3b were located in the same general area. However, completely different stream reaches were assessed in 2003 and 2004.

The two sites with the lowest BEHI scores were unusual stream segments. Site 3 was comprised of a somewhat dense riparian section along Rosewood Creek located above Northwood Blvd. The banks along this stream segment were much less incised with lower bank slopes than stream sections immediately upstream and downstream. This riparian area may have been formed in response to the placement of the channel through a culvert under Northwood Blvd. The second site (Site 9) was along a tree-lined, shallow riffle section of Third Creek that flowed though a park-like area at Incline Beach below Lakeshore Blvd. This site was moderate in most BEHI parameters, and exhibited higher rooting density and rooting depth than most other sites.

In contrast, sites 2 and 7 exhibited high BEHI scores resulting from a combination of very low rooting density and shallow rooting depth. Site 2 was particularly notable for its highly incised stream segment and very sparse riparian zone located along Rosewood Creek below Harold Drive. An important determination of bank erosion potential was soil texture. The coarse soil texture at Sites 4 and 7 contributed to their high erosion potential, whereas the somewhat finer soil texture at sites 1, 3, and 9 played a minor role in their bank erosion potential. Site 4 was particularly notable, as this area along Rosewood Creek just upstream of State Route 28 was comprised of a deep head cut just upstream of a large slope failure. The banks at this location were extremely sandy, as exhibited by a much coarser particle-size distribution (Figure 29, Site 4) relative to sites both upstream (Site 3) and downstream (Site 5).

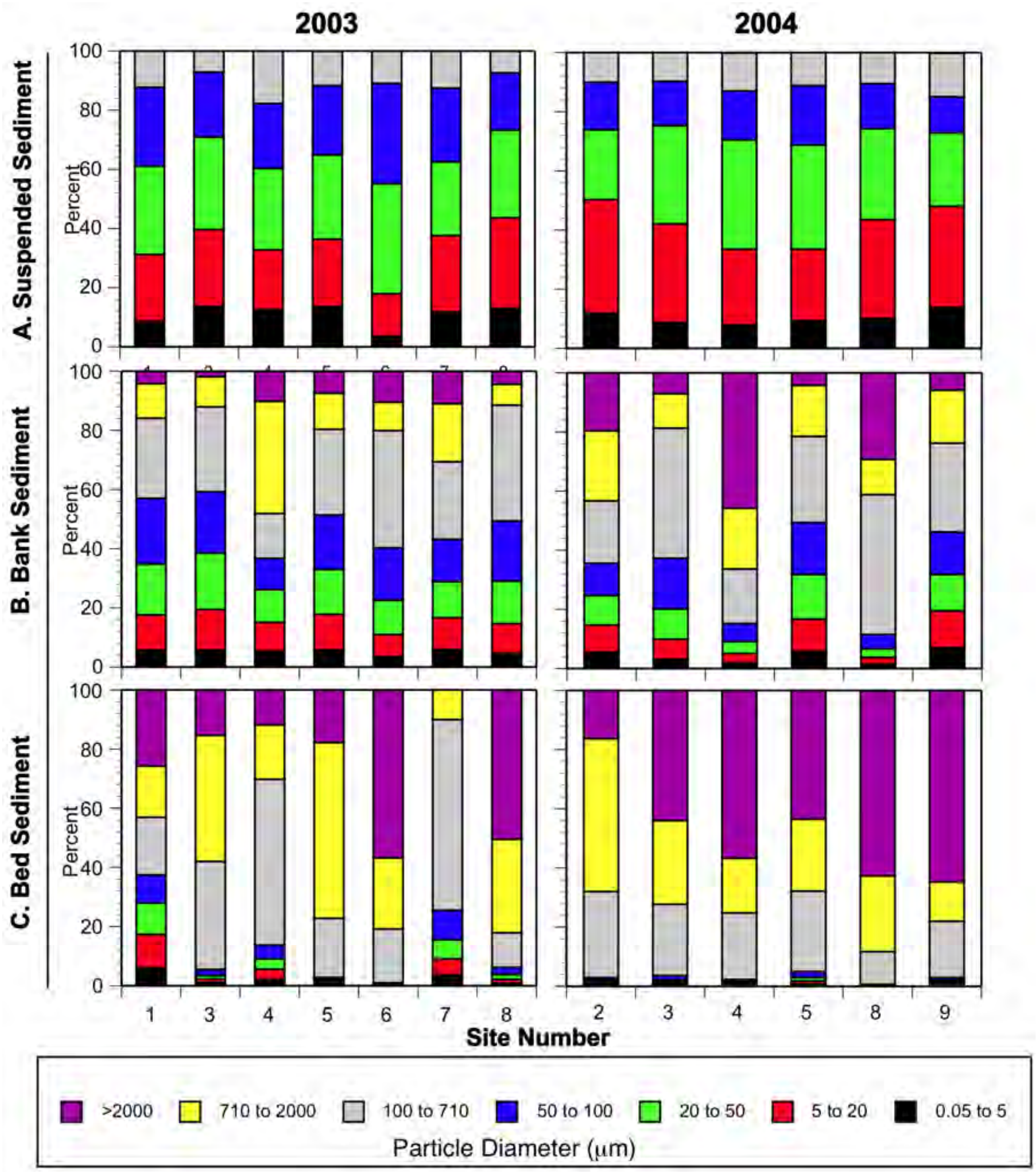

Figure 29. Particle size (in μm) of suspended (A), bank (B), and bed (C) sediment collected during the Bank Erosion Hazard Index studies in 2003 and 2004.

Preliminary evidence suggests that the ability of this head cut and slope failure to contribute *suspended* sediment to Rosewood Creek may not be large and was primarily limited to coarser particle sizes that were more likely to travel downstream as bed load. During a light snow/rain event (Event 2 in Table 12), SSC measured in grab samples taken above Northwood Blvd. and at RW-Abv indicated that the head-cut area was not a source of SSC. Grab samples collected immediately prior to the August 21, 2003 (Event 3 in Table 12), evening storm show a greater contribution from this area -- of the 225 mg L^{-1} of SSC observed at RW-Abv, 42 percent originated from the segment containing the head cut and slope failure, while 20 percent originated between Harold Drive and Northwood Blvd., and 37 percent originated from above Harold Drive. An accumulation of coarse sediments in the bed downstream of the head cut at RW-Abv was routinely observed. This coarse bed sediment would build up during low flows over the fall and winter and then be mobilized by higher flows during snowmelt and storm events. In 2003, the particle-size distribution of the bed sediment (Figure 29C, Site 5) was much coarser than the adjacent bank materials, suggesting transport from the coarser banks upstream (Site 4). However, this trend was not noted in 2004, presumably because of the removal and scouring of sources by the August 2003 thunderstorm event.

Variability in the particle size distributions of the bank, bed, and suspended sediments was not always consistent (Figure 29). For example, the particle size distribution of the bank sediment was more variable between sites in 2004 than it was in 2003. Bed sediment exhibited the opposite trend, having a greater variability in 2003 than 2004. In contrast, the particle size distribution of bed, bank, and suspended sediment was virtually unchanged at site 5 (RW-Abv) between 2003 and 2004, and SSC was similar at all sites during both years. This variability in sediment can be partly attributed to sampling error and the decision to select the stream segments that exhibited the greatest potential for erosion in 2003 compared to the selecting representative stream segments in 2004. Variability between sites and sampling times may also be a consequence of historical channel conditions and the presence or absence of upstream sediment sources.

In summary, the bank erosion potential of sites visited along Rosewood Creek was generally considered to be high because of incised banks and banks comprised of relatively coarse granite-derived soils. Even where rooting was present to stabilize the banks, undercutting was often found. Of the sites visited, Rosewood Creek below Harold Way was found to be problematic due to steep, incised banks and the absence of stabilizing riparian vegetation. A second site at Rosewood Creek above State Route 28, site 4, was found to have high bank erosion because of a deep head cut, but preliminary evidence suggests that this site may be a more important contributor of bed load and coarse particles than finer-sized suspended sediment.

Table 12. Suspended sediment concentration along Rosewood Creek during three events in 2003.

Event:	1	2	3
Date:	5/1/2003	5/3/2003	8/21/2003
Conditions:	Calm; Seasonal snowmelt	During light snow/rain	Between thunderstorms
Avg. Flow at RW-Abv:	0.024 cms	0.031 cms	0.037 cms
Rosewood Creek at			
Above State Route 431	86.7	--	--
Below Harold Drive	--	--	83.5
Above Northwood Drive	66.8	--	130.2
Below head cut, above St. Rte. 28	38.0	266.9	--
Below St. Rte. 28, RW-Abv	84.5	267.8	224.9
Below ball field path	--	--	303.9
Below Incline Way	--	--	371.5
Above confluence with Third Creek	--	--	488.0

COMPARATIVE LOADINGS AND RESTORATION EFFECTIVENESS EVALUATION

Under certain conditions, loading from Rosewood Creek was found to be a major contributor to the load of suspended sediment delivered by Third Creek into Lake Tahoe. During the period of record, Rosewood Creek was the source of between 41 percent and 72 percent of the total suspended sediment loads entering the lake from these two watersheds (Figure 30). The magnitude and timing of water loading was an important control on the delivery of suspended sediment. The slope of the cumulative suspended sediment load curve in Figure 30 during snowmelt events from Third Creek was typically greater than that from Rosewood Creek and occurred later in the spring. This was the result of more intense delivery of suspended sediment sourced from the higher-elevation Third Creek watershed.

The higher cumulative suspended sediment loading at RW-Blw during the 2005 snowmelt season was primarily driven by consistent, moderately elevated discharge throughout the entire season rather than elevated sediment levels over a shorter duration (see Figure 14). In WY 2005 to 2006, cumulative loadings suggested that the restoration project reduced sediment loads, primarily during mixed snow/rain-on-snow events that occurred at the end of 2005 and beginning of 2006 (Events 40-42).

Suspended sediment loads presented here from Rosewood and Third creeks are approximately 5 to 12 times lower than historical USGS Third Creek estimates from 1981 through 1998 for years of similar cumulative water loading (Rowe *et al.*, 2002). One reason for this discrepancy is that discharge-based sediment loading estimates typically overestimate sediment discharge (Guy and Simons, 1964; Lewis, 1996). For example, discharge-based estimates of suspended sediment loading from the Upper Carson River in Nevada during low to moderate flows were up to a factor of four higher than turbidity-based estimates (Susfalk *et al*., 2008). For the California portion of the Truckee River, discharge-based estimates were two to six orders of magnitude higher during hydrologic events than that predicted using turbidity-based estimates (Dana *et al.*, 2006). The second cause of this discrepancy was that the collection of turbidity surrogate data from Third Creek was not a priority after 2003.

Suspended sediment data from the USGS through 2005 were incorporated into the turbidity surrogate relationship; however, the bulk of these data was collected at lower turbidities. Therefore, the turbidity surrogate relationship developed for Third Creek was not necessarily adequate for describing higher flow conditions that delivered greater suspended sediment during from 2005 to 2007.

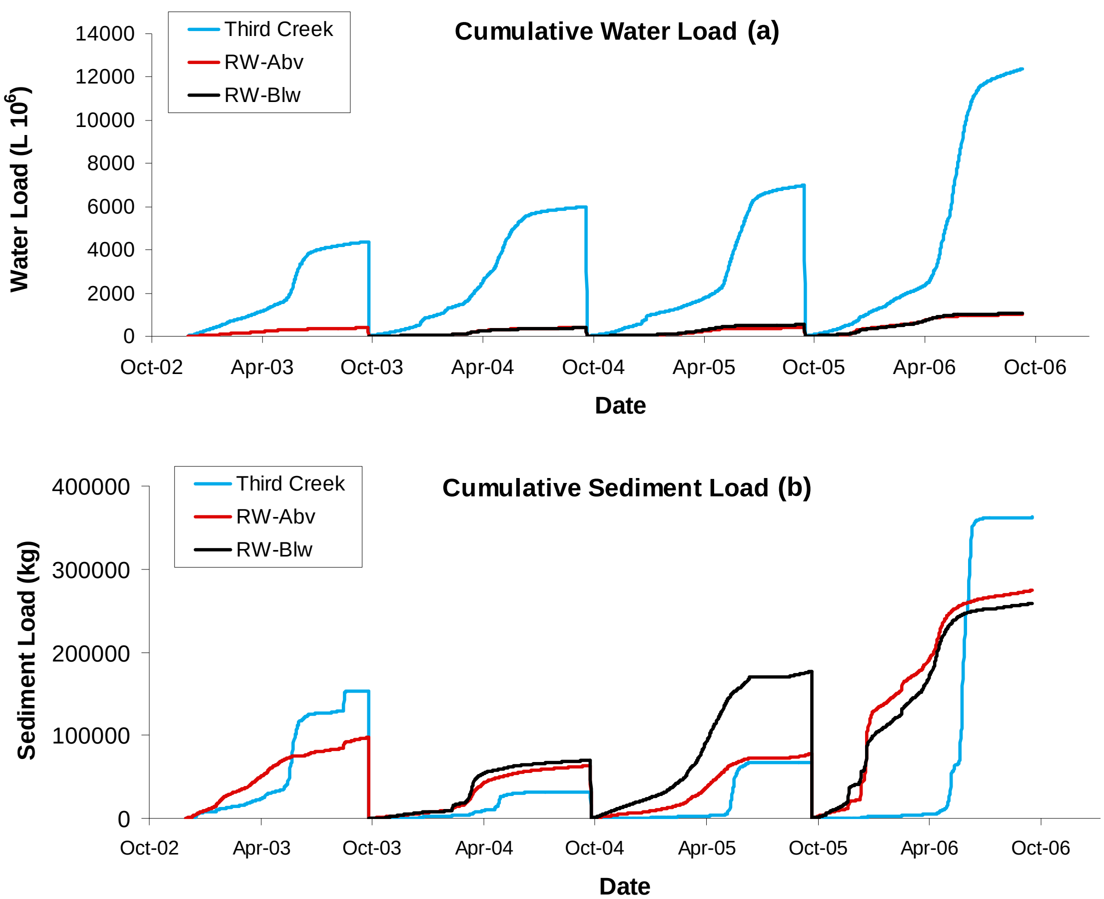

Figure 30. Cumulative water (a) and sediment (b) loading by water year.

Historical Period of Record

To provide additional context, we estimated historical sediment loads from Rosewood Creek based observations that: (a) low-elevation snowmelt preceded high-elevation snowmelt from weeks to months, and; (b) low-elevation snowmelt within the Third Creek watershed was dominated by that delivered by the Rosewood Creek watershed. Therefore, we hypothesized that the historical contribution by Rosewood Creek could be estimated by observing the relative timing of elevated seasonal discharge in Third Creek. This was accomplished by developing relationships between the suspended sediment load and daily discharge reported by the U.S. Geological Survey (USGS) National Water Information System (NWIS) for Third Creek from 1968 through the present. Total suspended sediment loads were then subsequently partitioned based on the source and timing of water delivery –

with early season snowmelt considered to be derived from the lower-elevation Rosewood Creek watershed and late season snowmelt considered to come from the higher-elevation Third Creek watershed. The date delineating low- and high-elevation snowmelt was visually determined and was typically unambiguous.

To test the suitability of this approach, sediment load estimates at RW-Abv reported earlier were compared with those derived utilizing historical Third Creek data (Table 13). During the only pre-construction year of record, 2003, Rosewood Creek accounted for 116 percent of the total Third Creek load during early snowmelt (Table 13). A contribution in excess of 100 percent indicated that sediment delivered from the faster moving Rosewood Creek into the slower moving Third Creek near State Route 28 was stored in the Third Creek channel until mobilized by higher water velocities later in the snowmelt season. Thereafter, early snowmelt sediment loads at RW-Abv ranged between 52 and 72 percent in WY 2004 through 2006, but was only 25 percent in the low water year of WY 2007. For late snowmelt, i.e., the period dominated by the upper Third Creek watershed, RW-Abv never accounted for more than 7 percent of the total load at Third Creek between WY 2003 and WY 2007. Using this approach, sediment loads estimated at the Third Creek site were expected to be lower after the completion of the restoration project in summer 2003 as it diverted Rosewood Creek around the USGS gauge so that it was no longer accounted for at the Third Creek site. This approach also double counted a small volume of water that was diverted from Rosewood Creek under high flows, as this volume was attributed to both RW-Abv and Third Creek.

Lastly, the load ratio was calculated as the ratio of low-elevation snowmelt considered to be from Rosewood Creek at RW-Abv to high-elevation snowmelt considered to be from Third Creek at USGS gaging station 10336698. For example, the suspended sediment load during early snowmelt period for Rosewood Creek in WY 2004 was 29,980 kg while the sediment load from Third Creek in WY 2004 was 57,559 kg. Dividing the Rosewood Creek load by the Third Creek load produced a low elevation load ratio of 52 percent.

Table 13. Date ranges, sediment loads, and percentage of seasonal snowmelt sediment load for the period of record, 2003-2007.

Snowmelt Period				Suspended Sediment Load (kg/period)				Percent Contribution of Rosewood to Third Creek		Load Ratio
Low Elevation		High Elevation		Low-Elevation Period		High-Elevation Period				
Start Date	End Date	Start Date	End Date	Rosewood	Third	Rosewood	Third	Low Elevation	High Elevation	Low:High
2/10/2003	5/12/2003	5/13/2003	6/21/2003	41,485	35,713	7,173	572,570	116*	1.3	0.062
3/5/2004	4/19/2004	4/20/2004	7/1/2004	29,980	57,559	11,826	206,840	52	5.7	0.278
3/2/2005	5/17/2005	5/18/2005	6/23/2005	44,482	68,425	11,014	1,068,051	65	1.0	0.064
2/26/2006	5/6/2006	5/7/2006	7/15/2006	81,301	113,291	30,703	3,603,289	72	0.9	0.031
2/24/2007	4/27/2007	4/28/2007	6/8/2007	8,391	33,471	3,560	50,346	25	7.1	0.665

*Data from 2003 were prior to the restoration project when Third Creek loads included those from both Rosewood and Third creeks.

Historical Comparison

The historical contribution of Rosewood Creek over the NWIS period of record was estimated using the snowmelt season segregation approach described above. The date ranges for the contribution from low- or high-elevation snowmelt were estimated from USGS daily load data with some influence from date ranges found during our period of record (2002 through 2007). For comparison purposes, the suspended sediment load ratio of early-season snowmelt to late-season snowmelt was computed for each water year (Table 14). The overall historical load ratio had a mean of 12.6 percent, median of 5.7 percent, and a standard deviation of 16.6 percent (n=35). For the period of overlap (2002-2007), the load ratios based on historical estimates (Table 14) compared favorably to those estimated for the period of record (Table 13), indicating the suitability of this approach.

Interestingly, the load ratio did not decrease after construction of the restoration project in 2003. The load ratio was, however, sensitive to water volume, as the relative load of suspended sediment from Rosewood was highest during lower water volume snowmelt seasons (Figure 31). This indicates that sediment loads from Rosewood Creek were more consistent, because they were less influenced by seasonal fluctuations of water volume.

Historical snowmelt suspended sediment loads estimated for RW-Abv had a mean of 55,951 kg, with a median of 36,365 kg, and standard deviation of 60,969 kg (n = 35) (Figure 32). These historical loads reflect sediment delivered only from the middle and upper sections of the Rosewood Creek watershed above State Route 28 and should be used with caution because of the number of assumptions needed to produce these estimates.

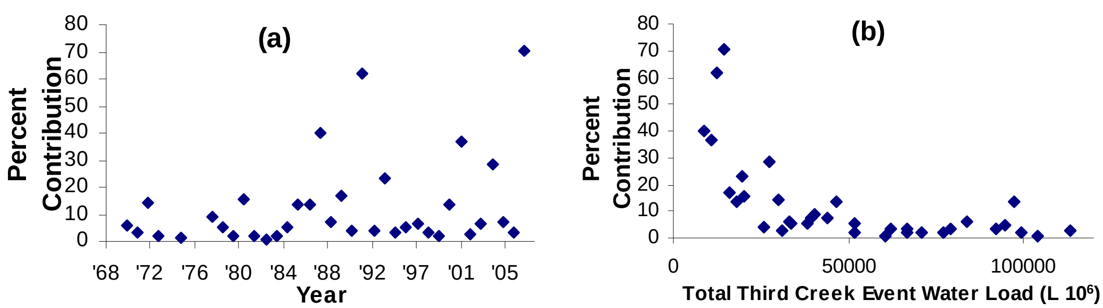

Figure 31. Load ratios a) by year, and b) versus total Third Creek snowmelt, n = 35.

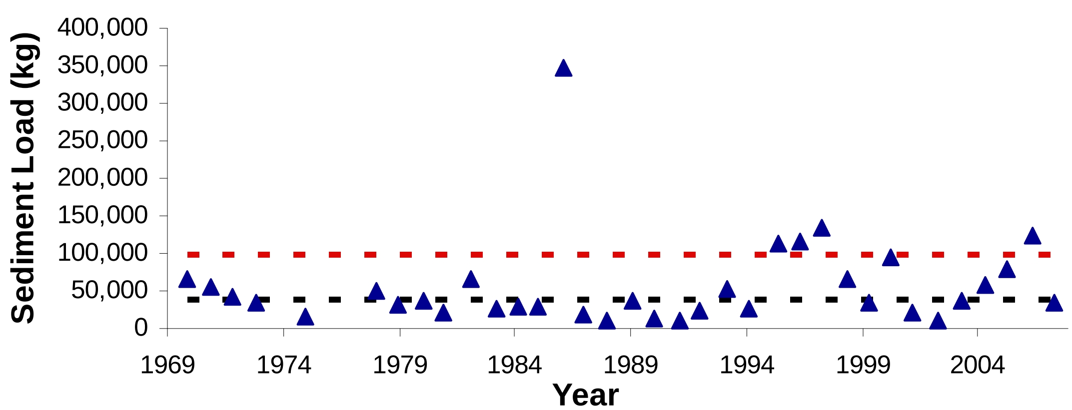

Figure 32. Historical snowmelt period sediment loads at RW-Abv, estimated from USGS loads for low-elevation snowmelt period each water year. Black dashed line is the median, red dashed line is one standard deviation.

Table 14. Results of historical comparison of early versus late snowmelt periods. The total sediment load in kilograms is given for the early and late periods. The Load Ratio is calculated for comparison to the results in Table 13.

Snowmelt Period				Suspended Sediment Load		
Low Elevation		High Elevation		Low Elevation	High Elevation	Load Ratio
Start Date	End Date	Start Date	End Date	total kg	total kg	Low:High
3/13/1970	4/18/1970	4/19/1970	7/5/1970	65,341	1,148,324	0.057
3/14/1971	4/25/1971	4/26/1971	7/21/1971	54,611	1,699,461	0.032
3/3/1972	4/19/1972	4/20/1972	6/27/1972	43,386	303,139	0.143
3/23/1973	4/19/1973	4/20/1973	6/28/1973	34,070	1,514,549	0.022
3/21/1975	4/17/1975	4/18/1975	7/23/1975	15,778	1,615,154	0.010
2/28/1978	4/30/1978	5/1/1978	7/24/1978	50,060	552,885	0.091
3/5/1979	4/25/1979	4/26/1979	7/6/1979	31,492	588,641	0.053
2/16/1980	4/5/1980	4/6/1980	8/8/1980	36,915	1,943,704	0.019
2/13/1981	4/3/1981	4/4/1981	6/15/1981	20,013	126,743	0.158
2/13/1982	4/5/1982	4/6/1982	8/21/1982	66,045	3,034,689	0.022
2/21/1983	3/29/1983	3/30/1983	9/17/1983	25,929	3,084,356	0.008
3/1/1984	4/1/1984	4/2/1984	8/8/1984	28,570	1,632,783	0.017
2/22/1985	3/28/1985	3/29/1985	6/21/1985	28,118	536,391	0.052
2/12/1986	4/17/1986	4/18/1986	7/31/1986	347,383	2,539,460	0.137
3/2/1987	4/4/1987	4/5/1987	6/4/1987	17,923	130,516	0.137
2/26/1988	3/30/1988	3/31/1988	5/19/1988	10,185	25,405	0.401
2/22/1989	3/31/1989	4/1/1989	6/28/1989	36,862	500,931	0.074
2/19/1990	3/15/1990	3/16/1990	6/4/1990	12,700	76,341	0.166
3/2/1991	4/1/1991	4/2/1991	7/4/1991	10,710	283,999	0.038
2/11/1992	4/7/1992	4/8/1992	5/23/1992	22,457	36,326	0.618
2/27/1993	4/4/1993	4/5/1993	7/26/1993	52,733	1,481,252	0.036
2/8/1994	4/10/1994	4/11/1994	6/6/1994	26,918	115,260	0.234
2/19/1995	4/19/1995	4/20/1995	9/11/1995	112,565	3,862,879	0.029
2/4/1996	4/4/1996	4/5/1996	8/27/1996	115,616	2,384,912	0.048
3/6/1997	4/13/1997	4/14/1997	8/5/1997	134,615	2,132,373	0.063
3/10/1998	4/14/1998	4/15/1998	8/19/1998	64,803	2,122,807	0.031
3/13/1999	4/11/1999	4/12/1999	7/27/1999	34,776	1,575,885	0.022
2/13/2000	4/19/2000	4/20/2000	7/8/2000	95,771	703,980	0.136
3/18/2001	4/22/2001	4/23/2001	5/23/2001	19,890	53,938	0.369
2/22/2002	3/30/2002	3/31/2002	6/28/2002	9,408	381,166	0.025
2/10/2003	5/11/2003	5/12/2003	6/21/2003	36,365	574,015	0.063
3/5/2004	4/18/2004	4/19/2004	7/1/2004	58,334	206,276	0.283
3/2/2005	5/16/2005	5/17/2005	6/23/2005	79,650	1,077,302	0.074
2/26/2006	5/5/2006	5/6/2006	7/15/2006	123,555	3,599,132	0.034
2/24/2007	4/26/2007	4/27/2007	6/8/2007	34,743	49,285	0.705

Mobilization Index

We propose the use of a mobilization index (MI) that can be used to assess the post-construction efficiency of sediment reduction. The MI defines the relative sediment load difference between that entering and exiting the restoration as a function of water volume:

$$\frac{(\text{RW-BDiv SSL} - \text{RW-Blw SSL})}{(\text{RW-BDiv Q} - \text{RW-Blw Q})}$$

where RW-BDiv SSL was the below diversion suspended sediment load, RW-Blw SSL was the suspended sediment load below the restoration, RW-BDiv Q was the water load below the diversion, and RW-Blw Q was water load below the restoration.

The MI can also be considered the relative mass of sediment retained within the restoration zone normalized by water volume. An index such as this provides the comparison of performance during all types of flow regimes and events (Figure 33). A low index number indicates less sediment transported through the project and better sediment removal efficiency. Overall, the restoration project may have a positive effect on relative sediment load reductions as the magnitude and variability in MI observed during the first two years after construction declined after October 2005. Despite lower mobilization indices in the later years, snowmelt events continued to mobilize sediment out of the restoration project (black squares and blue diamonds in Figure 33), just to a lesser degree. In 2006, a large snowpack at low elevation contributed a significant volume of water to the creek within the restoration project (black squares). A poor snowfall year in 2007, in contrast, had little low-elevation contribution (blue diamonds). The restoration project did reduce sediment loads during several events (green diamonds and red triangles), typically rain and rain-on-snow events.

The efficiency of the restoration project to reduce sediment loads can only be suitably assessed when net water volumes through the project are reduced (blue diamonds and red triangles). It is only during these events when the majority of the water exiting the project has actually traveled through the entire restoration zone and flood-spreading basins. Other events having significant surface water inflows within the project are not suitable for efficiency determination, as surface water inputs only travel through part of the project and are therefore only partly treated. Further investigation into parsing the mobilization index such as isolating and assessing mid- and high-elevation snowmelt events that have no low-elevation surface runoff component is warranted. This was not completed as part of this report because of time constraints.

Another approach to assess the potential relative mobility of streambed sediment would be to estimate the ratio of fine sediment volume to the sum of water volume plus fine sediment volume (Hilton and Lisle, 1993). For Rosewood Creek, this or similar methods of streambed sediment monitoring may provide additional information about sediment retention and mobilization over time through the restoration area. This was not completed as part of this report because of time constraints and may be included in the next report.

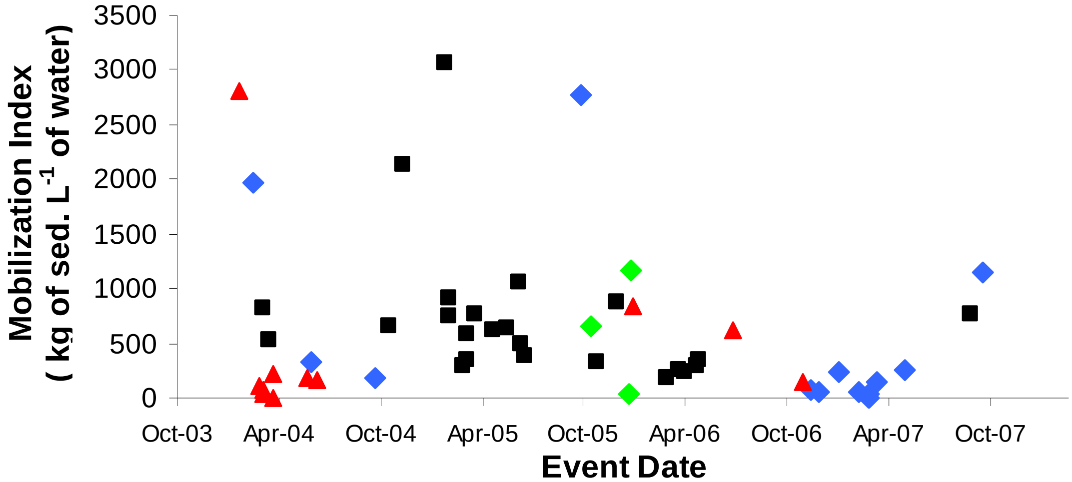

Figure 33. Results of Mobilization Index calculation, where 1) green diamonds represent events where sediment loads were reduced and water volumes increased within the restoration project; 2) red triangles represent events where the restoration project reduced both sediment loads and water volumes; 3) black squares represent events where both sediment loads and water volumes increased within the restoration project; and 4) blue diamonds represent events where sediment loads increased and water volumes decreased within the restoration project.

DISCUSSION

A fully quantitative and statistically significant comparison of how the restoration project affected sediment loads was not possible because of the inherent variability and error associated with comparing environmental measurements. Uncertainty was compounded by the need to subtract results from the two sites that were separated by 975 m to produce an estimate of suspended sediment loading. There is error associated in the measurement of turbidity, the collection and analysis of SSC samples, the derivation of the turbidity surrogate relationship, and the estimation of flow. Of these, the greatest sources of error are the two components that constitute a sediment load: estimation of SSC through the turbidity surrogate and to a lesser degree the estimation of flow. Errors presented here were solely derived from the Prediction Intervals (PI) of the turbidity surrogate regression models. Prediction Intervals provide a somewhat localized measure of error, as those regions of the estimated model that are determined by a number of accurate points will have tighter prediction intervals than regions that have fewer data points. The quality of PIs when applied to turbidity/SSC surrogate data is a direct reflection on the number and range of samples collected. Uncertainty arises when the number of peak turbidity measurements is infrequent relative to lower turbidity values. To calculate event loadings, estimated SSC and its point-wise PI were summed up over the entire time period, with on the order of 130,000 data points for a 90-day snowmelt period, for example. As it typical for streams, the summation for the PI term was dominated by a handful of high turbidity values for which few observed data points existed. To compound this problem, the dynamic changes observed within Rosewood Creek that affected the turbidity/SSC surrogate relationship made it difficult to group multiple years of data together in an effort to narrow the PIs. This was particularly important for RW-Blw, whose surrogate model changed considerably from year to year as the restoration project matured. Therefore, to provide the best estimate, yearly surrogate models were chosen to estimate sediment loading, reducing the number of points contributing to each model, and increasing the importance that high-turbidity samples over a wide range of values contributed to the overall error estimates. Therefore, the original cost-effective sampling design, which relied on the power of an aggregated surrogate model based on fewer event samples collected over a longer multi-year period, was shown to be ineffective.

The dataset provided here incorporates a weight of evidence that relates to the trends and changes observed as the restoration project matured. During the first two post-construction years, the delivery of suspended sediment from the restoration project was variable and difficult to estimate using a turbidity surrogate. The 2004 snowmelt season was difficult to assess because of the presence of coarser suspended sediment that doubled the mean particle diameter from 51 µm observed entering the project to 122 µm exiting the project. However, this coarser sediment was depleted over time as the mean diameter dropped back to lower levels at the onset of peak discharge. In WY 2005, a statistically significant regression model could not be developed due to poor correlation between SSC and turbidity at RW-Blw. The mean particle size increased from 35 µm during the initial snowmelt peaks in early March 2005 up to greater than 150 µm during the middle of the snowmelt season in April 2005. This coarse sediment was, however, not related to significant increases in either discharge or turbidity. The exact causes for this remain unknown; however, 2005 was an unusual year in that there was a greater than average snowpack at the lower elevations that resulted in a flat and elongated snowmelt period characterized by a consistent, moderately elevated discharge with low peak discharges. These relatively stable continuous flows of about 0.051 cms may have had enough energy to transport coarser sediment from upstream sources that were previously deposited at various locations within the project. Coarser-sized particles entrained in flow were not observed to be entering the restoration project during these events.

In the last two years of this study, surrogate models had higher correlation coefficients than the first two years, indicating that suspended sediment delivery from the restoration project has become more predictable. However, the correlation coefficients from RW-Blw have yet to become as significant as those at RW-Abv. Finally, the slopes of the regression models at RW-Blw have decreased year to year, indicating a decrease in the quantity of suspended sediment delivered per unit of turbidity. This observation was consistent with a shift to finer-sized particles – as the turbidity sensors were more sensitive to the presence of fine-sized particles than to coarse-sized particles. This trend was not just related to inter-annual variability in discharge, as the slope decreased between WYs 2004 to 2005 and 2006 to 2007 when the water volume passing through the restoration zone increased by a factor of 2.4. Taken together, these results highlight the changes experienced by the creek during the maturation of the restoration project and indicate that equilibrium with respect to suspended sediment delivery has not yet occurred.

CONCLUSIONS

Water and sediment loadings were provided for 60 events on Rosewood Creek based on monitoring conducted from November 2002 through September 2007. Events included an intense summer thunderstorm in 2003 (Event 8), an intense rain-on-snow event in 2006 (Event 42), as well as seasonal snowmelt events (Events 2, 12, 25, 44, and 55) over five years.

Pre-project monitoring indicated that Rosewood Creek could contribute significant suspended sediment loads to Third Creek and ultimately to Lake Tahoe. The relative contribution of suspended sediment by Rosewood Creek was the greatest during lake-level snowmelt and rainstorms that impacted low-elevation watersheds, while high-elevation water and sediment sources were dormant. During these events, Rosewood Creek can become highly turbid, whereas adjacent Third Creek can remain relatively clear, indicating a perceived sediment problem on Rosewood Creek. For example, low-elevation snowmelt (Event 2) from Rosewood Creek contributed an estimated 68,755 kg from March through May 2003, compared to 51,817 kg delivered by Third Creek during this same time period. In comparison, when high-elevation snowmelt occurred in May and June (Event 6), an additional 146,472 kg were delivered by Third Creek compared to only 19,226 kg from Rosewood Creek.

Overall, Rosewood Creek was an important contributor of suspended sediment to Third Creek. In the above example, Rosewood Creek did contribute approximately 30 percent of the suspended sediment load to Third Creek during the 2003 snowmelt season. Normalized to the watershed areas, sediment yields from each respective snowmelt period were nearly three times greater from Rosewood (29,890 kg km^{-2}; Event 2) than from Third Creek (11,010 kg km^{-2}; Event 6). The actual load of suspended sediment from Rosewood Creek was also important during some precipitation events, such as a summer thunderstorm in 2003 (Event 8) that impacted both watersheds. During this event, Rosewood Creek delivered 45 percent of the 28,833 kg mobilized from the Third Creek watershed. Despite its small area, the Rosewood Creek watershed did respond rapidly to storm events. Of the six rain events during WYs 2003 through 2005, the mean event maximum turbidity was 390 NTU for Rosewood Creek and 235 NTU for Third Creek. Nearly the entire length of Rosewood Creek flowed within an urbanized watershed, so it was very susceptible to contributions from low-elevation urban runoff. This urban surface runoff that entered Rosewood Creek could have an immediate and significant impact on stream flow increases, given that the average daily discharge for WYs 2003 through 2007 was only 0.020 cms. In contrast, urban runoff that entered Third Creek had a smaller impact, as only 10 percent of the watershed area was urbanized and had a ten-fold greater average daily flow of 0.238 cms. Assuming an equivalent load of sediment delivered to both creeks, Rosewood Creek would quickly become turbid, whereas dilution within Third Creek resulted in lower, less flashy turbidity values.

The delivery of suspended sediment from Rosewood Creek to Third Creek was altered after construction of the project. Rather than delivering its water and sediment loads into Third Creek just south of State Route 28, Rosewood Creek now travels an additional 975 m to the new confluence with Third Creek at Lakeshore Blvd. In addition to the increased channel length, two other factors may affect the delivery of suspended sediment.

First, the incorporation of flood-spreading zones into the restored channel should cause the creek to flow out of its banks under higher water conditions, providing an opportunity to slow water velocities and drop suspended sediment. Second, the slope of the channel in the restored section was much shallower than the channel slope in the middle and upper reaches of the watershed. Shallower channel slopes resulted in lower water velocities and a decrease in the potential to mobilize or retain suspended sediment in the water column. Hysteresis curves developed during the first year of post-construction monitoring show that less water energy was needed to transport sediment into the restoration zone than out of it (Figure 34), primarily due to the decreases in the slope of the creek. The net result is that the restoration project can act as a sediment sink until higher flows and water energies become available to transport this stored sediment further downstream and into Third Creek.

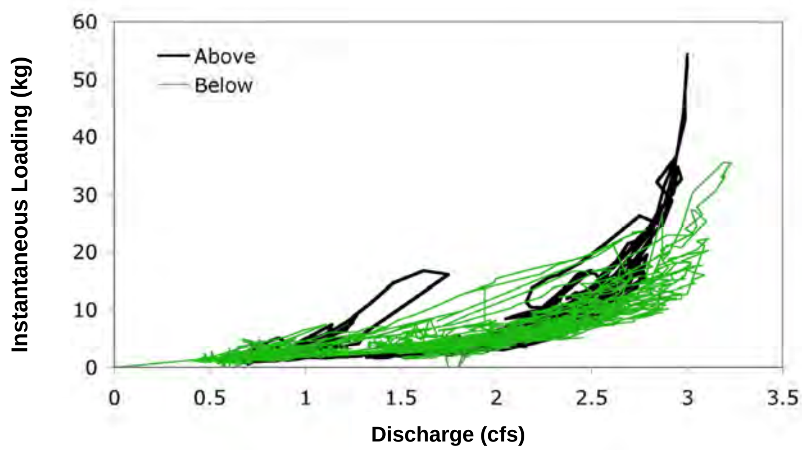

Figure 34. Hysteresis curves from monitoring sites above and below the restoration zone during the 2005 snowmelt. The y-axis is the instantaneous suspended sediment loading. Note that higher discharges are needed at the lower site to achieve the same loading.

As a result, the source and particle size of sediment entering the restoration zone is important. An initial reconnaissance of potential upstream sources using indices of bank erosion potential indicated the middle reach below Harold Way had a high bank erosion potential. This was a result of steeply incised stream banks that were characterized by a lower than average bank stabilization from the general absence of riparian vegetation. High erosion potential was also found several hundred meters upstream of the RW-Abv site because of a deep head cut and subsequent slope failures. This latter site, however, appeared to primarily contribute coarse sediment, much of which traveled in bed load as it entered the restoration project.

The delivery of suspended sediment from Lower Rosewood Creek Restoration Project at RW-Blw was primarily dependent on the volume of water (Figure 35). In general, snowmelt (triangles) delivered low to intermediate relative sediment yields, whereas rain (diamond) and rain on snow (square) were typically either low or high. Two rain-on-snow events (Events 10 and 39) and one rain event (Event 38) delivered the highest relative suspended sediment loads and water volumes. These events were of a shorter duration, less than 2.3 days, with precipitation rates of higher than normal intensity.

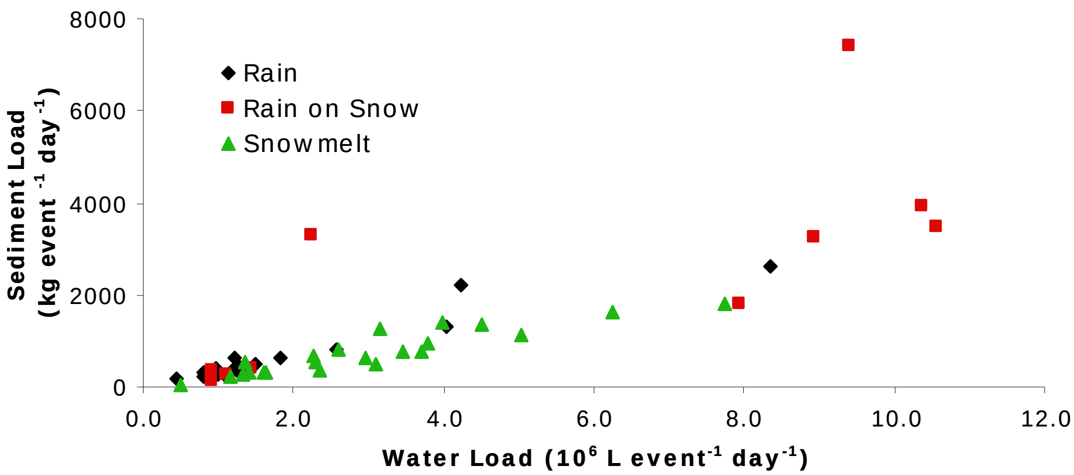

Figure 35. Water and suspended sediment loads from RW-Blw by event. Rain-on-snow events 10 and 39, and rain event 38, are the outliers.

The ability of the restoration project to alter water volumes or sediment loads was also dependent on the type of event (Figure 36). Each point in this graph was calculated as the differential loading between the RW-Abv and RW-Blw. Points in the lower left quadrant reflect events where water volumes and suspended sediment loads were lower at the bottom of the restoration project (RW-Blw) than at the top (RW-Bdiv). Points in the upper two quadrants represent events that had significant contributions of surface or urban runoff that entered the creek within the project area. In a majority of the cases, this augmentation of water also increased suspended sediment loads (upper right quadrant). However, there were several events where increased water volumes also resulted in decreased sediment loadings (upper left quadrant). These cases, however, all occurred during WY 2005 to 2006, and are likely an artifact of the nonsignificant turbidity/SSC surrogate model used to calculate sediment loads during this time period. Interpretations based on WY 2005 to 2006 data should be done with caution, as these points do not appear to match trends observed in the rest of the data.

Assuming these points were in error, the remaining snowmelt events appear to fall onto lines having different slopes, depending on the quadrant. Snowmelt events in the upper right quadrant have a shallower slope while events in the bottom left quadrant have a steeper slope. This indicates that a substantially greater decrease in water volume is needed to affect a reduction per unit of sediment load compared to the water volume needed to increase sediment loading by the same mass. However, the fact that there was a relationship in the bottom left quadrant suggests that the restoration project did, during snowmelt events, reduce suspended sediment loading into Third Creek. Events in this quadrant only included those that occurred during the 2004 and 2007 snowmelt seasons, the two lowest water years studied. For the events in this quadrant, suspended sediment load reductions were on the order of 11 to 30 percent for 2004 and 40 percent for 2007. Rain events also appeared to fall on a single line, whereas there was no trend with rain-on-snow events. The two rain events (Events 50 and 52) in the bottom left quadrant had a 28- to 30-percent decrease in suspended sediment loading.

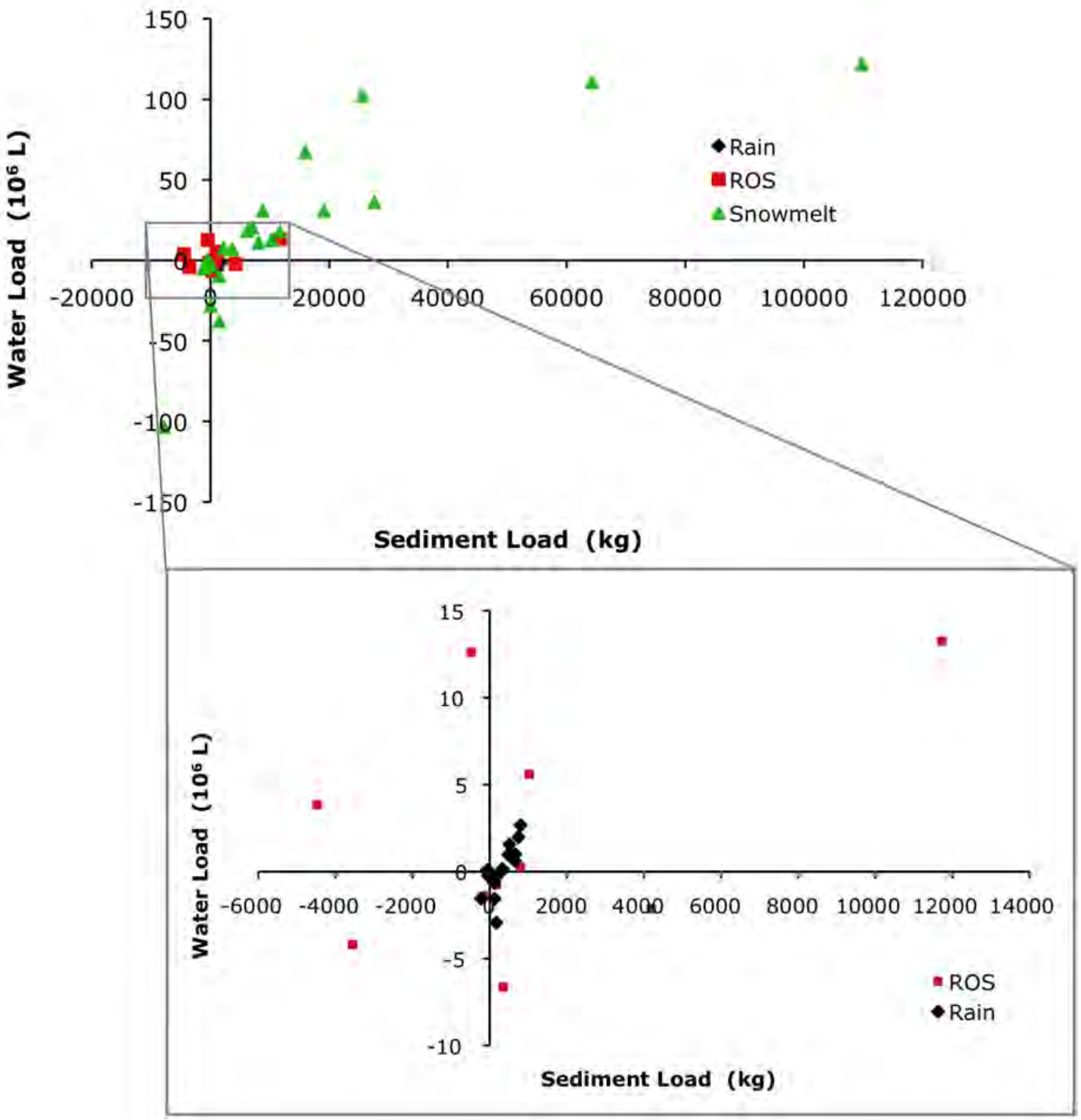

Figure 36. Reduction of suspended sediment load compared to reduction in water load from the restoration zone. Values were calculated by subtracting loads at RW-Blw from RW-Bdiv. The lower graph is an enlarged version of the boxed area in the upper graph. The upper right quadrant of the graph represents events where inputs from overland flow increased both water and sediment loads exiting the restoration project. Events in the lower right quadrant represent events where the restoration project reduced both water and sediment loads.

For most events, the efficiency of the restoration zone at reducing suspended sediment yields could not be directly assessed because the creek received significant water volumes from overland flow within the restoration project (upper right quadrant in Figure 36). The project was still likely yielding sediment reductions, but they could not be parsed from total loadings without knowledge of the sediment concentration, volume, and location of inputs to the creek. The most likely the events suitable for estimating project efficiency those where the majority of water load entered the project area through the creek at RW-Abv. Examples of these events included rain events where precipitation occurred predominately in the middle and upper reaches of the Rosewood Creek watershed or during the middle to later periods of snowmelt when the creek was fed from higher elevation snowmelt. Carefully parsing cumulative water loads and assessing those time periods that have no clear surface water inputs could yield additional effectiveness estimates.

These types of events were also more likely to exhibit reductions in suspended sediment loads, as the water would have a chance to travel through the entire length of the restoration zone. The input of surface water within the restoration zone could impact the effectiveness of the flood-spreading basins. Three conditions were necessary for the flood-spreading basins to be effective. First, there needs to be enough water traveling down the creek to over-bank and flood the spreading zones with water. Second, lower precipitation intensities result in slower water velocities that facilitate a greater residence time in the flood-spreading zone. Third, there needs to be a large enough immediate storage capacity to handle the water that over-banks the channel. Conditions for water infiltration within the flood zone would not be optimal under high precipitation intensity or when antecedent moisture conditions are too wet, such as during back-to-back rainstorms or during the falling limb of seasonal snowmelt.

RECOMMENDATIONS

Future relationships between SSC and turbidity will likely change based on new residential and commercial construction, implementation of BMPs, restoration of sections of Rosewood Creek in the middle and upper watershed, and maturity of the lower Rosewood restoration. The extent to which these factors will affect sediment loads will also be driven by the magnitude of water load in a particular water year and the types of events driving sediment mobilization. Changes in particle sources will also affect these relationships because of inherent biases in individual turbidity sensors to the size, shape, and composition of inorganic and organic particles. Therefore, changes in the SSC versus turbidity relationship over time on Rosewood Creek will be driven by these parameters. The energy and stage of a particular hydrologic event and the sources of sediment will dictate the amount and mobility of the sediment load. However, the SSC/turbidity relationship for the lower Rosewood Creek restoration section may come to equilibrium in the near future, as riparian vegetation and substrate armoring increase.

Starting in WY 2008, the sampling design was changed to collect a greater number of samples for an individual event. The additional data will be used to develop event-based turbidity/SSC surrogate models and seasonal and/or yearly models that have a greater number and distribution of points throughout the observed turbidity range. Data and interpretations found in this report will be reviewed for applicability as future surrogate models are developed.

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APPENDIX A. Turbidity and SSC of Water

List of turbidity (TU) and suspended sediment concentration (SSC) for samples collected on Third Creek and on Rosewood Creek above (RW-Abv) and below (RW-Blw) the restoration project.

Third Creek			RW-Blw			RW-Abv		
	TU (NTU)	SSC (mg/L^{-1})		TU (NTU)	SSC (mg/L^{-1})		TU (NTU)	SSC (mg/L^{-1})
12/13/02 18:10	9	34	12/11/02 18:50	31	90	12/24/03 9:50	56	321
12/13/02 21:40	29	33	12/12/02 23:20	37	11	3/7/04 14:10	27	207
1/3/03 15:50	6	5	1/7/03 22:00	17	54	3/7/04 15:10	58	337
1/3/03 16:40	6	5	1/10/03 12:50	23	67	3/7/04 17:20	45	394
1/4/03 11:20	6	6	1/13/03 15:10	20	150	3/8/04 15:00	57	686
1/4/03 12:20	6	6	1/22/03 15:30	55	260	3/9/04 16:10	50	221
1/8/03 19:30	12	22	1/22/03 18:40	249	955	3/13/04 13:30	21	394
1/8/03 19:50	5	8	1/22/03 19:00	330	1116	3/13/04 14:30	53	1332
1/12/03 4:20	8	17	1/22/03 19:20	277	842	3/13/04 15:00	46	1006
1/22/03 19:00	35	152	1/22/03 19:50	212	618	3/14/04 17:10	41	502
1/22/03 19:40	68	186	1/23/03 1:30	47	323	3/15/04 15:30	53	532
1/22/03 20:00	90	220	3/15/03 7:20	154	608	3/16/04 15:30	31	175
1/22/03 20:30	75	197	3/15/03 13:10	372	1679	3/21/04 2:10	17	180
1/22/03 21:40	42	122	3/15/03 14:30	133	894	3/21/04 2:40	17	176
1/23/03 17:20	90	253	5/3/03 9:20	36	899	3/21/04 3:40	15	160
1/23/03 17:50	134	338	5/3/03 10:30	101	786	5/27/04 7:50	15	129
1/23/03 18:30	106	263	5/3/03 11:10	41	287	5/27/04 8:40	19	150
1/23/03 19:20	64	191	6/23/03 13:10	88	275	5/27/04 12:20	13	102
3/15/03 11:00	17	180	6/23/03 15:00	371	1357	5/27/04 18:40	13	117
3/15/03 14:30	83	106	6/23/03 17:10	192	677	6/9/04 9:40	72	321
3/15/03 15:40	43	106	7/22/03 18:30	557	1583	6/9/04 10:10	42	223
5/13/03 13:10	21	181	7/22/03 19:10	285	660	6/9/04 11:40	17	138
5/13/03 19:30	47	147	7/23/03 17:50	359	907	10/19/04 11:30	23	139
5/14/03 18:50	52	196	7/23/03 18:20	194	473	10/19/04 12:00	60	261
5/21/03 6:20	14	167	8/21/03 15:20	49	289	10/19/04 14:10	41	335
5/21/03 18:00	75	376	8/21/03 17:30	510	1740	10/19/04 17:20	43	319
5/29/03 20:10	112	733	8/21/03 19:40	95	339	10/19/04 20:10	44	333
5/30/03 18:00	30	730	12/24/03 8:50	82	202	11/10/04 19:20	51	466
6/23/03 15:00	32	75	2/16/04 12:00	165	464	11/10/04 19:40	175	678
6/23/03 18:10	55	97	2/16/04 13:30	384	983	11/10/04 19:50	140	358
6/23/03 18:40	47	72	2/16/04 17:40	173	425	1/25/05 11:50	51	205
7/22/03 19:20	26	226	3/7/04 12:40	21	176	1/25/05 13:20	137	409
7/22/03 19:50	86	193	3/7/04 14:20	57	215	1/25/05 13:50	155	294
7/22/03 20:50	58	157	3/7/04 17:10	44	174	1/25/05 14:10	149	251
8/21/03 10:30	658	1486	3/8/04 14:00	57	201	1/25/05 15:30	49	284
8/21/03 11:30	244	8303	3/9/04 17:10	44	308	2/10/05 17:50	36	602
8/21/03 20:50	116	347	3/10/04 12:20	21	206	2/12/05 15:00	49	529
8/22/03 2:00	221	638	3/10/04 12:40	23	172	2/16/05 12:50	54	654
8/22/03 12:30	31	6847	3/10/04 13:10	30	193	2/26/05 15:50	57	299
10/6/03 14:10	5	3	3/13/04 13:10	23	184	2/28/05 13:30	61	336
11/7/03 13:30	4	1	3/13/04 13:30	27	222	2/28/05 14:40	95	377
12/2/03 15:20	3	1	3/13/04 13:50	30	193	2/28/05 14:50	82	322
1/5/04 12:50	4	2	3/16/04 15:30	53	166	3/10/05 14:20	59	302
2/3/04 13:20	5	1	3/16/04 15:40	54	341	3/10/05 15:20	124	477

Third Creek			RW-Blw			RW-Abv		
	TU (NTU)	SSC (mg/L^{-1})		TU (NTU)	SSC (mg/L^{-1})		TU (NTU)	SSC (mg/L^{-1})
2/16/04 19:20	30	90	3/16/04 15:50	55	256	3/10/05 17:30	93	501
3/2/04 13:30	4	2	3/24/04 18:30	21	249	3/10/05 20:30	48	478
3/9/04 11:10	4	4	5/27/04 10:00	19	104	3/11/05 10:30	19	178
3/12/04 16:20	5		5/27/04 12:20	12	127	3/19/05 15:30	18	181
3/16/04 10:20	6	7	5/27/04 18:40	12	86	3/19/05 16:30	32	216
3/23/04 14:00	11	14	6/9/04 9:10	126	309	3/19/05 17:40	16	202
3/30/04 12:10	4	5	6/9/04 9:50	88	199	3/20/05 17:10	14	239
4/5/04 11:00	8	7	6/9/04 11:00	32	197	3/20/05 17:20	15	446
4/12/04 10:30	5	9	1/25/05 11:20	82	164	3/20/05 18:30	16	248
4/12/04 17:40	6	13	1/25/05 12:20	144	291	3/31/05 14:10	23	493
4/21/04 15:00	5	5	1/25/05 13:10	97	377	4/1/05 14:50	65	308
4/28/04 11:40	25	17	1/25/05 15:00	47	291	4/1/05 15:10	48	262
4/28/04 18:10	25	28	2/28/05 11:30	54	297	4/6/05 15:20	29	399
5/4/04 18:30	25	197	2/28/05 13:30	104	382	4/6/05 23:00	20	266
5/6/04 15:30	6	13	2/28/05 16:10	45	255	4/10/05 13:50	23	507
5/20/04 16:50	6	8	3/8/05 13:00	30	272	4/10/05 15:50	20	620
6/1/04 14:10	7	5	3/9/05 14:20	56	261	4/11/05 14:20	19	306
6/16/04 13:40	1	5	3/10/05 13:50	62	452	4/11/05 19:00	18	315
7/6/04 16:30	8	3	3/10/05 14:40	107	423	4/12/05 15:50	21	615
8/2/04 15:30	3	4	3/10/05 17:50	95	268	4/12/05 20:40	15	361
9/9/04 12:00	2	3	3/11/05 12:50	39	238	4/16/05 14:30	22	1210
10/4/04 14:50	4	1	3/28/05 12:20	60	206	4/16/05 15:50	60	695
11/4/04 14:30	2	3	3/28/05 14:50	47	205	4/16/05 22:20	19	1009
12/6/04 15:20	4	1	3/31/05 12:50	21	216	4/27/05 5:20	59	424
1/5/05 14:20	8	24	4/1/05 14:10	76	272	4/27/05 6:50	124	579
2/2/05 13:10	5	3	4/1/05 17:10	44	242	4/27/05 7:20	89	378
3/2/05 15:00	6	5	4/2/05 13:40	54	259	4/27/05 9:00	49	316
3/9/05 14:30	11	7	4/2/05 17:10	46	257	4/30/05 20:20	35	584
4/6/05 16:10	6	5	4/6/05 16:50	51	281	4/30/05 20:50	65	400
4/21/05 12:40	5	4	4/6/05 18:40	49	269	4/30/05 22:20	42	287
4/27/05 7:20	13	119	4/11/05 12:30	32	210	5/5/05 9:50	27	289
4/27/05 11:20	7	14	4/11/05 14:50	42	226	5/5/05 10:30	58	307
5/3/05 14:50	8	7	4/12/05 13:20	26	205	5/5/05 12:20	44	286
5/5/05 15:50	8	12	4/12/05 21:40	20	186	10/15/05 11:00	188	1761
5/13/05 15:50	8	8	4/16/05 14:30	51	279	10/15/05 11:20	133	763
5/14/05 21:30	25	150	4/16/05 15:40	85	513	12/1/05 6:20	116	332
5/16/05 13:50	18	104	4/16/05 18:50	48	256	12/1/05 7:50	117	364
5/17/05 16:00	5	16	4/17/05 14:00	52	303	12/1/05 10:40	116	342
5/19/05 11:40	11	54	4/17/05 18:30	46	250	12/1/05 19:30	222	893
5/20/05 12:30	9	42	4/30/05 10:20	12	0	12/21/05 2:30	14	129
5/23/05 15:30	6	31	4/30/05 20:10	69	312	12/21/05 2:50	14	130
5/24/05 0:00	26	230	4/30/05 21:00	84	336	12/21/05 16:40	27	151
5/31/05 15:30	5	32	4/30/05 22:10	43	223	12/21/05 17:30	73	258
6/8/05 16:40	9	14	5/5/05 10:00	70	290	12/21/05 18:00	123	387
6/15/05 17:50	9	51	5/8/05 13:10	67	253	12/21/05 18:30	200	713
6/22/05 14:40	3	11	5/8/05 13:40	142	484	12/21/05 18:50	258	589
7/8/05 15:10	5	8	5/8/05 14:10	126	421	12/28/05 12:30	63	634
8/1/05 16:20	5	1	9/27/05 1:40	264	760	12/28/05 13:20	50	328
9/12/05 17:40	12	3	12/1/05 5:00	127	445	12/28/05 18:50	19	290
			12/1/05 7:30	171	576	12/30/05 12:00	22	366

Third Creek			RW-Blw			RW-Abv		
	TU (NTU)	SSC (mg/L^{-1})		TU (NTU)	SSC (mg/L^{-1})		TU (NTU)	SSC (mg/L^{-1})
			12/1/05 9:30	194	851	12/30/05 17:10	103	548
			12/1/05 18:50	222	1407	12/31/05 1:50	204	452
			12/21/05 17:40	226	985	12/31/05 5:40	104	201
			12/21/05 19:50	227	1383	12/31/05 8:00	181	519
			12/22/05 6:20	299	296	12/31/05 17:30	57	249
			12/30/05 15:10	138	808	2/27/06 8:20	95	516
			12/30/05 16:20	201	1339	2/27/06 8:40	126	518
			12/30/05 22:50	181	1569	2/27/06 10:30	90	571
			4/3/06 1:00	24	598	2/27/06 14:00	103	714
			4/3/06 2:10	96	1199	2/27/06 15:00	139	786
			4/3/06 3:10	137	477	4/3/06 1:50	25	266
			4/25/06 17:00	112	552	4/3/06 2:40	70	429
			4/25/06 19:00	226	1036	4/3/06 6:20	44	261
			4/25/06 19:20	165	845	4/27/06 16:10	77	272
			4/25/06 19:40	123	635	7/21/06 20:20	27	117
			7/21/06 21:20	16	138	2/9/07 12:00	102	514
			2/9/07 13:30	110	288	2/10/07 11:50	178	504
			2/9/07 13:40	116	292	2/10/07 13:00	131	267
			2/10/07 11:10	154	471	3/13/07 16:20	23	264
			2/10/07 11:50	118	317	3/13/07 20:00	13	150
			3/13/07 15:50	22	133			
			8/31/07 13:10	56	164			

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APPENDIX B. Loadings and Errors

Each of the turbidity versus suspended sediment regressions has an inherent associated error. This error is best represented by the correlation coefficient (R^2), which is a measure of the discrepancy between the two parameters when compared against each other; the closer R^2 is to 1, the less divergence. The power of the relationship is described by the *p*-value of the regression, with values less than 0.05 being considered significant. Many regression forms were examined for their representation of the *in situ* relationship between SSC and turbidity for each event date range at two sites (Table 7). Many permutations of independent variables and types of regressions were performed apart from those presented here. For example, water temperature and/or EC were considered in addition to turbidity as part of multiple linear regressions but did not improve the predictive power of the equation. Likewise, log transformation of the dependent and/or the independent variables did not significantly improve the correlation coefficient to justify their use. Polynomial relationships were also investigated and found to better fit observed data than linear forms. Polynomial models were not reported, however, because they resulted in unrealistic, exponentially higher SSC estimates at higher turbidity values.

For consistency across the period of record, the regressions used for calculating loadings were chosen based on yearly data, not exclusively for their R^2 or *p*-value. The number of SSC samples taken during the year did influence the strength of these relationships.

Prediction intervals (PI) were calculated for each year at each site with 95-percent confidence (Figures B1 and B2). These PIs determined the maximum and minimum predicted continuous SSC values, which were then transformed into upper and lower sediment loads for each event. Regression models with poorer correlation coefficients had wider PIs that resulted in greater load estimates. Models with correlation coefficients above 0.50, like those for RW-Abv (equations 6A through 10A), have narrower PIs than those with lower correlation coefficients, such as for RW-Blw (Equations 7B through 13B). Water loads and estimated suspended sediment are presented in Table 8 by event, with PI-based errors depicted in the daily loading graphs in the section on rain events.

The accuracy of the SSC versus turbidity regressions may translate into small or large ranges for the resultant predicted event loads. The event load upper prediction was greater than the regression predicted load by as little as 28 percent, as with equation 10A, to as much as a 718 percent increase, as with the Third Creek regression. Equation 10A produces small prediction intervals because the SSC and turbidity values have a small range and have small residual errors from the regression equation. The Third Creek regression has a high PI range because the range of sample values is large, up to 8,300 mg L^{-1} SSC.

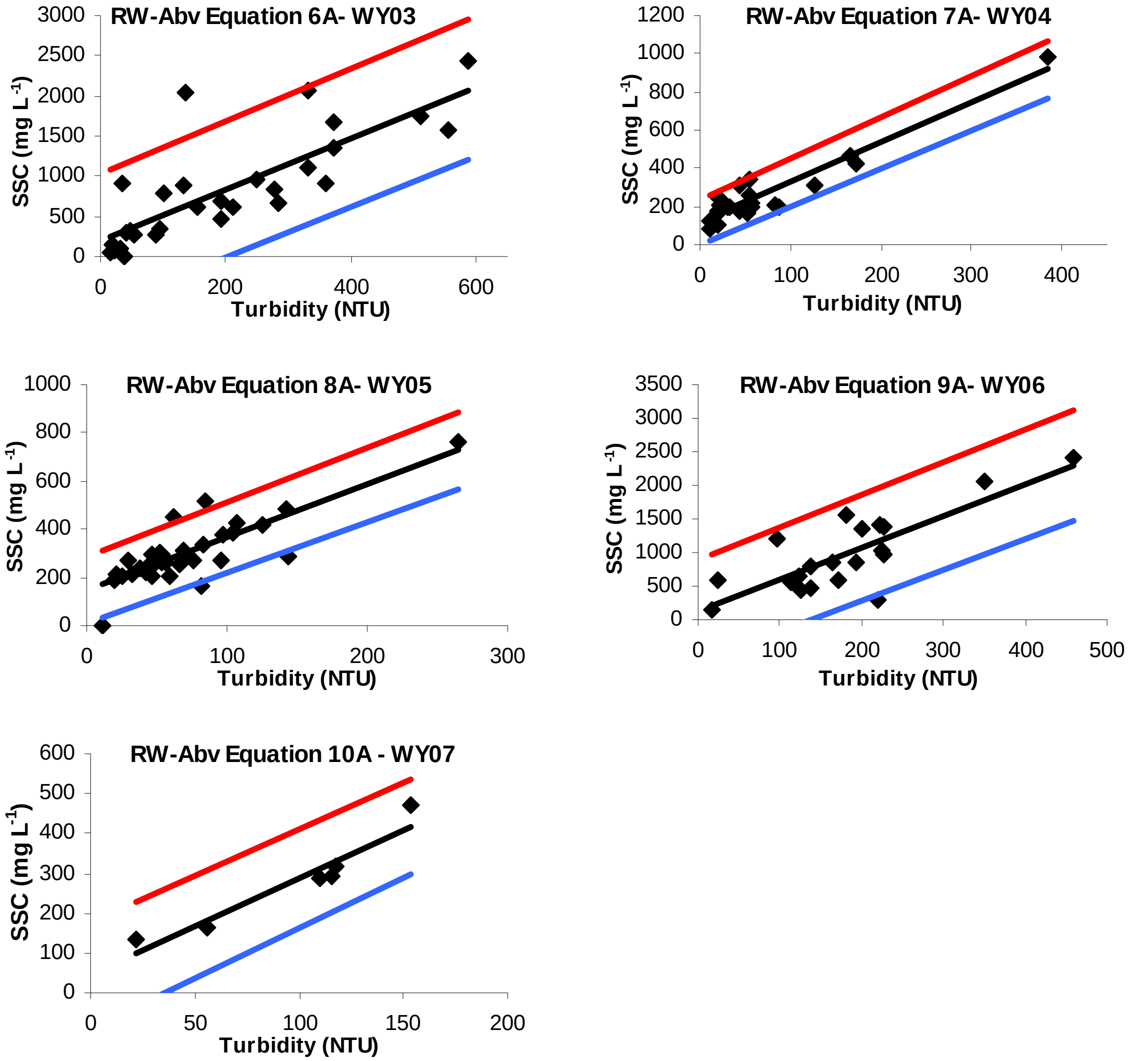

Figure B1. Plots of turbidity and SSC data, regression equations, and 95-percent prediction intervals (red and blue lines) for the State Route 28 (RW-Abv) site.

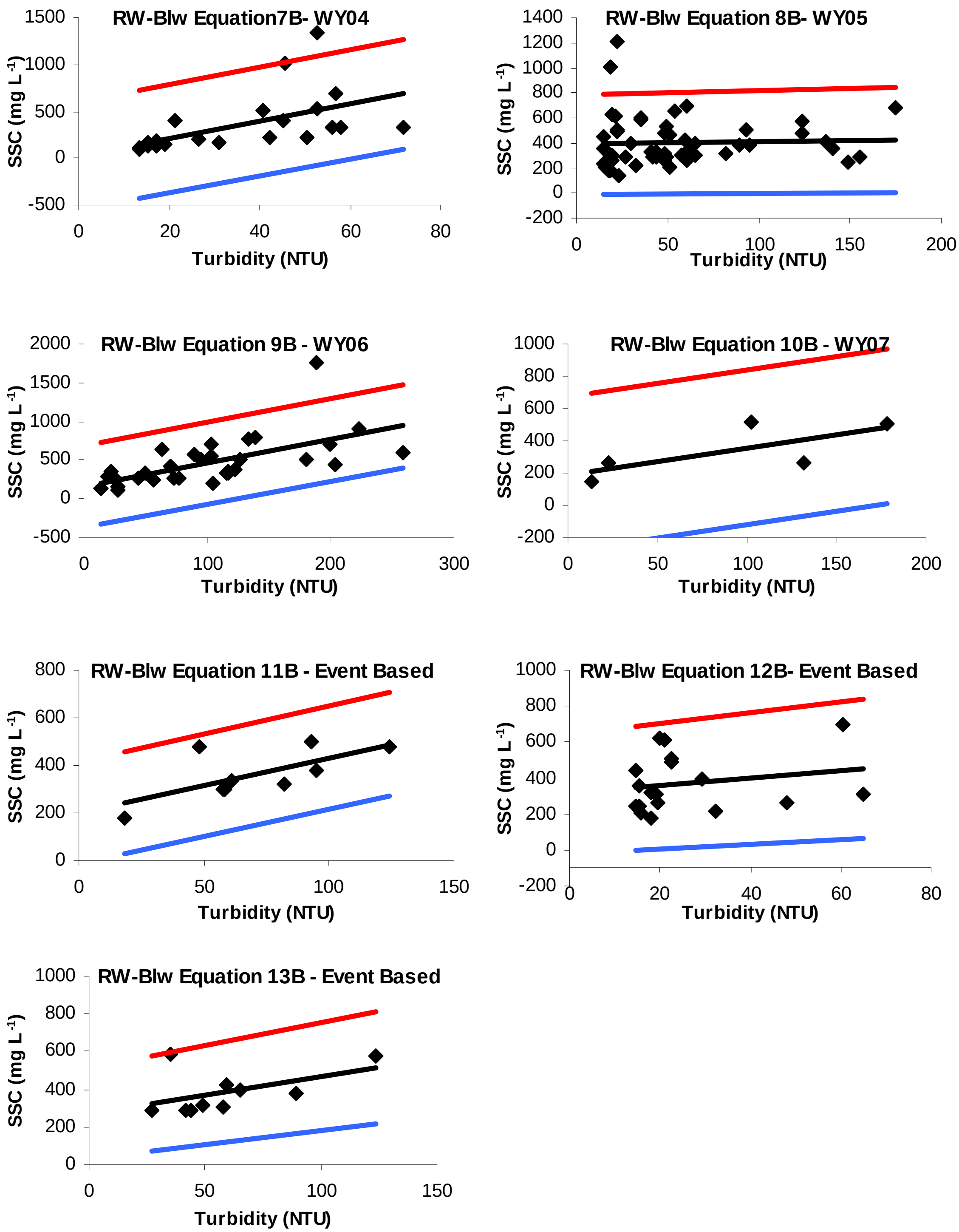

Figure B2. Plots of turbidity and SSC data, regression equations, and 95-percent prediction intervals (red and blue lines) for the RW-Blw (Lakeshore) site.