Rosewood Creek Monitoring Compendium 2002-2010

Chapter 1: Introduction

Chapter 2: Lower Rosewood Creek Restoration Project: Suspended Sediment Loads and Particle Size, 2002-2007

Richard B. Susfalk and Brian Fitzgerald

Chapter 3: Lower Rosewood Creek Restoration Project: 2007-2010

Section A: Introduction and Methods

Section B: Suspended Sediment Loads and Particle Size

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Section C: Chemistry and Water Temperature

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Chapter 4: Major Findings and Conclusions

Prepared by
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ABSTRACT

Rosewood Creek is a small, urban creek in the northeastern part of the Lake Tahoe Basin whose waters can become highly turbid during hydrologic events. Multiple restoration projects have either been constructed or are in the planning stages in an effort to improve the surrounding stream environmental zone and mitigate the delivery of sediment into Third Creek and ultimately Lake Tahoe. The two most recently completed projects are the Lower Rosewood Creek Restoration Project constructed during 2003 below Highway 28 and Area F of the Middle Rosewood Creek Restoration Project constructed during 2007 near Harold Drive. This report presents data collected above and below the lower project area during water years (WYs) 2003 to 2010 and for an additional site above the middle project area during WYs 2008 to 2010. Turbidity, water temperature, and specific conductance were measured continuously in-stream with discrete water samples collected during 88 hydrologic events analyzed for suspended sediment concentration and particle size analysis. Starting with WY 2008, samples were analyzed for common water chemistry constituents on an event mean concentration basis. Median constituent concentrations were found to decrease downstream while median constituent loads typically increased indicating that while urban surface water inputs diluted creek water its added volume was significant enough to increase constituent loads.

Suspended sediment loading was estimated using continuous in-stream turbidity readings as a surrogate for suspended sediment concentrations. Rosewood Creek was observed to contribute significant loads to Third Creek on an individual event basis, however seasonal snowmelt from the upper Third Creek watershed greatly dominated the load of sediment delivered by these watersheds into Lake Tahoe. Within the Rosewood Creek watershed, snowmelt events delivered two orders of magnitude more suspended sediment than rain or rain-on-snow events. The first two snowmelt seasons after construction of the Lower Rosewood Creek Restoration Project were characterized by higher sediment loads that were comprised of coarser-sized particles attributed primarily to the effects of construction disturbance. The mass of sediment delivered to the restoration project from upstream sources and the net loading of sediment through the project for all event types has typically been lower during the last four snowmelt seasons (WYs 2007 to 2010). This was a result of a combination of low seasonal snow pack and the growth of vegetation within flood spreading zones that enhances sediment deposition. The load of suspended sediment exiting the lower restoration project was, on average, 494 ± 403 kg day^{-1} less than that entering the project during 12 of 30 rain events monitored. This trend was not observed during the other rain events and was not observed at all during rain-on-snow or snowmelt events. These events typically included a significant input of unmeasured sediment and surface runoff from low elevation sources adjacent to or within the project area that confounded the estimation of net sediment loads through the project. Losses due to sediment deposition in the project's flood spreading zones appeared to be offset by these lower elevation inputs. Additional monitoring during higher snowfall years that are at least equivalent to WYs 2005 and 2006 would be required to provide performance information in years with normal or above average snowpack.

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CHAPTER 1: INTRODUCTION AND OBJECTIVES

Rosewood Creek is a small, urban tributary located within the Third Creek watershed in Incline Village, Nevada (Figure 1-1). Incline Village experienced heavy development in the 1960s and 1970s that caused excessive sediment erosion to the lake (Glancy, 1988). Once in the lake, suspended sediment can have a direct negative impact on visual water clarity (Jassby *et al*., 1999) and sediment can also serve as a source of nutrients that may stimulate algal growth in the lake.

In recent decades, urban development has slowed and sediment erosion rates have subsequently decreased (Rowe *et al*., 2002). However, watersheds within Incline Village still have high rates of erosion and nutrient yields compared to other basin streams. The Third Creek watershed has been rated as one of the highest contributors of average monthly *yield* of suspended sediment to the lake (Rowe *et al*., 2002) with Rosewood Creek an important sediment contributor to that yield (Simon et al., 2003). In an effort to reduce sediment loading, multiple restoration projects along various reaches of Rosewood Creek have either been conducted or are planned.

Lower Rosewood Creek Restoration Project

The Lower 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 stream environmental zone to more native conditions. This project increased the overall length of Rosewood Creek by approximately 975 linear meters, resulting in the relocation of its confluence with Third Creek from 60 m downstream of State Route 28 to just upstream 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 travel before discharging into the higher-velocity waters of Third Creek; 2) providing erosion control measures and a healthy riparian zone around the creek capable of mitigating poor water quality; 3) routing the creek through five flood-spreading basins to provide some hydrologic detention; and 4) construction of a storm detention basin to pre-treat water entering the creek above Incline Way.

Peak flows into the Lower Rosewood Creek Restoration project area controlled by a diversion structure located at the upstream end of the project. Water exits the structure either into Rosewood Creek or is diverted into Third Creek depending on the positioning of the headgate boards. After construction, the boards were positioned to only allow up to 0.40 cubic meters per second (cms) into the lower Rosewood Creek reach (Miller, 2004). This was done to protect the project from high-flow erosive damage while the vegetation matured. In 2007, the boards were reconfigured to allow up to 0.68 cms as recommended in the Project Operations and Maintenance Plan (Miller, 2004).

The overall objectives of research and monitoring for the Lower Rosewood Creek Restoration Project 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.

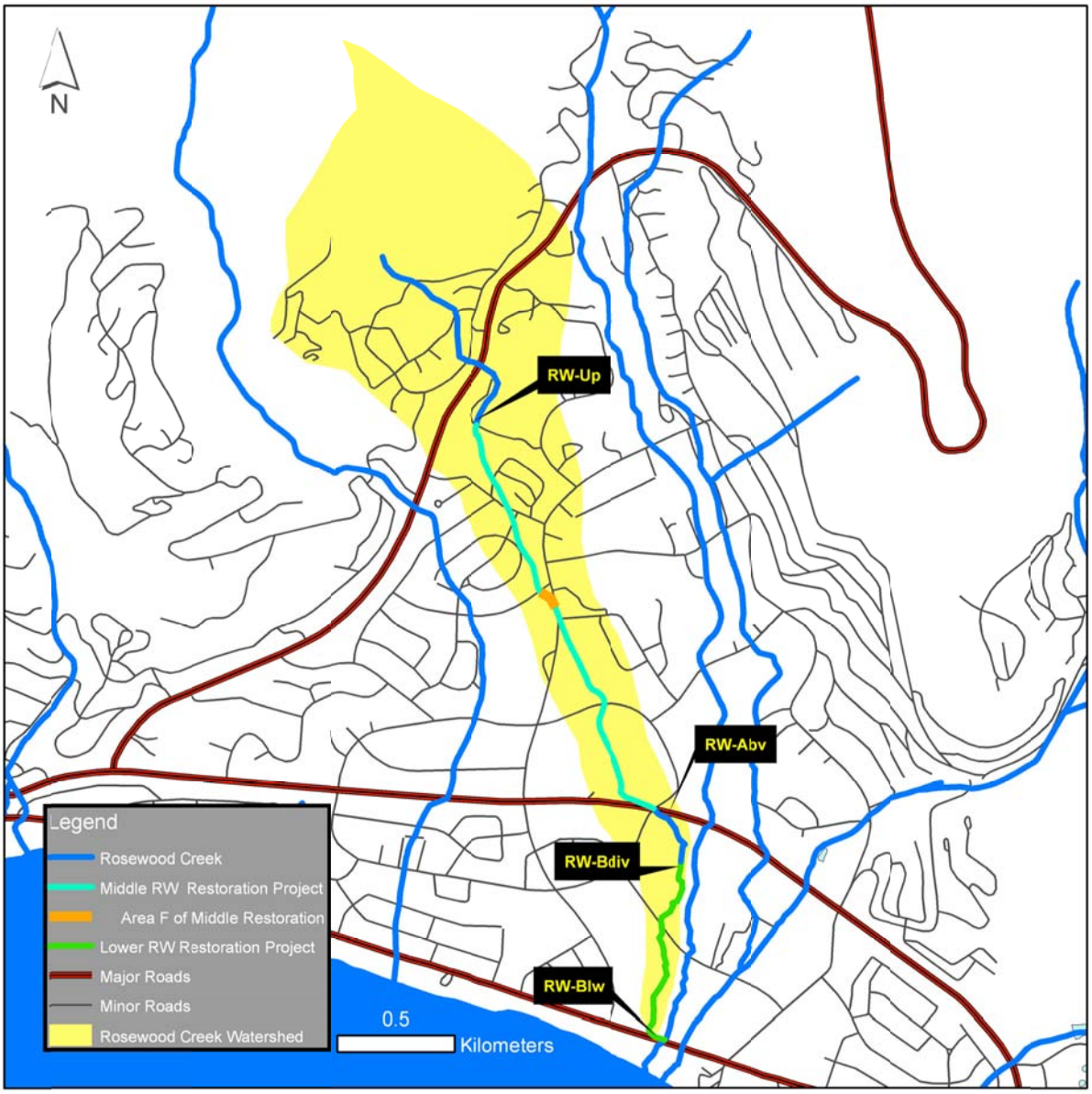

Figure 1-1. Map of the Rosewood Creek Restoration Project (green reach) within Incline Village, NV. Primary water quality monitoring sites are at RW-Blw, RW-Abv, and RW-Up. The diversion to Third Creek (not shown) is immediately above RW-BDiv. Discharge was the only parameter measured at RW-Bdiv. Area F (orange reach) of the Middle Restoration Project (light blue reach) was constructed in 2008. The project area extends south from the diversion that was installed as part of the restoration project.

Pre-project monitoring was initiated in November 2002 and monitoring continued through June 2010. Data collected at each site included continuous measurements of water discharge, turbidity, specific conductance (SC), water temperature, with discrete measurements of suspended sediment concentration (SSC) and particle-size. Water chemistry sampling was initiated by the Middle Rosewood Creek Restoration Project and was conducted within both restoration projects between 2007 and 2010.

Middle Rosewood Creek Restoration Project

The Middle Rosewood Creek Restoration encompasses approximately 2,250 linear meters of channel from State Route (SR) 28 upstream to SR 431.While the lower restoration project attempted to remove sediment load already entrained in the creek, the focus of middle reach restoration projects attempt to control the sources of sediment. For example, part of the middle reach has been incised over 3 m and multiple large headcuts are migrating upstream. The size of the middle reach has necessitated breaking the restoration effort into individual project "areas." One area was restored in 2008 (Area F) and another is projected for restoration in 2011 (Area A).

Area F is a 215 m section of the middle reach of Rosewood Creek located on private land from Village Blvd upstream to College Drive. Area F was restored in September 2008 and involved constructing six grade control structures in the creek, removal of numerous creek-spanning logs, stabilizing creek banks, and installing a new stormwater treatment feature between College Drive and the creek (Figure 1-3).

Area A is a 730 m linear section of the middle reach of Rosewood Creek also located on private land from SR 28 to 60 m upstream of Northwood Blvd. The proposed design will construct a new creek channel and fill in the highly degraded existing channel. Construction is scheduled to begin August 2011 and should be complete by October 2013.

Document Overview

The purpose of this document is to provide a compendium of research and monitoring activities that have occurred on Rosewood Creek between 2002 and 2010. Following this introduction, Chapter 2 contains an interim report previously delivered to the Nevada Division of State Lands presenting results from suspended sediment monitoring at the Lower Rosewood Creek Restoration Project between 2002 and 2007. Chapter 3 contains results from both the Lower and Middle Restoration Projects from 2007 through 2010, and is divided into two discrete sections with Part A detailing suspended sediment and Part B detailing water chemistry results. Lastly, the final chapter presents an overview of major results and conclusions presented in the previous chapters.

Figure 1-2A. Pictures of the Lower Rosewood Creek Restoration Project. The two uppermost pictures show a flood-spreading basin near Lakeshore Blvd during construction and during the snowmelt season two years after restoration. The pictures at the bottom show flooding of the channel during a rain event after completion of the project (left) and springtime flooding of a flood spreading basin six years after completion.

Figure 1-2B. Pictures of the flood spreading basin north of Incline Way. Clockwise from the upper left: 1) during construction; 2) during the third winter after completion; 3) during late snowmelt six years after completion; and, 4) during late snowmelt 2.5 years after completion.

Figure 1-2C. Pictures from the upper boundary of the Lower Rosewood Creek Restoration Project. From top to bottom: 1) Overland flow on the south side of Hwy 28 sourced from the surface flow from the golf course and BMP detention basin on the north side of the road; 2) Delivery of this overland flow (upper right portion of the picture) through a rip-rap structure into the creek (lower left); and, 3) The diversion structure looking downstream. Rosewood creek is to the right, with large flows diverted to Third Creek on the left. The Third Creek side check boards were removed by vandals at the time of this photo.

Figure 1-3. Outfall of Rosewood Creek from the culvert under College Drive before (a) and after (b) construction.

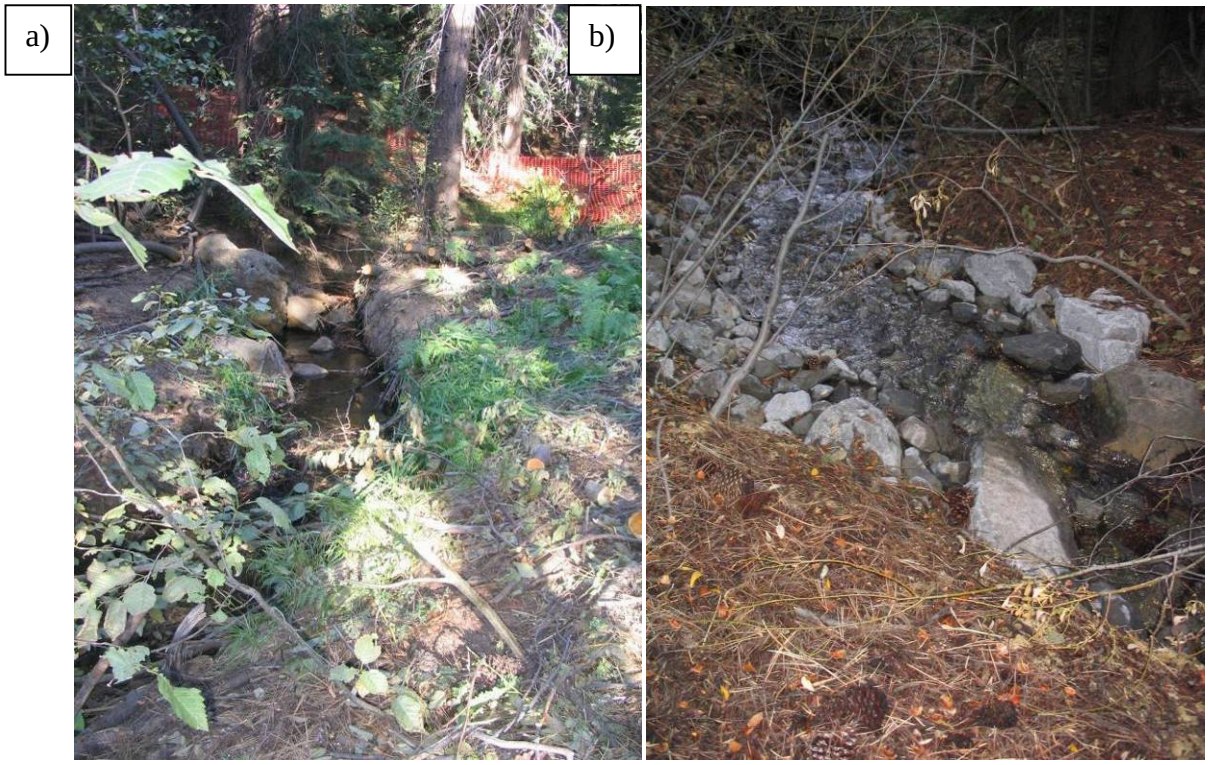

Figure 1-4. Grade Control Structure before (a) and after (b) construction.

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CHAPTER 2: 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 hydrologic events that affected only the lower-altitude sections of the Rosewood Creek watershed. 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 (suggesting) 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 that did not experience significant surface runoff contributions, the restoration project reduced sediment loads by a total of 14,000 kg during 10 events and increased sediment loads by 9,000 kg during the other 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.

INTRODUCTION

Rosewood Creek is a small, urban tributary located within the Third Creek watershed in Incline Village, Nevada (Figure 2-1). 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 2-2); and 4) construction of a storm detention basin to pre-treat water entering the creek above Incline Way.

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.

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.

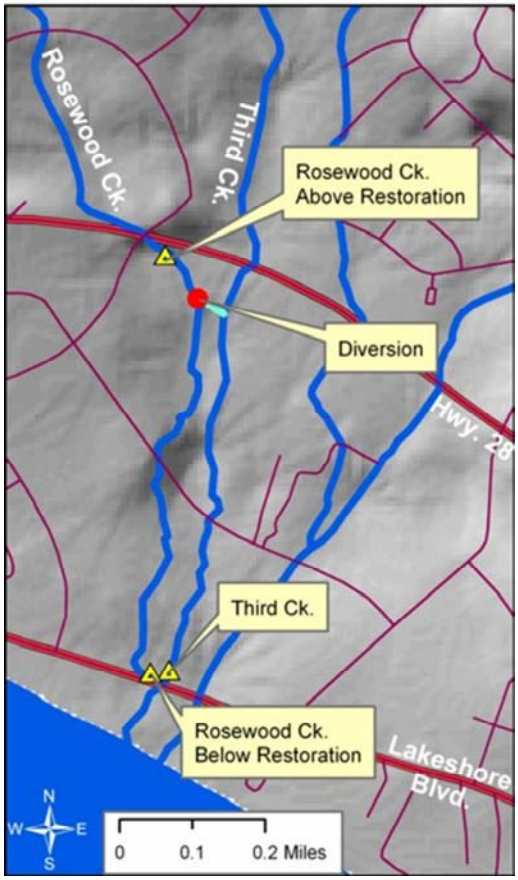

Figure 2-1. Map of the Rosewood Creek Restoration Project within Incline Village, NV. Water quality monitoring sites are denoted by yellow triangles. The project area extends south from the diversion that was installed as part of the restoration project.

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

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 2-1). 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 sensor'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 2-3). 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:

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

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

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

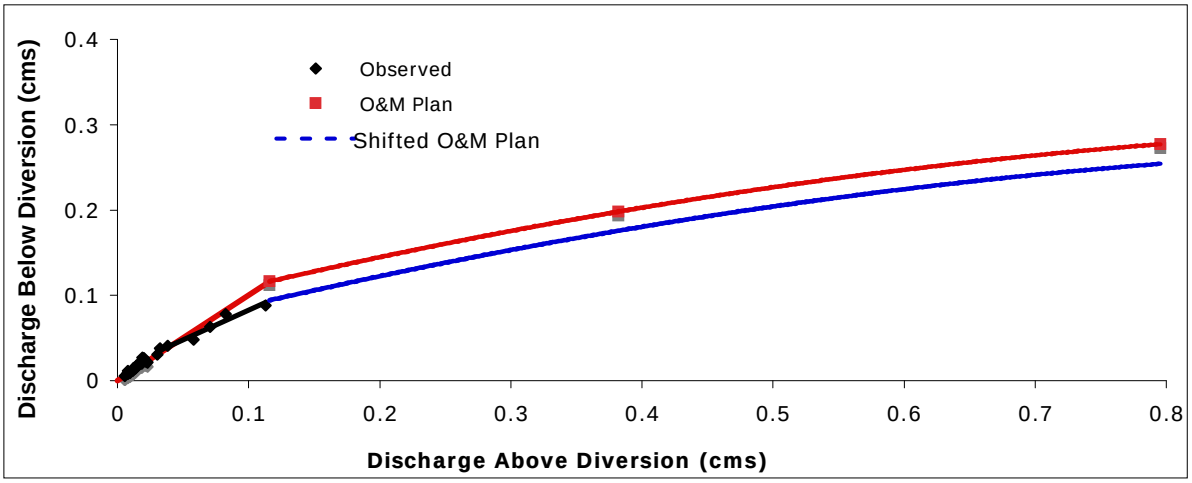

Figure 2-3. Alteration of discharge as it passes through the diversion structure at the top of the restoration project. The diversion structure had one board open to Rosewood Creek and one board closed to Third Creek during the period of observation.

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 ($x_1, \ldots, x_n$, 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 Whom It May Concern: 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, coefficients of determination 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 2-1). The hydrographs during each of the four post-construction years show a striking year-to-year variability (Figure 2-5). 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 2-5).

Turbidity levels in Rosewood Creek were found to be very responsive to small changes in discharge (Figure 2-5 and Tables 2-2 through 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 2-6). 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 2-5). 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 2-4) 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.

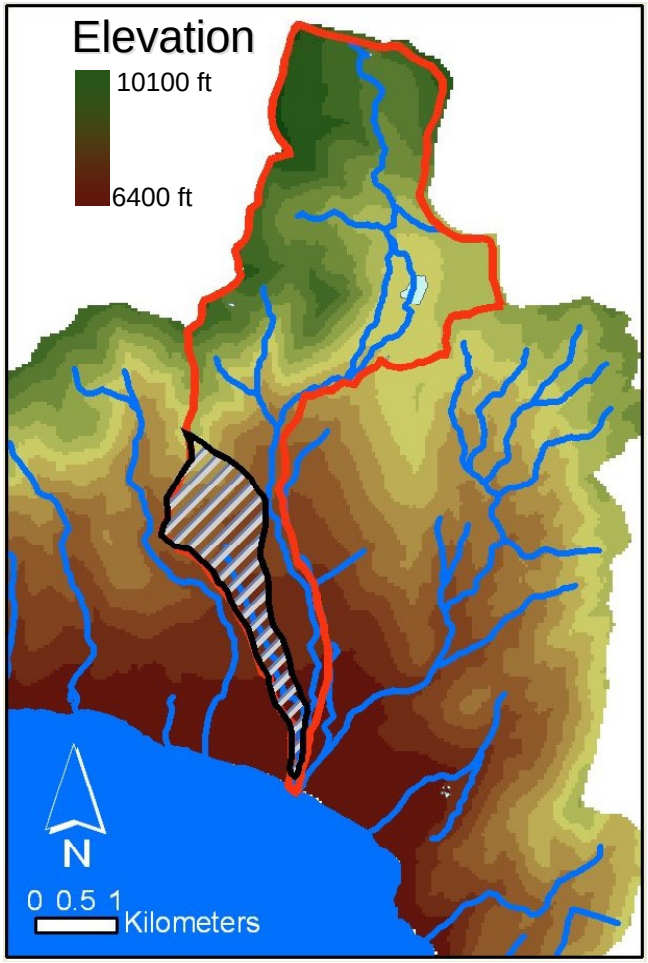

Figure 2-4. Elevation map of the Third (red outline) and Rosewood (black outline, hatched) creek watersheds.

Summary statistics for SSC, turbidity, EC, and water temperature are presented in Tables 2-2 through 2-4. 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.

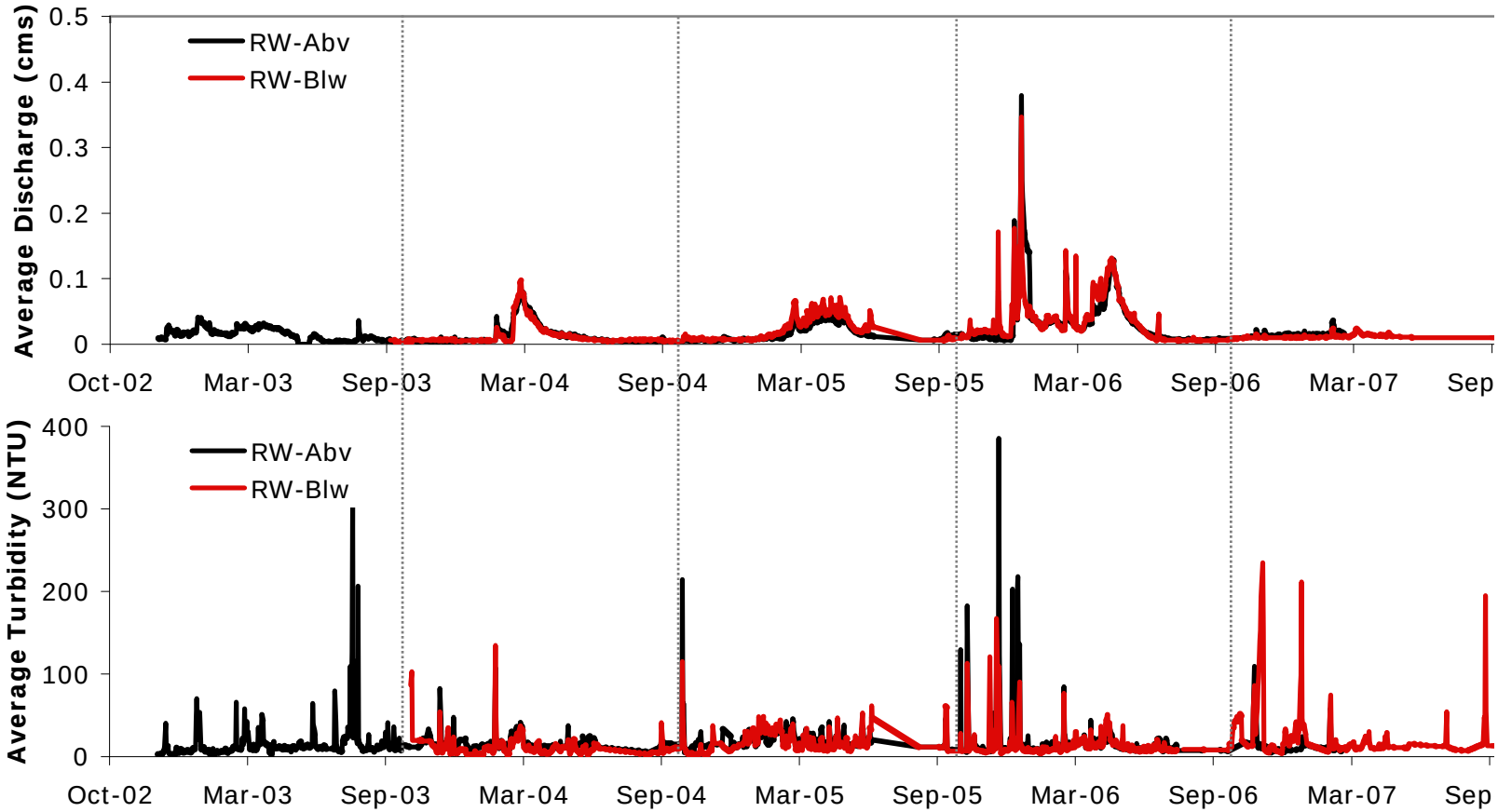

Figure 2-5. Average daily discharge and average daily turbidity above (RW-Abv) and below (RW-Blw) the restoration project. Dashed vertical lines represent water years. The use of daily averaged data reduces the fluctuation observed in the 10-minute interval dataset, such as presented in Tables 2-1 through 2-4.

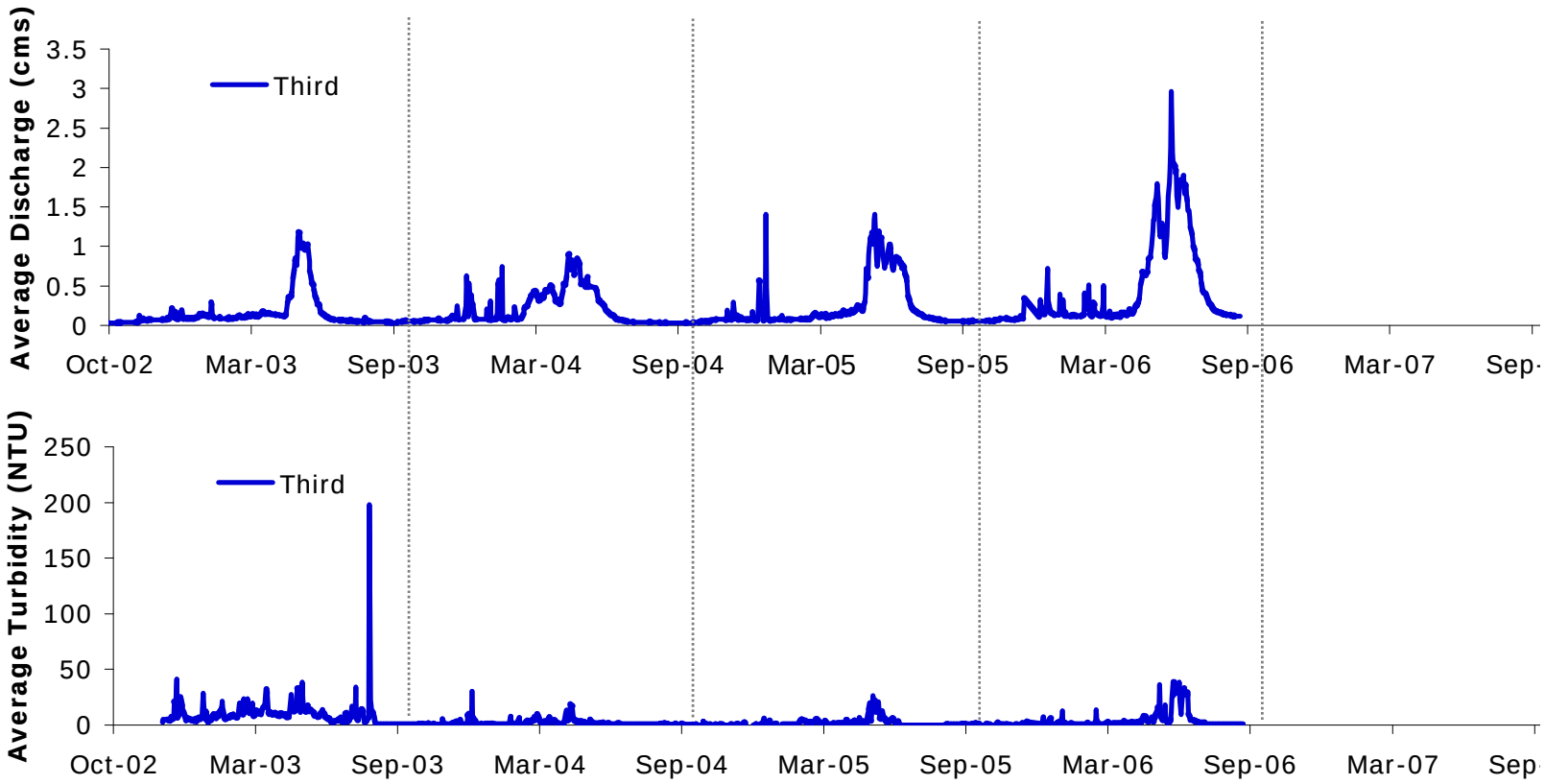

Figure 2-6. Average daily discharge and average daily turbidity at the Third Creek site.

Table 2-1. 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 2-1. 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 2-2. 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 (^{o}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 2-3. 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 2-4. 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 ($\mu S\ cm^{-1}$)			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 2-5. 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 2-7). 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 2-8 and on a sample basis in Figure 2-9 and Table 2-6. 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.

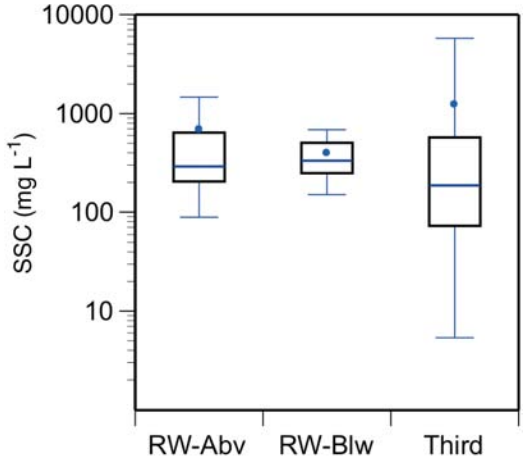

Figure 2-7. Suspended sediment concentration box plot for the period of record. The top, bottom, and middle line of the box correspond to the 75th, 25th, and 50th percentile (median), respectively. The whiskers extend from the bottom 10th percentile and the top 90th percentile. The filled circle within 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.

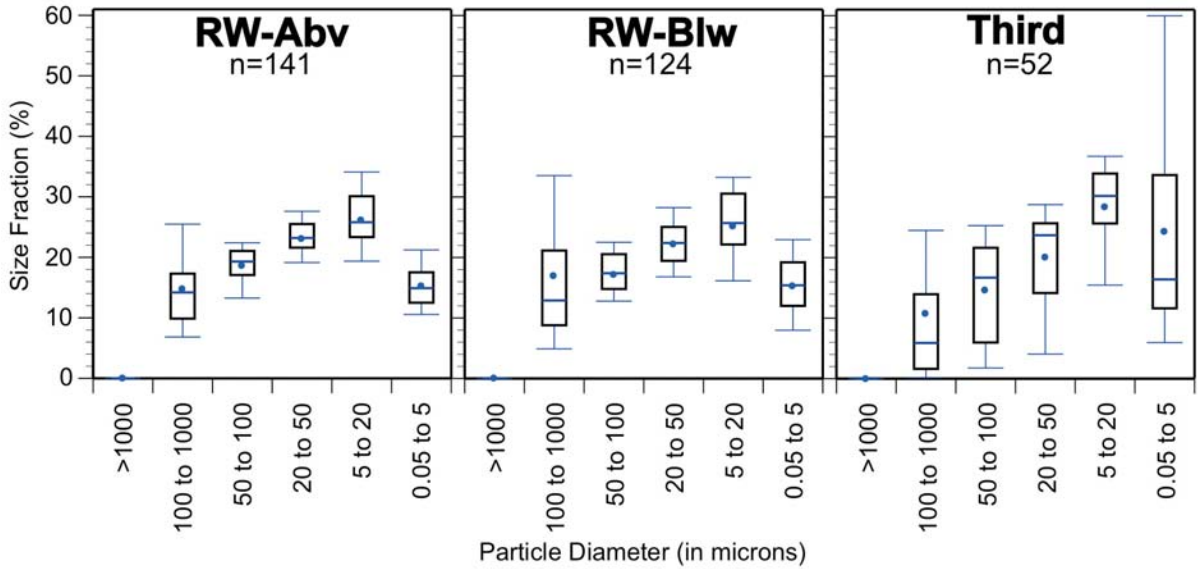

Figure 2-8. Particle size distribution box plot for all suspended sediment samples by site. See Figure 2-7 for definition of box plot symbology.

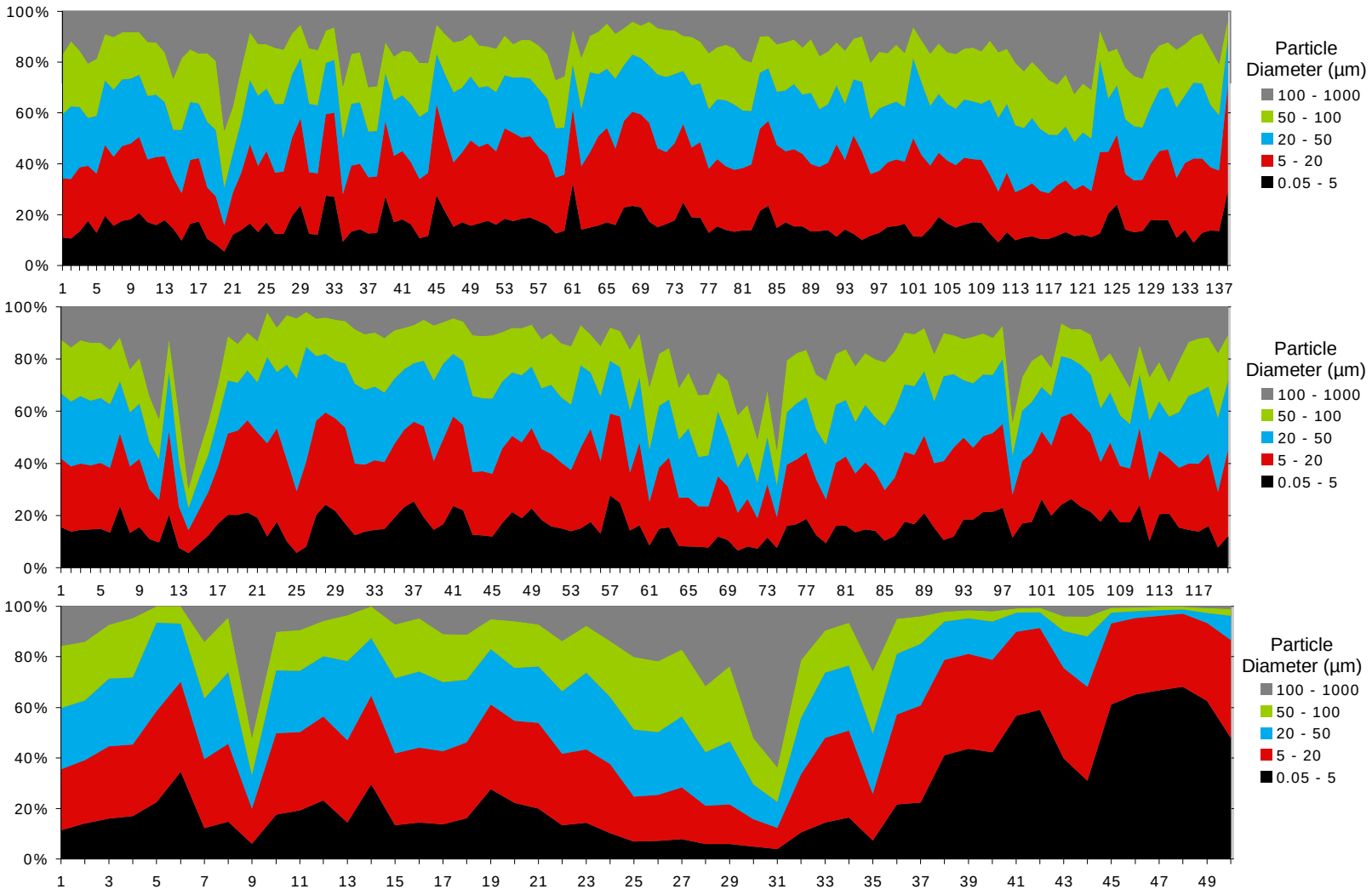

Figure 2-9. Particle size distribution of suspended sediment samples by site. The x-axis denotes the sample number collected at each site. See Table 2-6 for event key. Particle size fractionation is denoted by different colors for different size fractions.

Table 2-6. Sample collection times for samples shown in Figure 2-9.

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 2-1) 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 lower 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 Creek monitoring site. Therefore, Third and Rosewood Creek discharge must be summed together after July 7, 2003 to represent the same watershed areas that were measured by the Third Creek site alone prior to July 2003.

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 2-10). 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 2-9). 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 2-11).

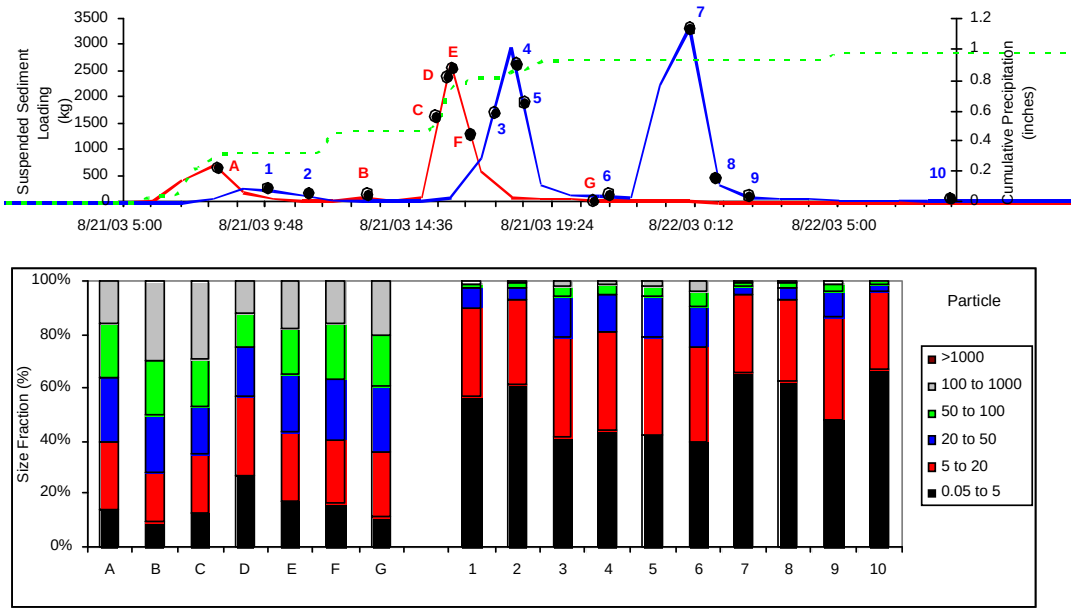

Figure 2-10. Particle size distribution for water samples collected at RW-Abv and Third during the August 21, 2003, thunderstorms. The top graph shows the suspended sediment loading at RW-Abv (red line) and Third (blue line), and the cumulative precipitation measured below Tyrol Village (dotted green line). The particle size distribution of samples collected at RW-Abv (A-G) and Third (1-10) are shown in the lower graph.

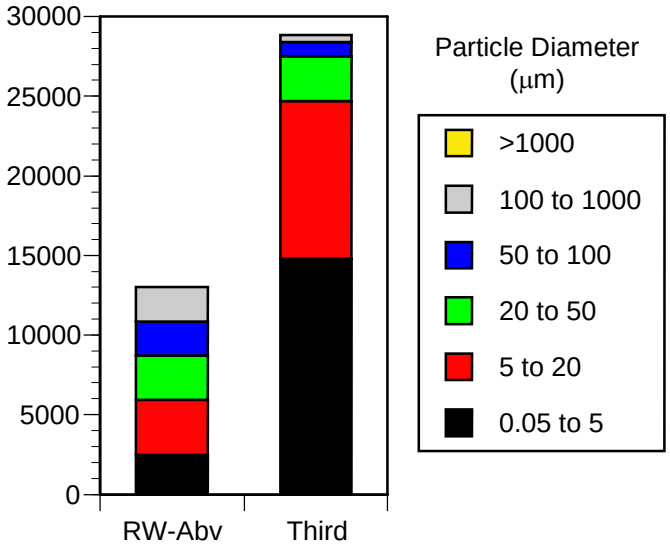

Figure 2-11. Total suspended sediment loading, by particle size during the August 21, 2003 thunderstorms (Event 8).

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 2-12). 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 2-7. 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 coefficient of

determination (R^2) of the regression models using this approach was 0.70 at RW-Abv (regression 1A, Table 2-7), 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.

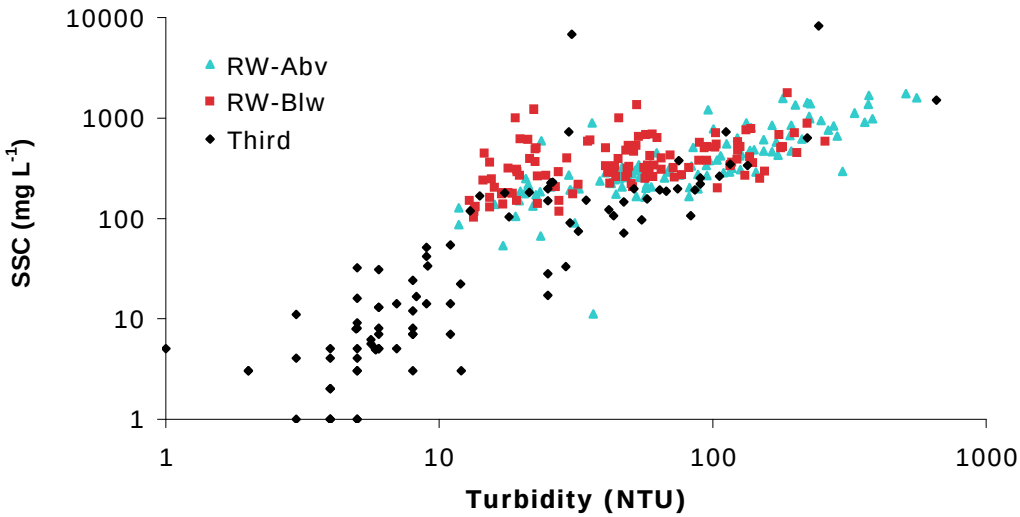

Figure 2-12. Comparison of SSC from discrete water samples and in-stream turbidity for all sites. See Appendix A for tabular form of this data. RW-Abv, n = 121. RW-Blw, n= 114. Third, n = 89.

To test this hypothesis, supplementary regressions were also developed by splitting the post-restoration time-period in half (regressions 3 to 5 in Table 2-7) to better understand how these models change through time. Below the restoration, the 0.15 coefficient of determination of the combined model (regression 2B including WYs 2003 to 2007) dropped to 0.01 during the early period (regression 4B including WYs 2003 to 2005) and increased to 0.37 during the later period (regression 5B including WYs 2005 to 2007). This indicated that suspended sediment delivery at RW-Blw was not as predictable and more highly variable during the first two years after construction compared to the subsequent third and fourth years. Additionally, coefficients of determination for models above the restoration zone were considerably better (0.68 and 0.76 for regressions 3A and 3B), indicating that factors within the restoration project contributed to a significant decline in the ability to predict sediment delivery exiting the restoration project (regressions 4B and 5B).

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 coefficients of determination ranging from 0.63 to 0.90. For RW-Blw, WY 2003 to 2004 had higher coefficients of determination, WY 2004 to 2005 remained poor, and WYs 2005 to 2007 coefficients of determination remained unchanged. Further investigation revealed that dividing the season (regression 8B) 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 improved coefficients of determination and significant or near significant *p*-values. The regression model specific to the intervening period (regression 12B) did not improve, however.

Table 2-7. 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 2-8 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 2-7 also provides event-specific models (regressions 14 to 30). In many cases, particularly at RW-Blw, event-based regressions yielded models with higher coefficients of determination, 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. Construction of the restoration project itself resulted in an unusually high variability in the relationship between SSC and turbidity in the early years of the restoration. 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 2-13. 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 2-2) 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 2-14). 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 project.

Table 2-8. Suspended sediment and water loadings by event. RW-Abv is above the diversion, whereas RW-Bdiv is below the diversion. Both Linear and polynomial models were used to calculate loading at RW-Abv. 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	Event	Event	Event	Linear	Total Suspended Sediment Load (kg event^{-1})				Water Load (10^6 L event^{-1})			
Numbe	Type	Start	End	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	--

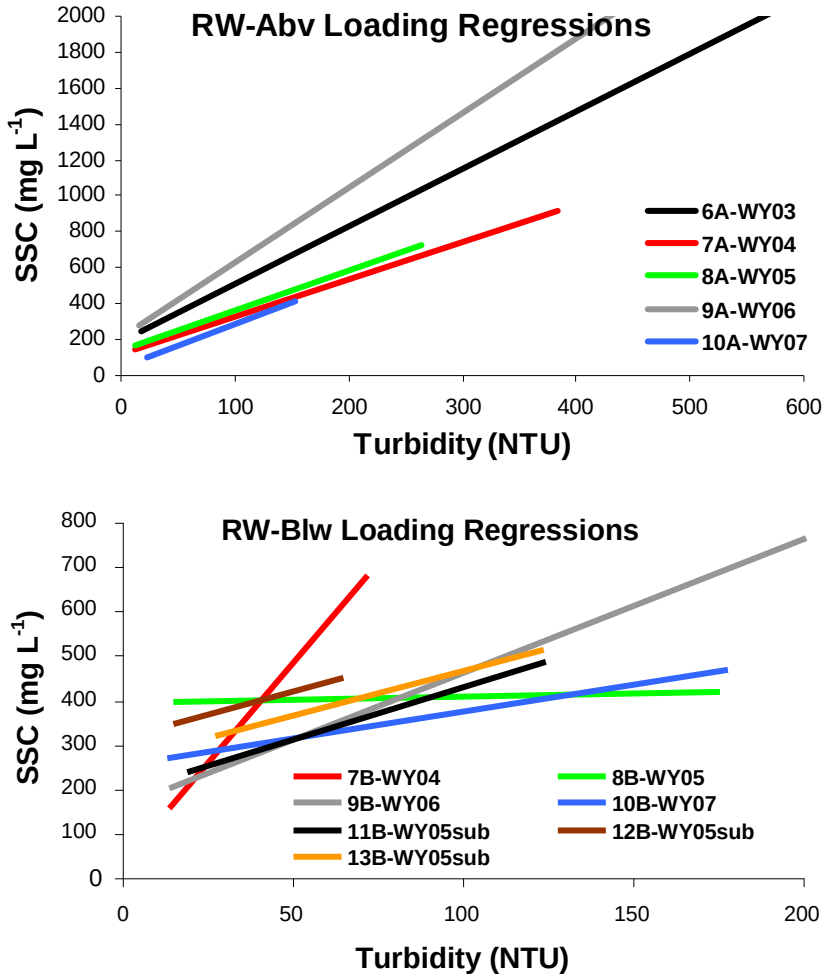

Figure 2-13. Visual comparison of regression models used (Table 2-7) to estimate suspended sediment loading from RW-Abv (top) and RW-Blw (bottom). Number of samples for each regression can be found in Table 2-7.

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

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

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.

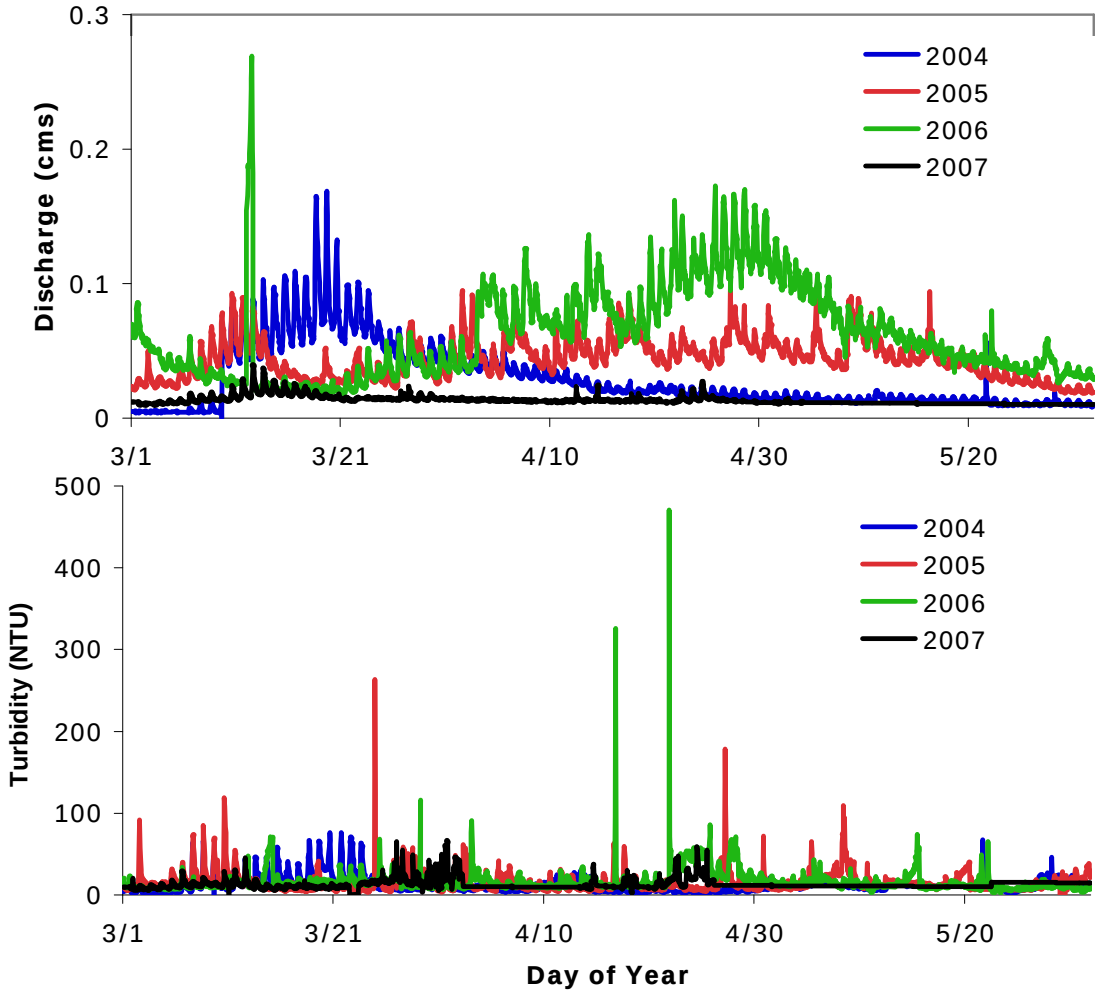

Figure 2-14. Comparison of average hourly discharge and turbidity during snowmelt at RW-Blw.

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 2-14). 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. RW-Blw was exceptional in the poor correlation between SSC and turbidity in WYs 2003-2005.

RAIN EVENTS

There were 20 rain events that occurred after the construction of the restoration project through WY 2007 (Figure 2-15). On Rosewood Creek, these events delivered from 60 to 13,000 kg of suspended sediment in conjunction with 0.3×10^6 to 7.8×10^6 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 2-16), was the largest post-construction rain event, delivering an estimated 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 2-17), 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 2-16), 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.

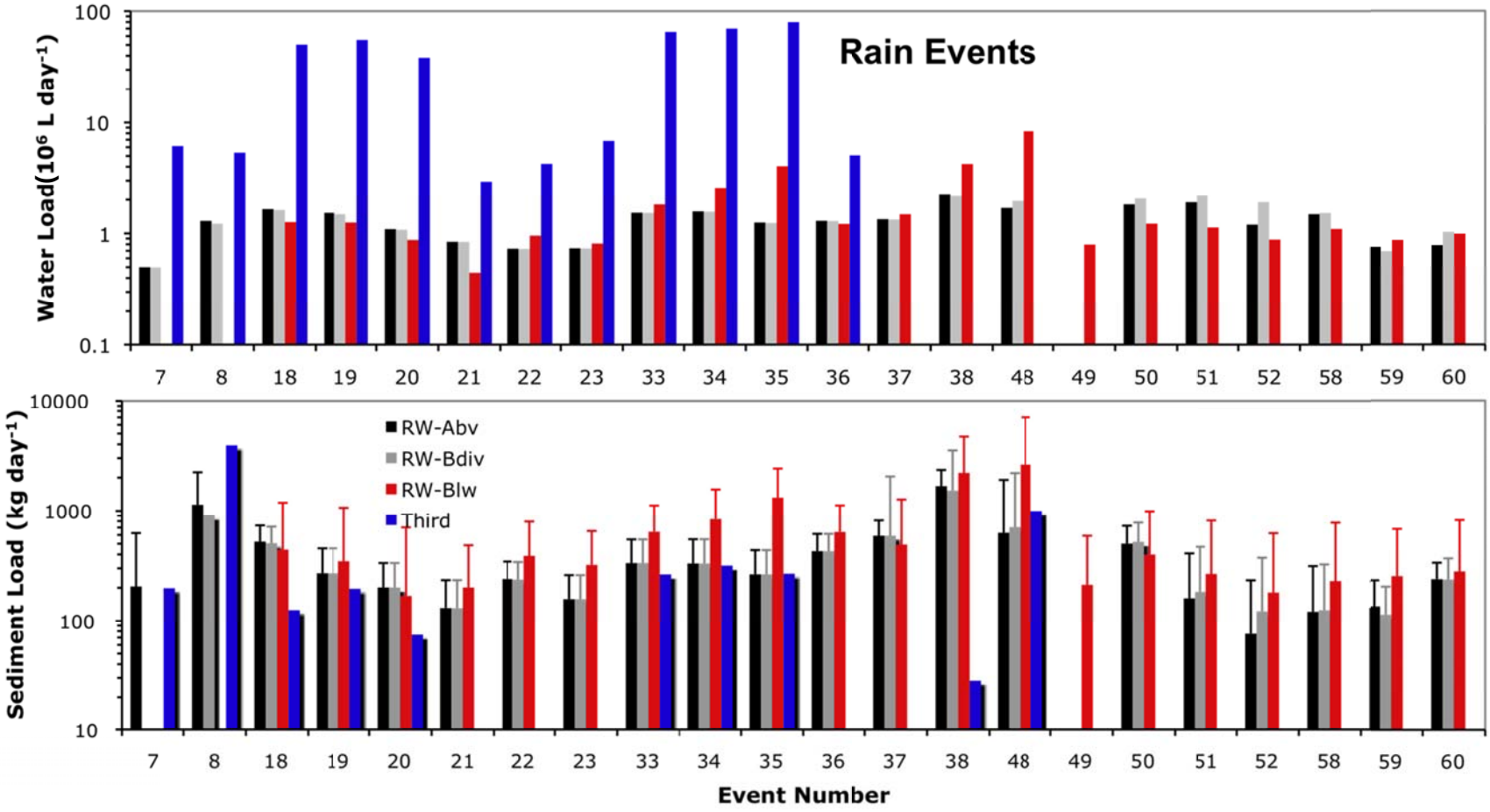

Figure 2-15. Average daily water loading (above) and suspended sediment loading with error bars (below) for all rain events. RW-Abv reflects conditions above the diversion structure whereas RW-Bdiv estimates conditions below the structure on Rosewood Creek. Error bars are the standard error of measurements. See the section on methods for additional discussion of how RW-Bdiv was calculated.

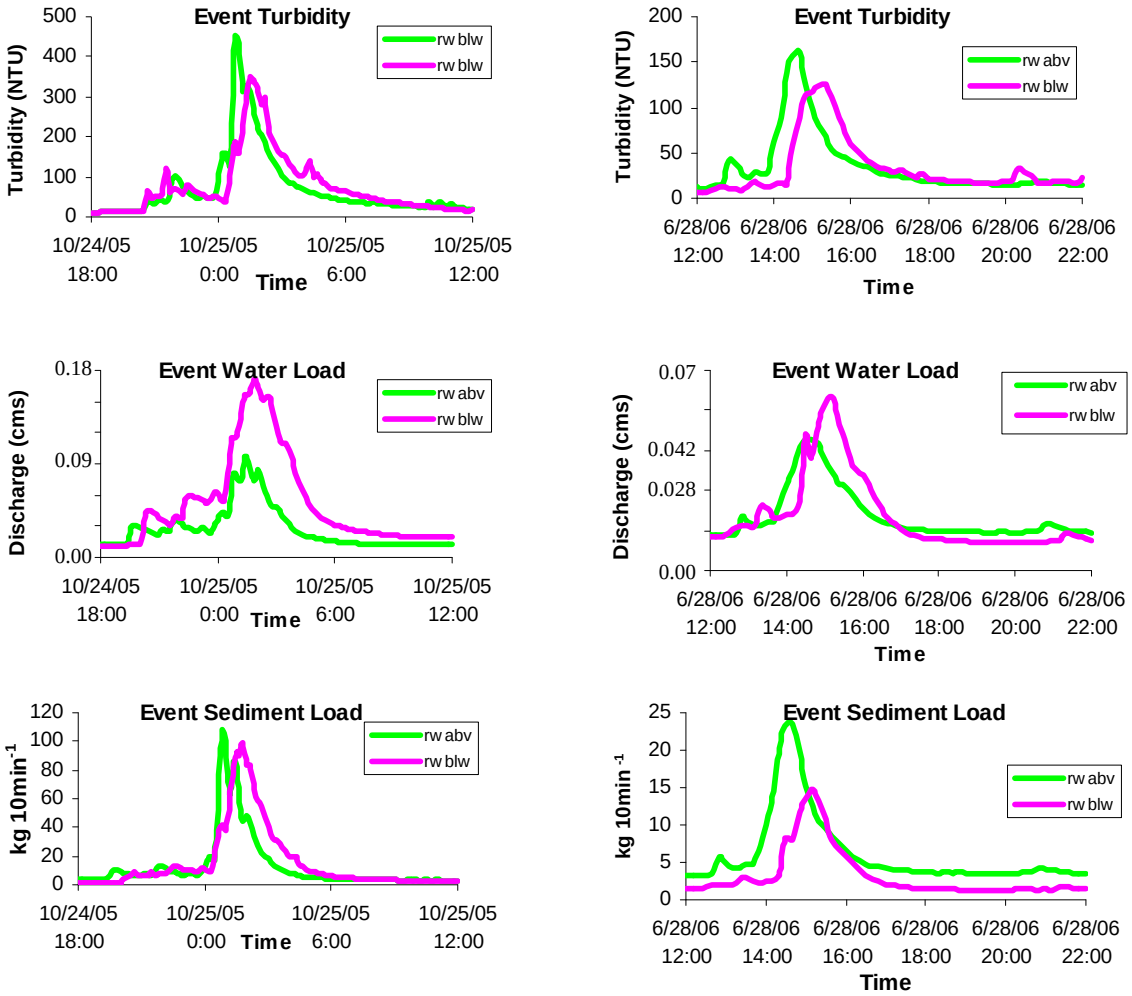

Figure 2-16. Turbidity, water load, and sediment load during Event 38 (October 24, 2005) and Event 48 (June 28, 2006).

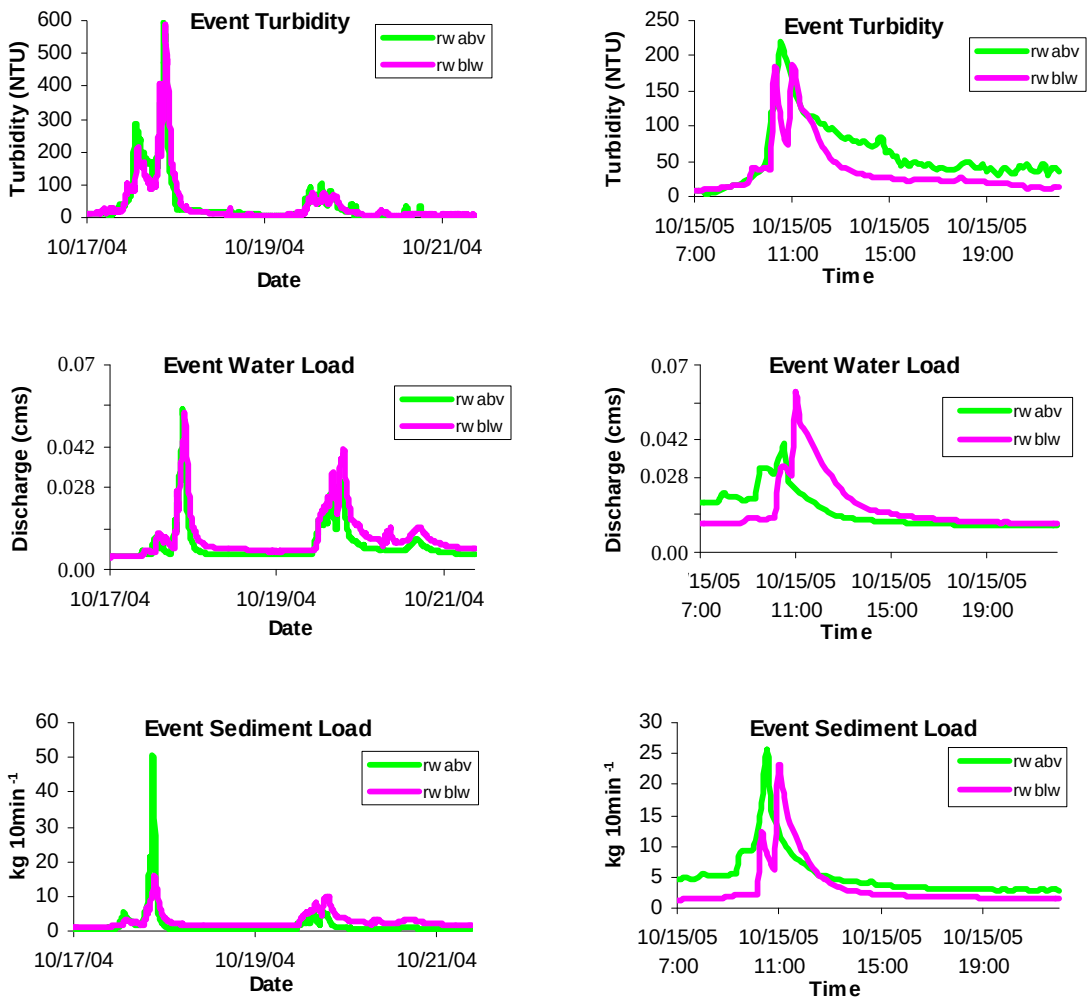

Figure 2-17. Turbidity, water load, and sediment load during Event 22 (October 17, 2004) and Event 37 (October 15, 2005).

The last event, Event 37 (Figure 2-17), 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 x 10^6 L. We hypothesize that the creek was unable to access the flood spreading zones below this level.

RAIN-ON-SNOW EVENTS

Rain-on-snow events (Figure 2-18) 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 2-19) 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 2-20). 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.

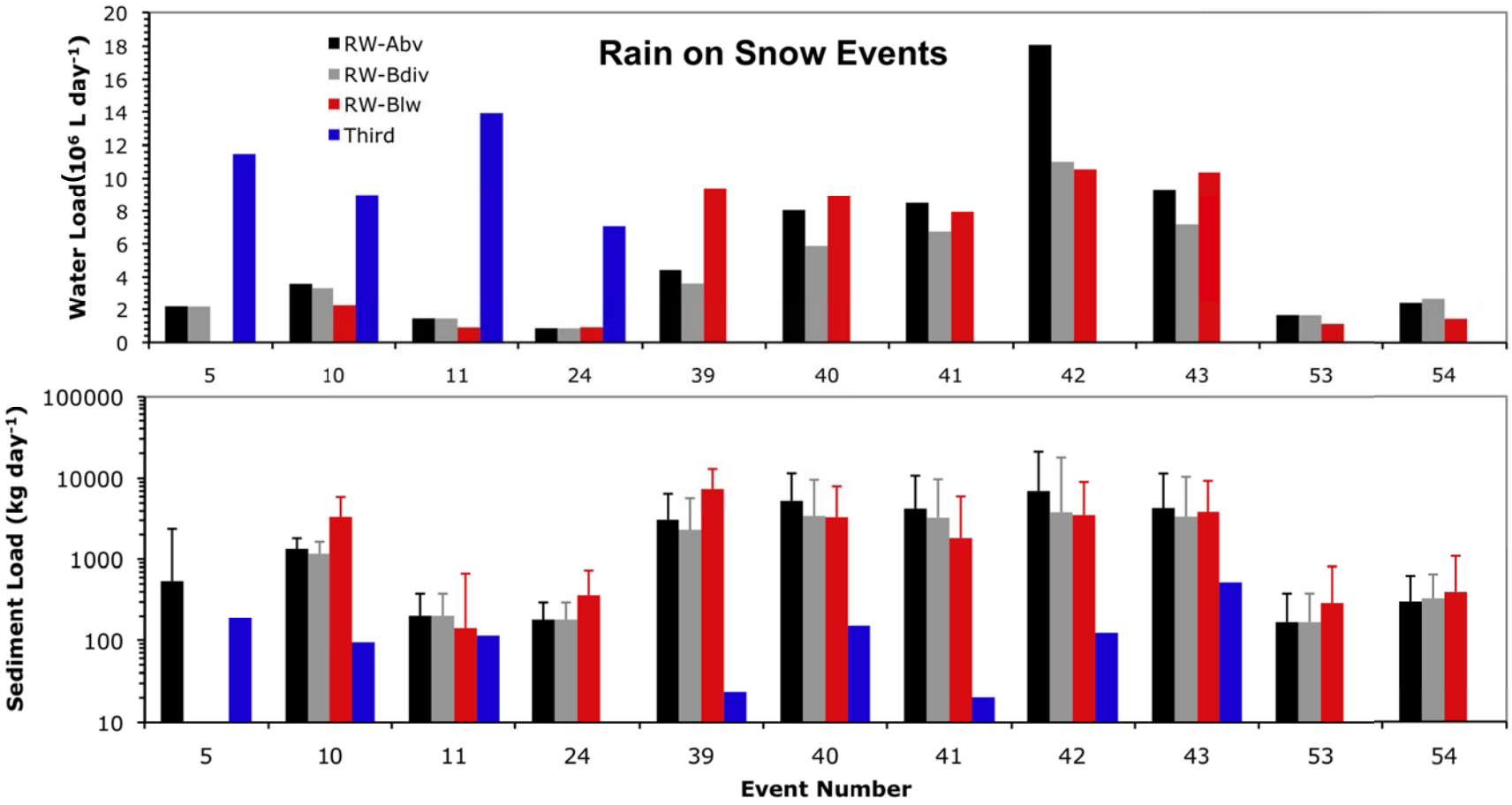

Figure 2-18. Daily water loading (above) and suspended sediment loading (below) for all rain-on-snow events. RW-Abv reflects conditions above the diversion structure, whereas RW-Bdiv estimates conditions below the structure on Rosewood Creek. See the methods section for additional discussion of how RW-Bdiv was calculated. Error bars are the standard error of measurements.

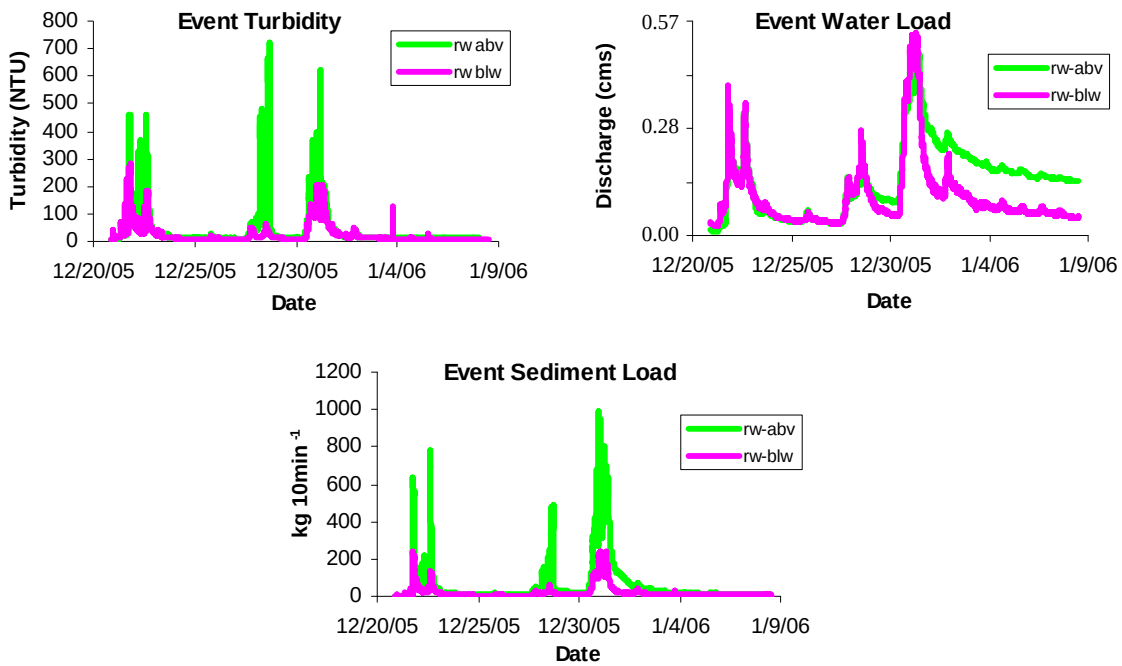

Figure 2-19. Turbidity, water load, and sediment load during Events 40, 41, and 42 (December 2005 through January 2006).

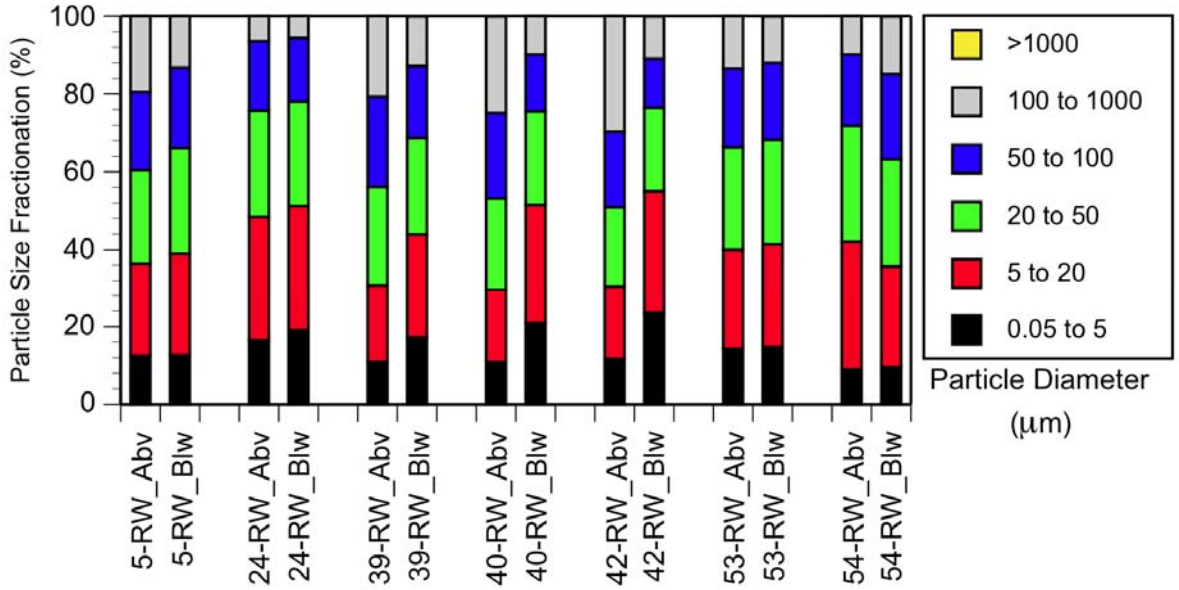

Figure 2-20. Particle size distributions for rain-on-snow events.

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 2-21). 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}.

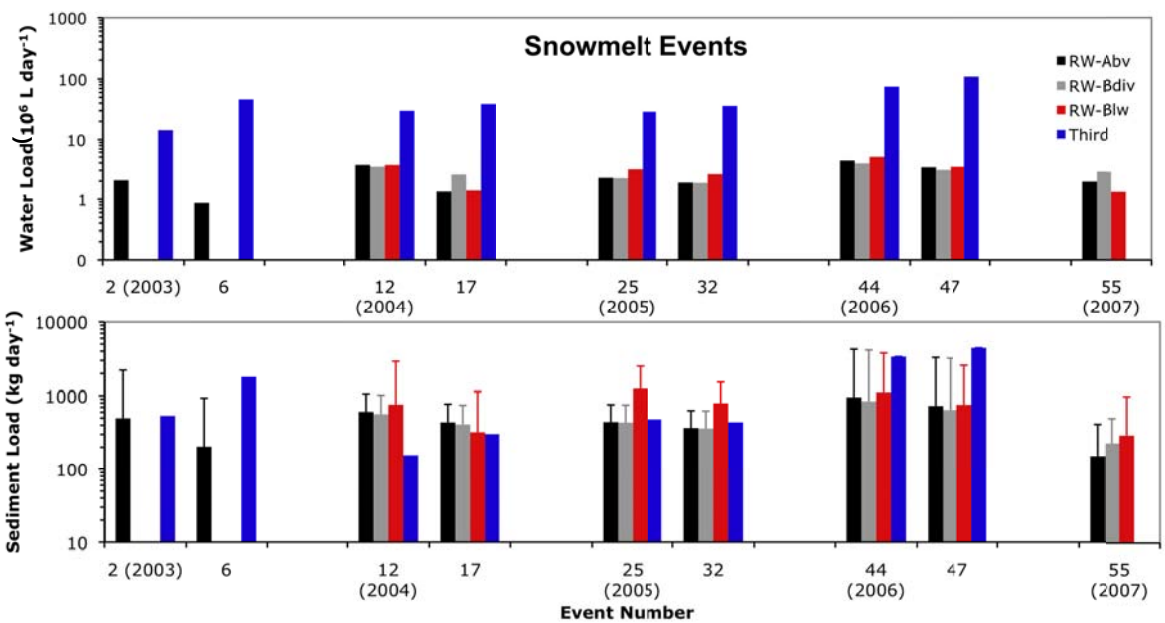

Figure 2-21. Daily water and sediment loads during each snowmelt period. Error bars are the standard error of measurements.

The flow-weighted particle size distribution and the mean particle diameter (MPD) during snowmelt varied between sites and from year to year (Figure 2-22). 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 2-14) 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.

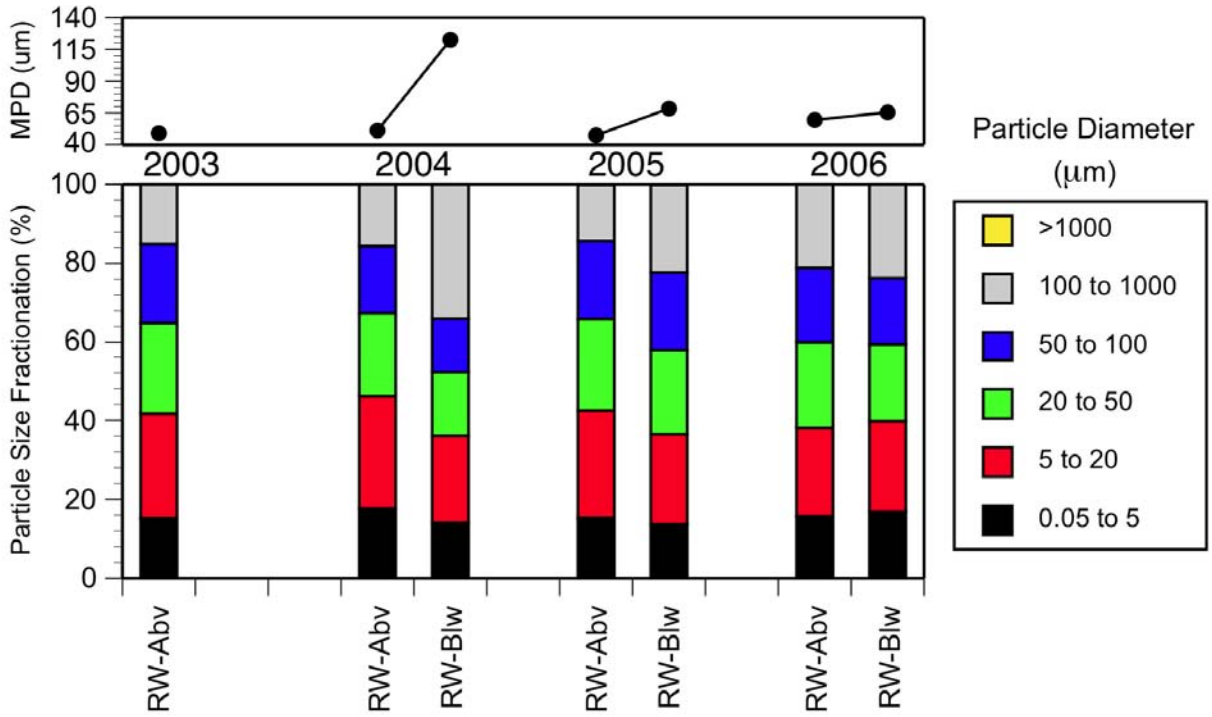

Figure 2-22. Flow-weighted average particle size fractionation (bottom) and mean particle diameter (MPD, top) for samples collected during snowmelt events. The analysis of particle size samples was biased towards the higher SSC samples that comprised the bulk of the suspended sediment load. Data from 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 2-23). 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 2-24. The greater separation of the lines parallel to the x-axis at RW-Blw indicates that hysteresis was more prevalent at this site. In this case, the rising limb of the hydrograph will have higher SSC than the falling limb for a given discharge. 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 2-24). 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.

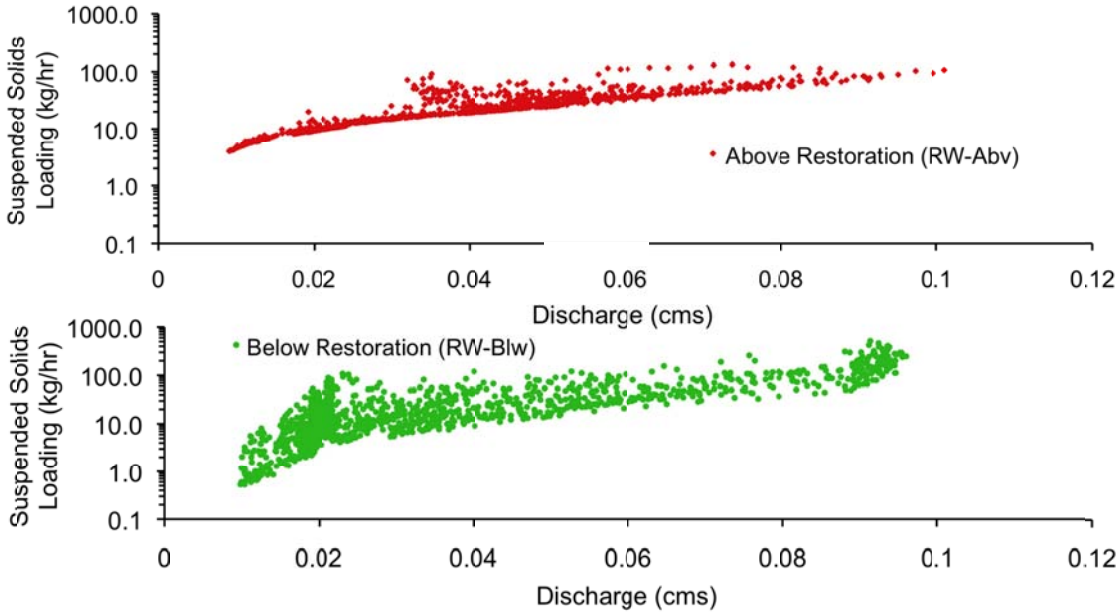

Figure 2-23. Discharge versus suspended solids loading relationships at both Rosewood Creek sites during 2004 low-elevation snowmelt (Event 12). Each 10-minute measurement during this time period is represented by a point on these plots.

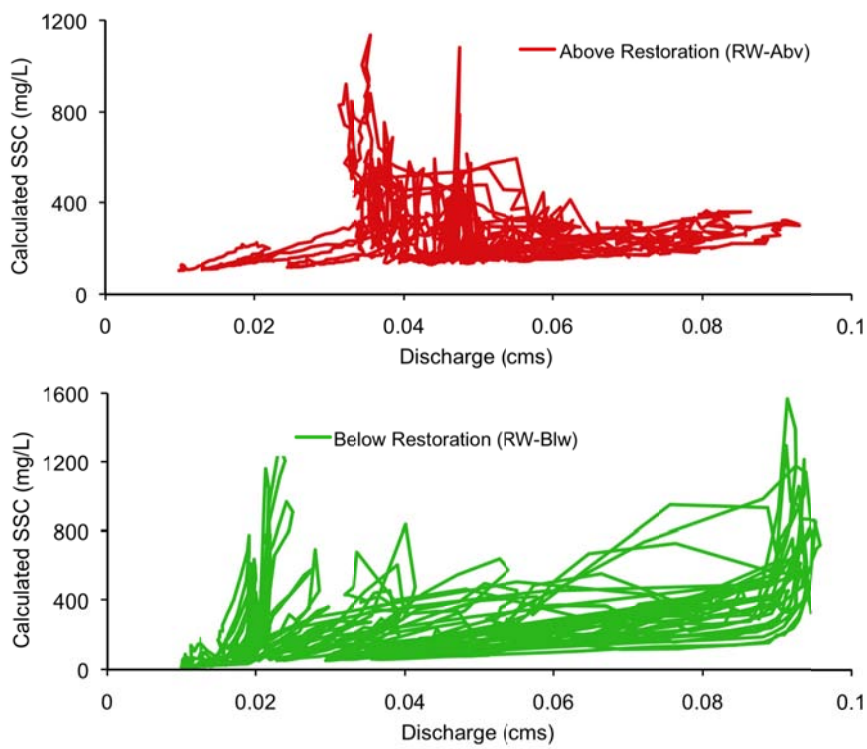

Figure 2-24. Hysteresis relationship at both Rosewood Creek sites between March 9 and March 16, 2004. The data in this graph are a subset of those presented in Figure 2-23, and use lines rather than points. Changes through time are viewed by following the line.

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.

2006

In 2006, water sources to the creek were investigated using instantaneous discharge measurements taken at several sites during snowmelt (Figure 2-25 and Table 2-9). 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 2-25) 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.

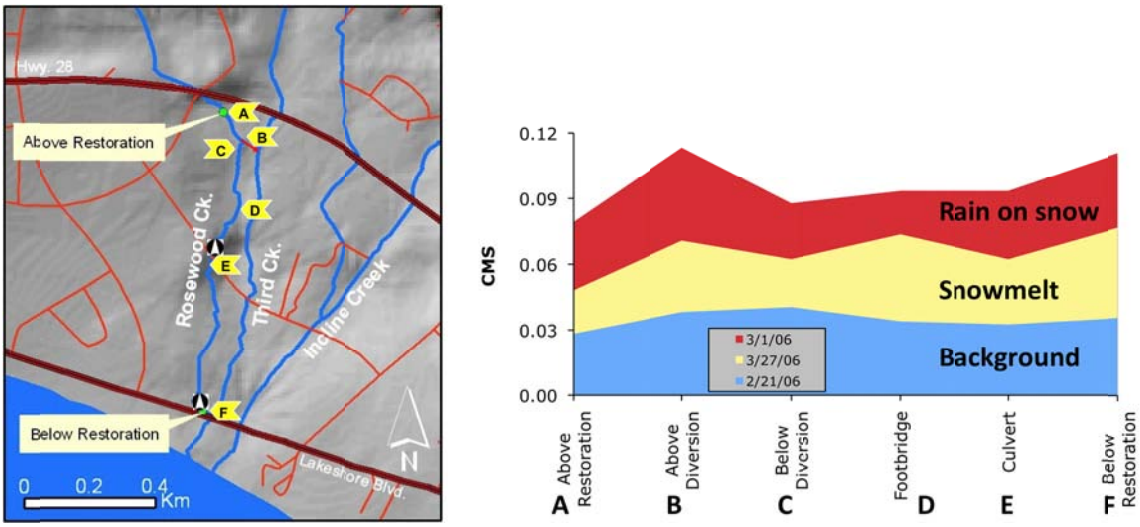

Figure 2-25. Water sources to the lower reach of Rosewood Creek on three days during the 2006 snowmelt season.

Table 2-9. Latitude and longitude of sites in the lower Rosewood Creek restoration project. Site letters refer to the sites as presented in Figures 2-26 and 2-27. 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 2-26) 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 2-27). 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,

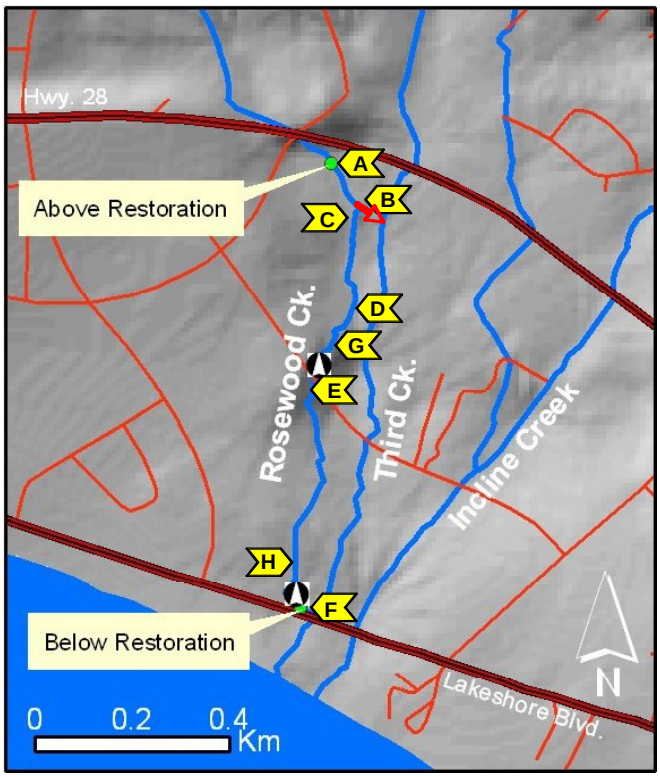

Figure 2-26. Location of stage monitoring sites within the restoration project starting in June 2006. Sites A-F are the same as in Figure 2-27. Black circles with arrows are spreading zones.

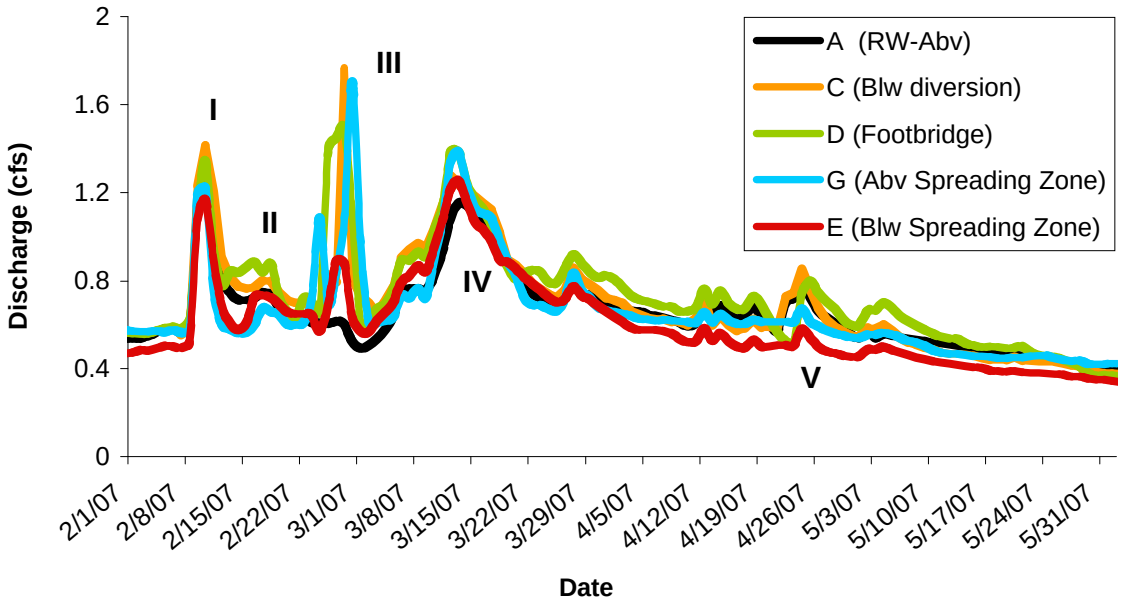

Figure 2-27. Snowmelt-driven discharge at several sites within the restoration project during spring 2007. See Figure 2-26 for locations. Data from sites B, H, and RW-Blw were omitted for clarity.

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, a result of an increase in overland discharge above the diversion structure (C); discharge remained steady at RW-Abv (A). This surface runoff accounted for 6.2 x 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 x 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 x 10^6 L below the diversion to 58.0 x 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 2-28 and Table 2-10).

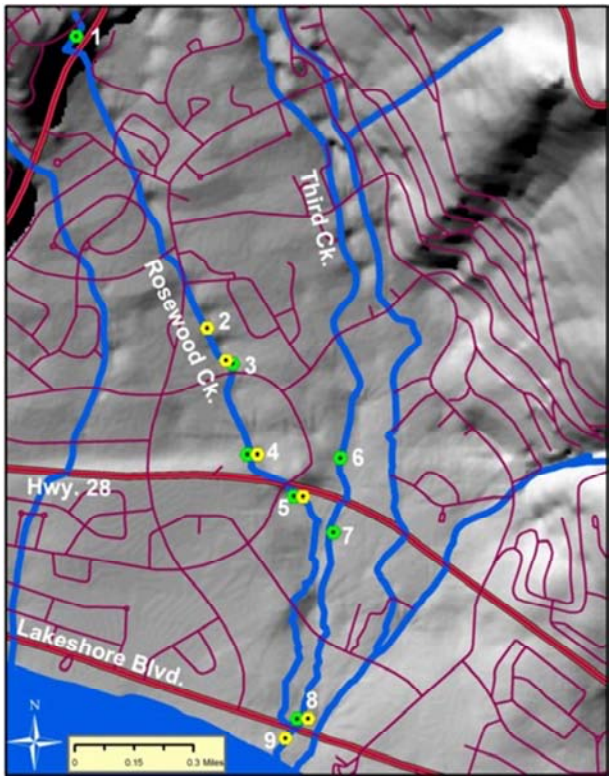

Figure 2-28. Map showing the locations of the bank erosion study sites. Green circles denote sites visited in the 2003 survey, and yellow circles denote sites visited in the 2004 survey.

Table 2-10. 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 2-11). 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 2-11. Date, location, and BEHI results.

Site	Date	Location (NAD27 CONUS) Latitude	Longitude	Bank Erosion Hazard Index
Rosewood Creek				
1	5/1/2003	39° 16' 1.7"	119° 57' 11.3"	High
2	4/16/2004	n/a	n/a	High
3a*	5/1/2003	39° 15' 13.2"	119° 56' 49.9"	High
3b	4/16/2004	n/a	n/a	Low
4	5/1/2003	39° 14' 59.0"	119° 56' 45.2"	High
4	4/16/2004	39° 14' 59.0"	119° 56' 45.2"	High
5	5/1/2003	39° 16' 24.4"	119° 55' 55.9"	High
5	4/16/2004	39° 16' 24.4"	119° 55' 55.9"	High
Third Creek				
6	5/3/2003	39° 14' 58.7"	119° 56' 21.4"	High
7	5/3/2003	39° 14' 50.0"	119° 56' 35.4"	Very high
8	5/3/2003	39° 14' 25.6"	119° 56' 40.7"	Moderate
8	4/16/2004	39° 14' 25.6"	119° 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 2-29, Site 4) relative to sites both upstream (Site 3) and downstream (Site 5).

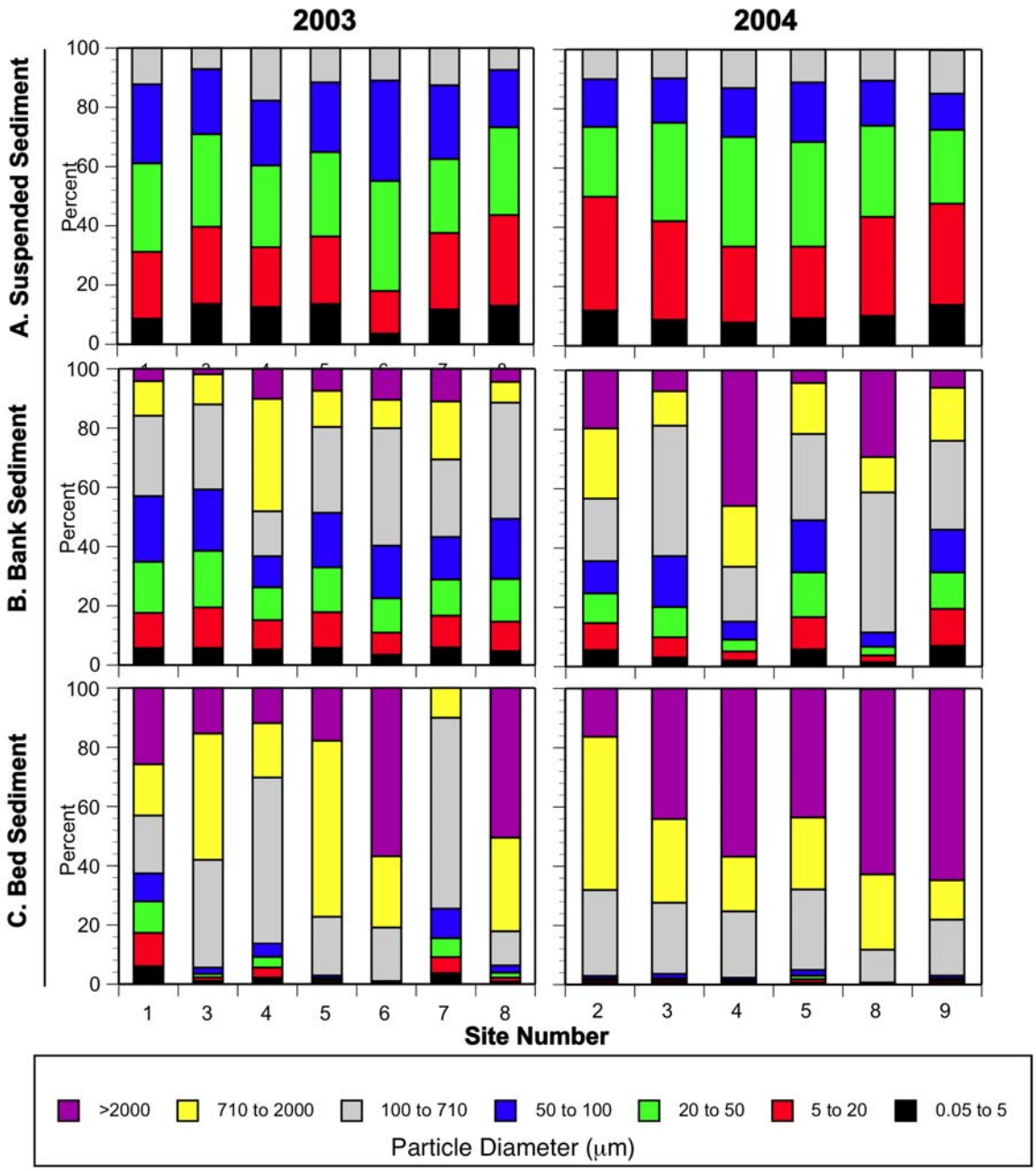

Figure 2-29. Particle size (in μm) of suspended (A), bank (B), and bed (C) sediment collected during the Bank Erosion Hazard Index studies in 2003 and 2004.

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 2-12), 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 2-12), 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 2-29C, 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 2-29). 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 2-12. 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 2-30). 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 2-30 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 2-14). 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.

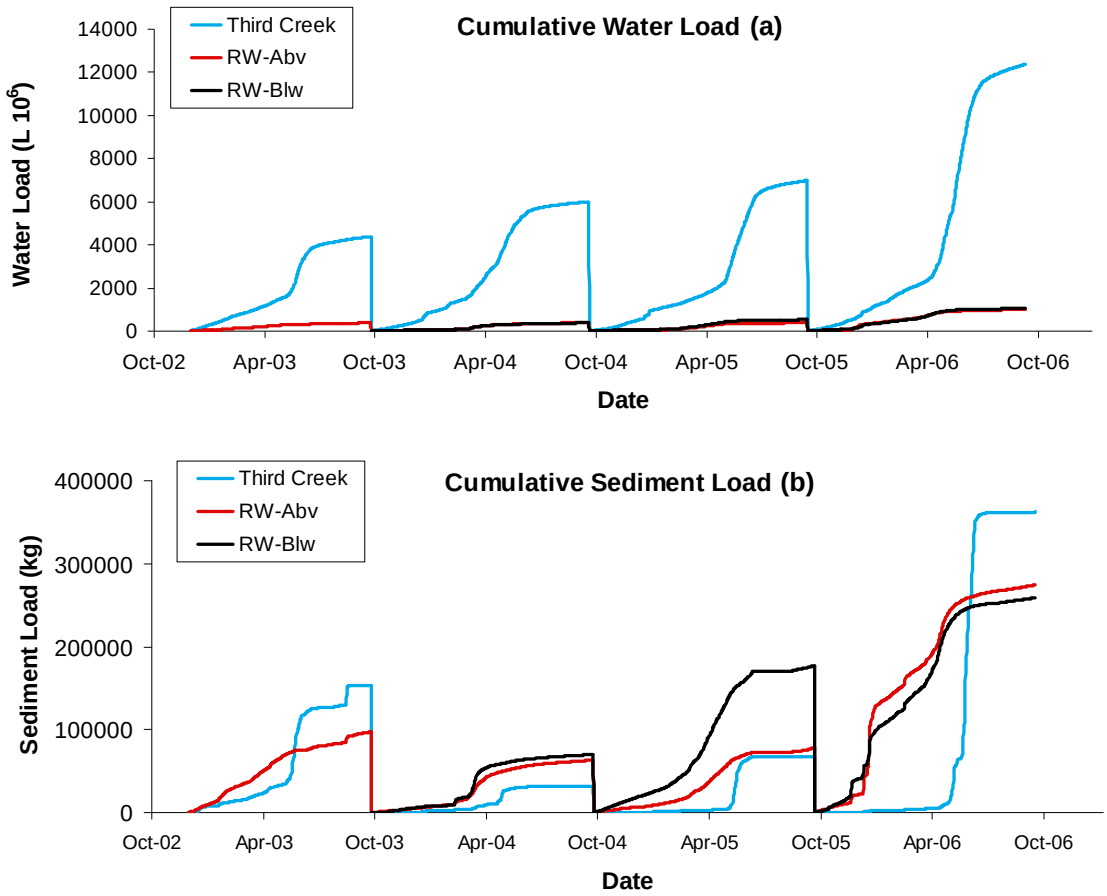

Figure 2-30. Cumulative water (a) and sediment (b) loading by water year.

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 2-13). 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 2-13). 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 2-13. 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 2-14). 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 2-14) compared favorably to those estimated for the period of record (Table 2-13), 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 2-31). 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 2-32). 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.

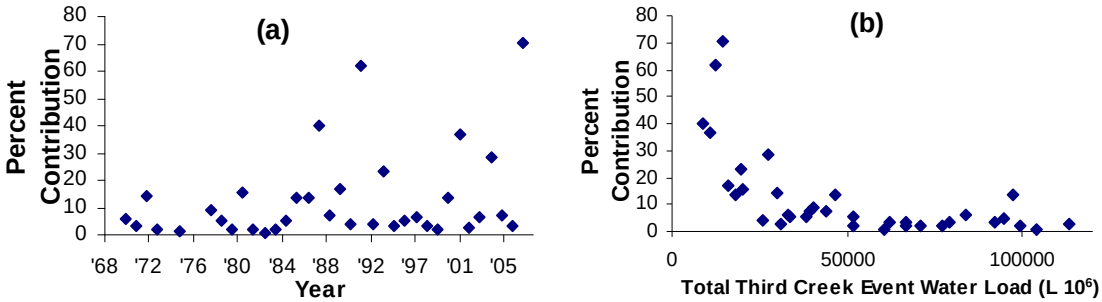

Figure 2-31. Load ratios a) by year, and b) versus total Third Creek snowmelt, n = 35.

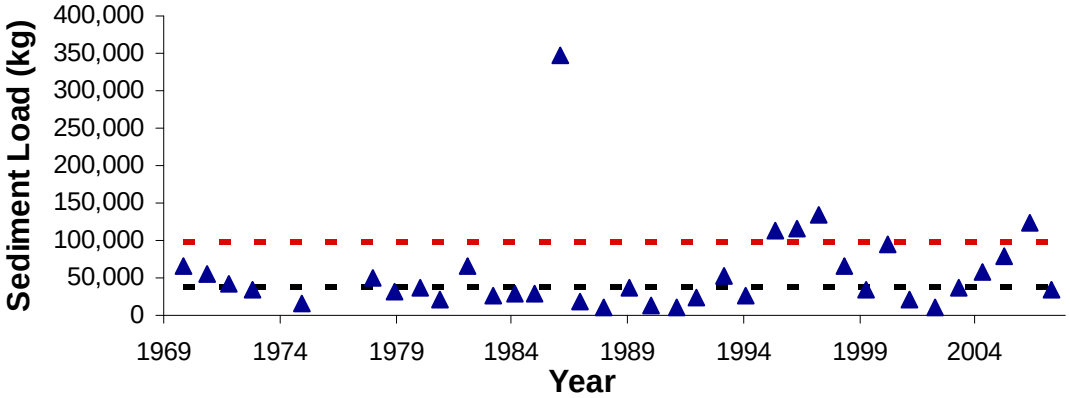

Figure 2-32. Historical snowmelt period sediment loads at RW-Abv, estimated from USGS loads for low-elevation snowmelt period each water year. Black dashed line is the median, red dashed line is one standard deviation.

Table 2-14. 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 2-13.

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 2-33). 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 2-33), 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.

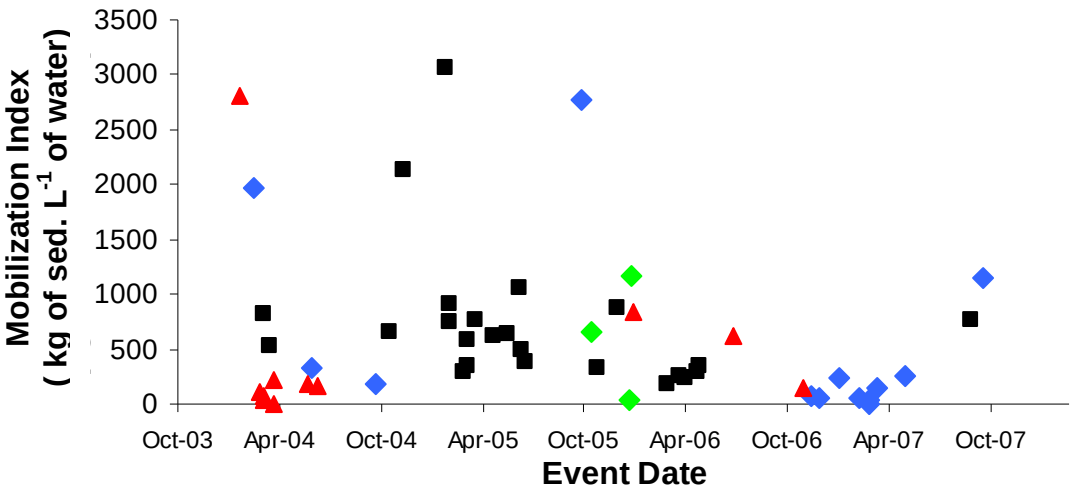

Figure 2-33. Results of Mobilization Index calculation, where 1) green diamonds represent events where sediment loads were reduced and water volumes increased within the restoration project; 2) red triangles represent events where the restoration project reduced both sediment loads and water volumes; 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 coefficient of determination than the first two years, indicating that suspended sediment delivery from the restoration project has become more predictable. However, the coefficients of determination 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 2-34), 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.

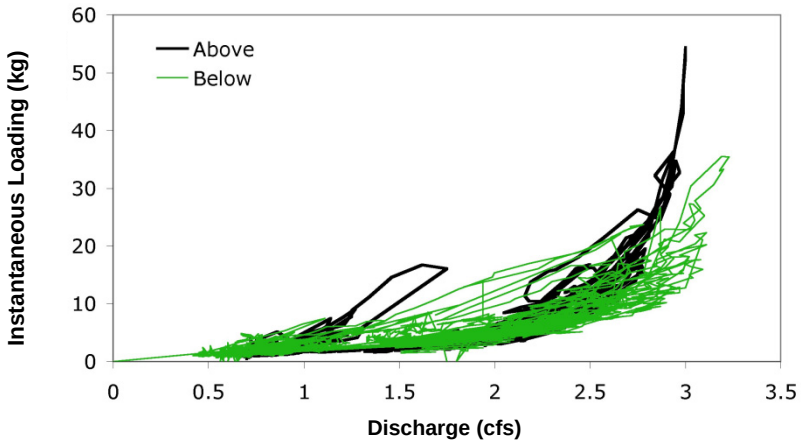

Figure 2-34. Hysteresis curves from monitoring sites above and below the restoration zone during the 2005 snowmelt. The y-axis is the instantaneous suspended sediment loading. Note that higher discharges are needed at the lower site to achieve the same loading.

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 2-35). 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.

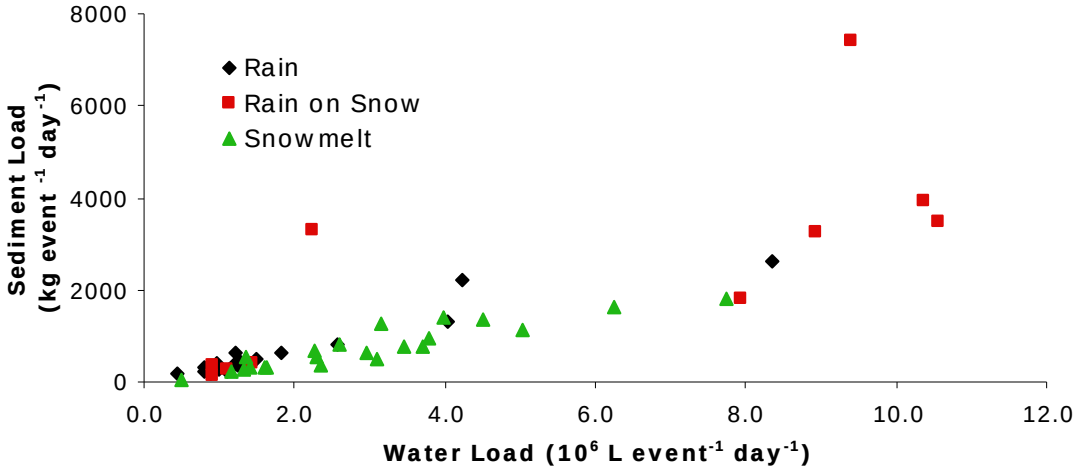

Figure 2-35. Water and suspended sediment loads from RW-Blw by event. Rain-on-snow events 10 and 39, and rain event 38, are the outliers.

The ability of the restoration project to alter water volumes or sediment loads was also dependent on the type of event (Figure 2-36). 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 poorly correlated turbidity/SSC regressions 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.

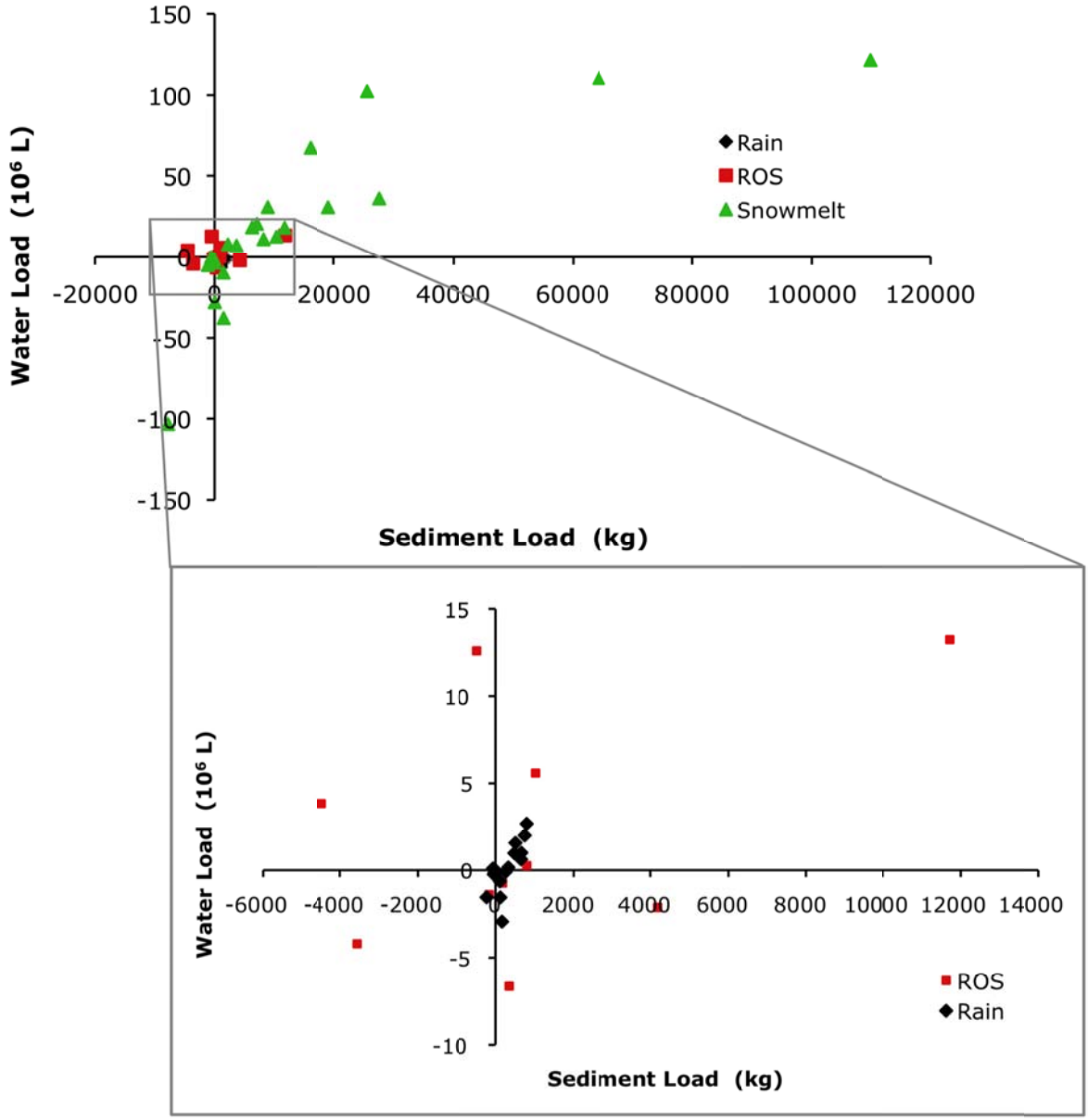

Figure 2-36. Reduction of suspended sediment load compared to reduction in water load from the restoration zone. Values were calculated by subtracting loads at RW-Blw from RW-Bdiv. The lower graph is an enlarged version of the boxed area in the upper graph. The upper right quadrant of the graph represents 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 2-

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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CHAPTER 3: LOWER AND MIDDLE ROSEWOOD CREEK RESTORATION PROJECTS: 2007-2010

PART A: INTRODUCTION AND METHODS

INTRODUCTION

Results in this section are derived from data collected between 2007 and 2010. For consistency with the results from WY2003 through WY2007 presented in Chapter 2, site names will be maintained and events will continue to be numbered sequentially. Monitoring stations downstream near Lakeshore Drive (Rosewood Below, or "RW-Blw") and upstream near Highway 28 (Rosewood-Above, or "RW-Abv") provide the bounds for the Lower Rosewood Creek Restoration Project (Figure 1-1). Monitoring stations downstream at RW-Abv and upstream off of Titlist Drive (Rosewood-Upland, or "RW-Up") provide the boundaries for the Middle Rosewood Creek Restoration Project starting in 2007 (Figure 1-1). This chapter presents the results from all three monitoring sites (RW-Blw, RW-Abv, RW-Up) and is divided in two parts discussing suspended sediment loading (Part A) and water chemistry (Part B).

METHODS

The majority of methods used during this project have already been presented in Chapter 2. Methods presented in this section are intended to provide a brief summary and also include that relating to the subsequent installation and operation of the RW-Up site.

Equipment, Sampling, and General Analyses

The third Rosewood Creek water quality monitoring site (RW-Up) was installed in the spring of 2006 by NTCD to provide background water quality data for the anticipated restoration of the middle reach of Rosewood Creek. RW-Up was located at the end of Titlist Road, 100 m downstream and 24 m lower in elevation than State Route 431 and evaluated water quality draining from a portion of Highway 431, a few residential county roads, and the upper forested area of the Rosewood Creek watershed. RW-Up is approximately 2.4 km upstream and 150 m higher in elevation than RW-Abv.

RW-Up was equipped with an in-stream turbidimeter (model OBS-3, D&A Instrument Co., Logan, UT) and an SC and water temperature sensor (CS547A Campbell Scientific, Logan, UT). Data from these sensors was recorded every 10 minutes by a datalogger (model CR1000, Campbell Scientific, Logan, UT). Power was provided by a solar panel and two 12v deep cycle batteries. As originally installed, a pressure transducer (Teledyne Isco 720 Submerged Flow module, Lincoln, NE) was directly connected to the autosampler (Teledyne Isco 6712, Lincoln, NE) and recorded stage every 10 minutes. Up to 24 1-liter water samples were collected when the creek stage exceeded a preset rate of change. Samples were analyzed by High Sierra Water Labs through June 2007.

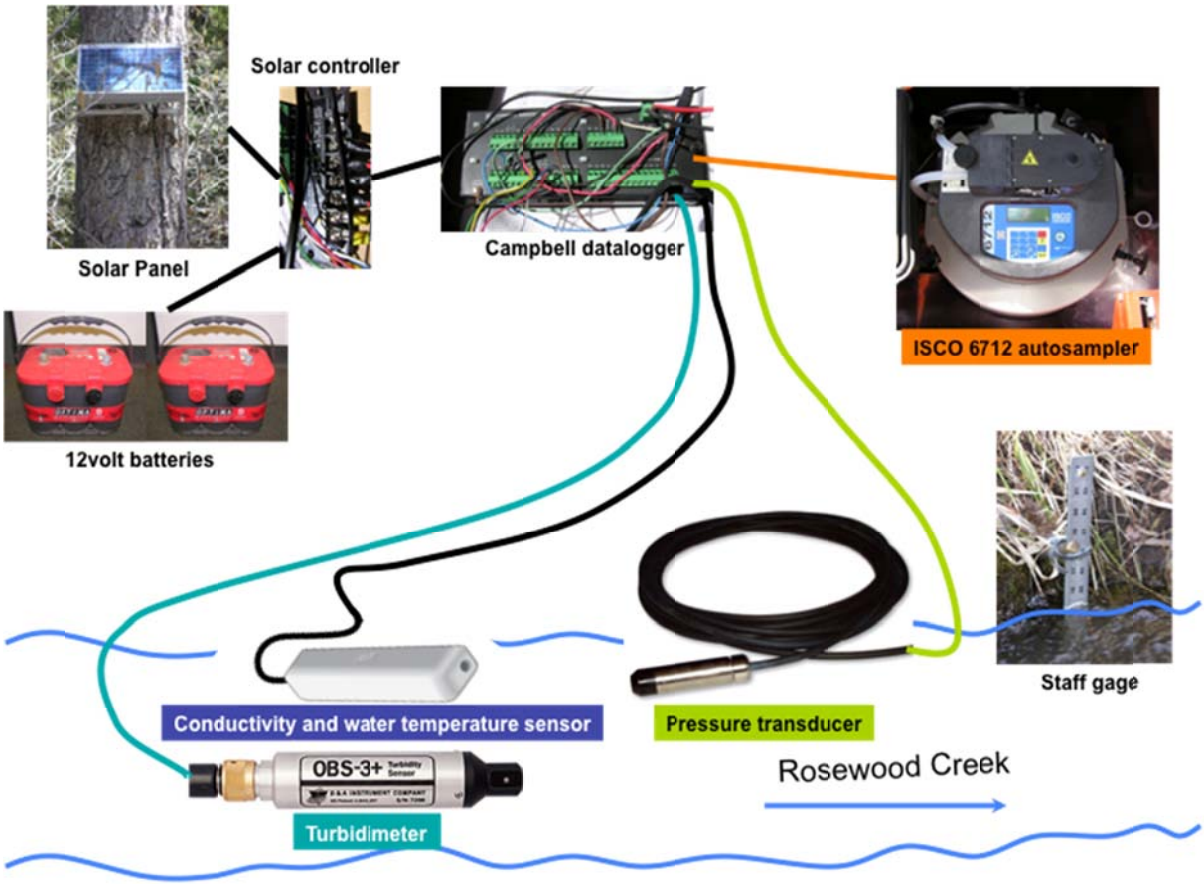

Figure 3A-1. Schematic of the equipment at RW-Up.

In March 2008, NTCD began a partnership with DRI to share monitoring duties at RW-Up and the two lower sites. NTCD continued to clean sensors, check battery capacity, and conduct discharge measurements, but DRI provided the sample programming, downloaded data, and analyzed samples (sample analysis began in July 2007). In order to ensure the samples were collected as consistently as possible, the equipment at RW-Up was reconfigured to be as similar as possible to the downstream sites. As a result, the Isco 720 flow module was replaced with a Campbell Scientific pressure transducer (CS408) and sampling by the Isco 6712 was controlled by the datalogger. Early data indicated that the modified Turbidity Threshold Program (Rand Eads, Redwood Sciences Laboratory, U.S. Forest Service) used at the lower sample sites would not be applicable for sediment and water chemistry sampling at this site due to RW-Up's lower range of turbidity. Instead, a similar datalogger program utilizing a stage threshold triggering system (similar to the turbidity threshold programs at the other two sites, but using stage instead of turbidity) was used.

Analyses

Water samples collected at RW-Up between April 2006 and July 2007 were analyzed by the High Sierra Water Laboratory (Truckee, CA) using standard methods, with modifications that are routinely employed to assess low concentration constituents typical of surface water samples from the Lake Tahoe basin. Water chemistry samples were submitted

to the Water Analysis Laboratory at DRI beginning July 2007. For water chemistry samples, individual bottles collected by autosampler were bulked using into a single flow-weighted composite sample and analyzed for nitrate, ammonium, orthophosphate, dissolved phosphorus, total phosphorus, dissolved Kjeldahl nitrogen, total Kjeldahl nitrogen, pH, and total suspended solids following accepted methods. Suspended sediment concentration (SSC) and laser particle size analysis for all RW-Blw, RW-Abv, and samples after July 2007 at RW-Up were quantified by DRI's Soil Characterization Laboratory. To facilitate turbidity-sediment comparisons, multiple discrete samples collected during selected events were analyzed in addition to the composite sample (See Chapter 1).

Quality assurance was performed on all continuous data using the custom designed software QAdjuster (R.Susfalk, DRI) for RW-Blw, RW-Abv, and RW-Up from October 1, 2007 to June 1, 2010. Raw stage and raw turbidity values were adjusted when needed using various graphical editing techniques including: point editing, reconstruction from surrogates, linear interpolation, and simple and swing shifting. Corrections or deletions were also applied when the sensors were biofouled or impaired by other sensor blockage.

Discharge

Hand stage-discharge measurements were taken by DRI (with a Marsh-McBirney, Inc., Flo-Mate model 2000) and NTCD (with a Swoffer Instruments, Inc., Portable Flowmeter model 2100) personnel at least monthly at RW-Up. The rating curve developed for RW-Up had greater error than the sites lower in the watershed due to: 1) the lack of a non-changing hydrologic control; 2) low velocity values near the lower limit of the velocity meter's range (particularly with the Swoffer 2100), and; 3) sandy composition of the banks and bed resulted in near continuous changes in the cross section. These issues are typical for a small volume, steep sloped, mountainous creeks in the Lake Tahoe basin. Stage-discharge measurements at RW-Abv and RW-Blw, and several auxiliary sites (as discussed in the Method section of Chapter 2) within the Lower Rosewood Creek Restoration Project continued to be monitored by DRI.

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CHAPTER 3: LOWER AND MIDDLE ROSEWOOD CREEK RESTORATION PROJECTS: 2007-2010

PART B: SUSPENDED SEDIMENT LOADS AND PARTICLE SIZE

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INTRODUCTION AND SUMMARY STATISTICS

Chapter 2 presented the results of monitoring through WY 2007, with additional results of WYs 2008 through 2010 presented in this section. The three most significant changes between these monitoring periods were: 1) the inclusion of a third Rosewood Creek site located below Highway 431 near Titlist Drive, designated as the Rosewood-Upland (RW-Up); 2) the switch to a self-wiping turbidity sensor at RW-Blw and RW-Abv that greatly reduced the potential for poor data quality due to biofouling of the sensor optics, and; 3) the analysis of water samples for specific water chemistry (discussed in Part C of this chapter). For consistency with Chapter 2, this section includes summary statistics for continuously measured water quality parameters including discharge, turbidity, conductance, and water temperature. Suspended sediment concentration are also presented prior to the discussion and presentation of suspended sediment load estimates for bulk and the less than 20 µm particle diameter fractions. A discussion and summary of these results is presented in Chapter 4.

Overview and Event Summary Statistics

Twenty-eight discrete hydrologic events occurred from October 2007 through May 2010 (Table 3B-1) at one or more of the sample locations. This included 15 rain events, 9 rain-on-snow (ROS) events, and 4 snowmelt (SM) events over the 32 month period. Spring snowmelt for WY 2008 (Event 62) and WY 2009 (Event 73) were considered in their entirety due to low seasonal snowfall, whereas the WY 2010 snowmelt was broken into a early (Event 83) and late (Event 24) periods.

As in previous years, snowmelt dominated the yearly hydrologic cycle (Figure 3B-1), however, annual average discharge for WY 2008 through 2010 were lower than that observed previous years, especially for WYs 2005 and 2006 (Tables 2-5 and 3B-5). Low snowpack totals in WY 2008 and to a lesser extent in WY 2009, resulted in the majority of snowmelt entering the creek upstream of Highway 28 from the middle and upper reaches of Rosewood Creek (Figure 3B-2). Water year 2010, in contrast, included a significant lake-level snowmelt component manifested as a greater discharge at RW-Blw compared to RW-Abv during the WY 2010 snowmelt. Snowmelt seasons each have their own individual characteristics, such as being long and drawn out (WY 2010 compared to WY 2008) or

occurring with significant rain events (WY 2009 compared to WY 2008) as exhibited by a comparison of discharge and turbidity during snowmelt at RW-Blw (Figure 3B-3).

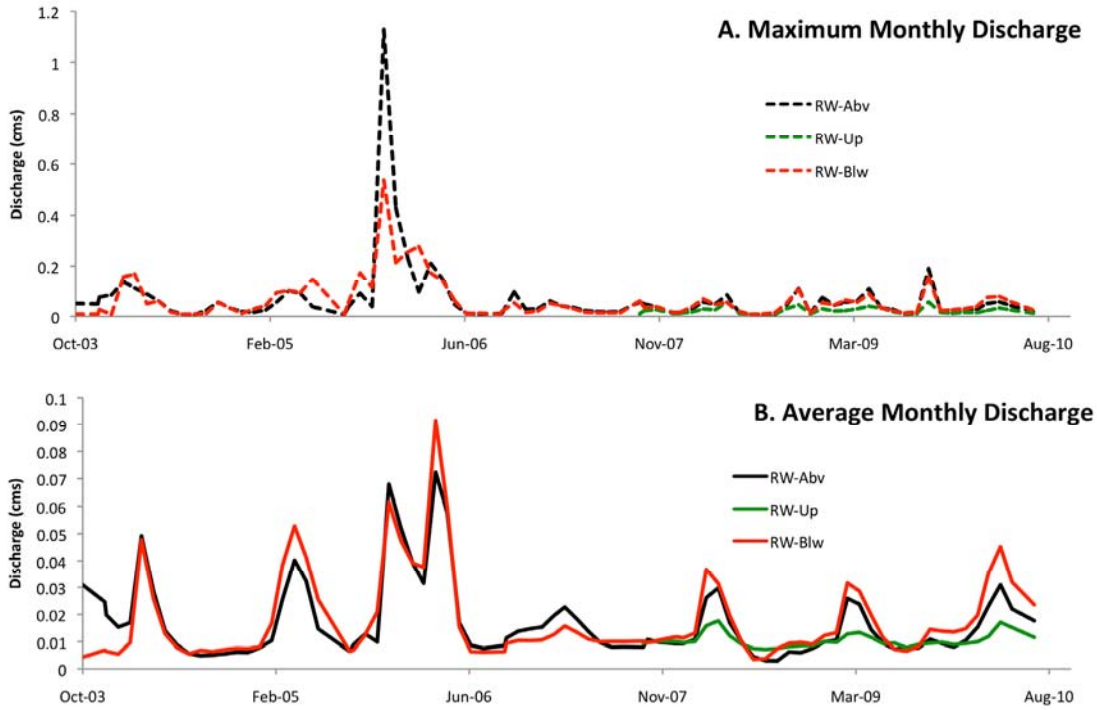

Figure 3B-1. Maximum (top) and average (bottom) monthly discharge for the period of record.

The different hydrologic characteristics of each snowmelt season resulted in trends in observed turbidity values. Snowmelt seasons were typically characterized by a few large melting events and daily turbidity spikes throughout the rising limb of the snowmelt hydrograph. In contrast, the more gradual snowmelt season of WY 2010 resulted in fewer daily turbidity spikes that were generally lower in magnitude than those of WY 2008. In contrast, elevated turbidity events during WY 2009 were primarily driven by several rain events that occurred throughout the snowmelt season.

The highest frequency of rain and rain-on-snow events was between September 2008 through May 2009 and the largest rain event during this period of study occurred on October 13, 2009 (Event 82). This rain event mobilized a significant mass of sediment out of the watershed, sediment that otherwise may have been available to be mobilized and contributed to daily turbidity spikes that were relatively absent during the 2010 snowmelt season.

Table 3B-1. List of hydrologic events (SM = snowmelt; ROS = rain-on-snow) for WY2007 through 2010. The water year starts on October 1 and ends on September 30. See Table 2-1 for the first 60 events that occurred from 2002 through 2007.

Event #	Event Type	RW-Up			RW-Abv			RW-Blw			Notes
		Event Start	Event End	Duration (Days)	Event Start	Event End	Duration (Days)	Event Start	Event End	Duration (Days)	
Water Year 2007-2008											
61	Rain	--	--	--	10/19/07 21:20	10/20/07 4:40	0.3	10/19/07 21:10	10/20/07 6:30	0.4	
62	SM	2/25/08 6:00	5/20/08 15:00	85.1	2/25/08 6:00	5/20/08 15:00	85.3	2/25/08 6:00	5/20/08 15:00	85.3	Entire Snowmelt Season
63	ROS	--	--	--	3/13/08 1:50	3/13/08 8:10	0.3	3/13/08 2:20	3/13/08 9:00	0.3	
64	Rain	5/4/08 14:00	5/4/08 21:20	0.3	--	--	--	--	--	--	
65	Rain	5/20/08 19:10	5/21/08 7:10	0.5	5/20/08 19:10	5/21/08 5:40	0.4	5/20/08 19:00	5/21/08 11:00	0.7	Series of Four Rain Storms
66	Rain	--	--	--	5/24/08 3:40	5/24/08 21:20	0.7	5/24/08 4:50	5/24/08 21:20	0.7	Series of Four Rain Storms
67	Rain	--	--	--	5/25/08 16:00	5/25/08 22:20	0.3	5/25/08 16:40	5/25/08 22:30	0.2	Series of Four Rain Storms
68	Rain	--	--	--	5/26/08 15:30	5/26/08 23:20	0.3	--	--	--	Series of Four Rain Storms
Water Year 2008-2009											
69	Rain	10/3/08 17:20	10/4/08 9:20	0.7	--	--	--	10/3/08 18:30	10/4/08 15:50	0.9	
70	Rain	11/1/08 18:20	11/2/08 8:50	0.6	--	--	--	11/1/08 20:30	11/2/08 8:20	0.5	
71	ROS	1/21/09 19:40	1/23/09 0:40	1.2	--	--	--	1/21/09 22:30	1/23/09 0:40	1.1	
72	ROS	1/23/09 0:50	1/26/09 22:50	3.9	--	--	--	1/23/09 0:50	1/25/09 5:50	2.2	
73	SM	2/22/09 6:00	5/1/09 6:00	68.0	2/22/09 6:00	5/1/09 6:00	68.0	2/22/09 6:00	5/1/09 6:00	68.0	Entire Snowmelt Season
74	ROS	2/22/09 6:20	2/23/09 23:30	1.7	2/22/09 7:40	2/24/09 1:00	1.7	2/22/09 9:00	2/24/09 0:50	1.7	
75	ROS	--	--	--	3/1/09 17:00	3/3/09 12:00	1.8	3/1/09 17:30	3/3/09 12:00	1.8	
76	ROS	--	--	--	3/17/09 11:30	3/20/09 5:20	2.7	--	--	--	
77	ROS	4/10/09 10:10	4/10/09 17:40	0.3	4/10/09 10:30	4/10/09 22:30	0.5	--	--	--	
78	Rain	5/1/09 6:40	5/2/09 20:00	1.5	5/1/09 8:10	5/2/09 10:30	1.1	5/1/09 10:20	5/3/09 4:10	1.7	
79	Rain	5/3/09 4:00	5/4/09 11:10	1.3	5/3/09 4:20	5/4/09 14:00	1.4	5/3/09 4:20	5/4/09 14:00	1.4	
80	Rain	6/1/09 18:20	6/1/09 22:20	0.1	6/1/09 19:40	6/2/09 2:00	0.3	6/1/09 19:40	6/2/09 2:00	0.3	
81	Rain	--	--	--	7/28/09 16:50	7/29/09 0:10	0.3	7/28/09 17:50	7/29/09 0:20	0.3	
Water Year 2009-2010											
82	Rain	10/13/09 6:50	10/14/09 3:30	0.9	10/13/09 8:10	10/14/09 3:40	0.8	10/13/09 9:10	10/14/09 4:00	0.7	Major Rain Event
83	SM	2/2/10 8:00	2/22/10 2:00	19.8	2/2/10 8:00	2/22/10 2:00	19.1	2/2/10 8:00	2/22/10 2:00	19.8	Early Snowmelt Season
84	SM	2/24/10 0:00	5/21/10 15:00	86.6	2/24/10 0:00	5/21/10 15:00	86.6	2/24/10 0:00	5/21/10 15:00	86.6	Late Snowmelt Season
85	ROS	--	--	--	3/22/10 13:10	3/23/10 0:30	0.5	3/22/10 13:20	3/23/10 4:10	0.6	
86	ROS	3/29/10 13:10	3/30/10 10:10	0.9	3/29/10 13:40	3/30/10 18:30	1.2	3/29/10 14:40	3/30/10 23:10	1.3	
87	Rain	4/20/10 9:20	4/20/10 20:00	0.4	4/20/10 9:40	4/20/10 17:00	0.3	4/20/10 10:10	4/20/10 18:40	0.3	
88	Rain	--	--	--	4/27/10 9:10	4/27/10 23:20	0.6	4/27/10 10:10	4/28/10 1:20	0.6	

Table 3B-2. Minium (min), average (avg), and maximum (max) values for turbidity, SC, water temperature, and discharge during each event at RW-Blw (near Lakeshore Drive) site. This site is at the lower extent of the Lower Rosewood Creek Restoration Project. Values for Events 1-60 are presented in Table 2-3.

Event	Turbidity (NTU)			Water Temp (°C)			SC (µS cm^{-1})			Discharge (cms)		
#	min	avg	max	min	avg	max	min	avg	max	min	avg	max
61	3	31	163	5.4	6.8	7.7	122	137	230	0.00801	0.01833	0.03537
62	2	7	114	-0.3	4.9	19.3	145	226	619	0.01074	0.02984	0.06786
63	15	35	75	1.9	2.2	2.5	208	221	241	0.03940	0.04155	0.04609
65	5	87	491	6.5	8.4	11.6	195	226	651	0.01426	0.02129	0.05466
66	6	32	91	4.1	5.6	7.1	141	177	228	0.01659	0.02660	0.04208
67	10	44	143	6.2	7.0	7.8	161	182	206	0.02234	0.03385	0.04820
69	1	44	304	8.1	8.7	9.8	131	151	220	0.00956	0.02222	0.05149
70	9	73	295	5.3	6.0	6.9	105	128	201	0.02438	0.04655	0.10657
71	1	28	197	1.0	2.2	2.7	118	160	407	0.01058	0.02701	0.04647
72	2	9	77	1.0	2.7	4.8	124	165	203	0.01472	0.02474	0.05385
73	1	5	138	-0.3	3.8	15.1	137	234	512	0.01214	0.02937	0.06325
74	2	26	88	0.2	1.8	3.1	160	214	376	0.01271	0.03179	0.04445
75	4	22	138	-0.2	1.2	3.1	137	184	284	0.01891	0.03784	0.06325
78	4	23	128	4.3	6.6	9.6	175	241	377	0.02078	0.03073	0.05856
79	4	40	307	3.6	5.6	8.7	126	217	262	0.02435	0.03811	0.08839
80	4	34	75	9.4	10.2	11.2	213	230	249	0.01304	0.01871	0.02609
81	2	40	146	14.1	15.4	18.5	194	202	221	0.00111	0.01088	0.02220
82	6	123	402	5.7	6.2	6.7	86	136	183	0.01979	0.07031	0.15681
83	1	2	22	-0.2	1.9	6.1	158	203	433	0.01326	0.01880	0.03347
84	1	5	86	-0.2	4.0	15.3	166	256	725	0.01772	0.03791	0.07826
85	4	16	48	1.7	4.6	9.5	229	251	308	0.04192	0.05131	0.06514
86	4	16	86	0.2	3.2	10.1	241	275	393	0.04464	0.05770	0.07460
87	5	28	74	3.1	5.9	8.4	230	285	478	0.04853	0.05526	0.07009
88	7	24	63	2.0	3.9	5.3	225	232	247	0.04755	0.05903	0.07099

Table 3B-3. Minium (min), average (avg), and maximum (max) values for turbidity, SC, water temperature, and discharge during each event at the RW-Abv (near Highway 28) site. This site is at the lower upper extent of the Lower Rosewood Creek Restoration Project and the lower extent of the Middle Rosewood Creek Restoration Project. Values for Events 1-60 are presented in Table 2-2.

Event	Turbidity (NTU)			Water Temp (°C)			SC (µS cm^{-1})			Discharge (cms)		
#	min	avg	max	min	avg	max	min	avg	max	min	avg	max
61	4	36	179	6.1	7.1	7.8	112	134	246	0.01265	0.02508	0.04837
62	2	6	98	0.2	4.6	15.6	139	200	660	0.00869	0.02451	0.05577
63	12	35	98	3.1	3.2	3.3	192	205	231	0.03023	0.03335	0.03996
65	6	100	515	6.6	8.7	11.4	141	205	561	0.01253	0.02436	0.08400
66	3	25	76	4.2	5.1	5.8	105	145	189	0.01327	0.02478	0.04399
67	9	33	116	6.1	6.9	7.8	133	156	174	0.01915	0.03272	0.05132
68	7	37	129	6.4	6.8	7.2	136	158	184	0.02329	0.03853	0.05974
73	1	5	200	-0.3	3.6	12.6	155	202	684	0.00755	0.02403	0.06090
74	3	23	81	1.7	2.4	3.3	170	211	381	0.00761	0.02702	0.04335
75	3	18	200	-0.2	1.6	3.4	165	183	274	0.01152	0.02879	0.05024
76	3	9	75	2.1	4.1	7.5	197	211	250	0.02321	0.03423	0.05096
77	5	24	81	3.1	4.7	6.3	202	253	365	0.02692	0.03886	0.06090
78	4	32	160	4.3	6.0	8.0	135	202	369	0.01470	0.03258	0.07214
79	4	32	265	3.9	5.3	7.4	118	165	194	0.01617	0.03393	0.10929
80	6	37	103	9.0	9.8	10.6	203	223	265	0.01065	0.01734	0.03065
81	3	51	325	13.5	14.1	14.8	265	275	287	0.00720	0.00999	0.02724
82	8	124	389	5.7	6.3	6.7	83	120	176	0.01166	0.06757	0.19047
83	1	2	17	0.0	2.3	4.8	111	142	299	0.01121	0.01494	0.02676
84	1	5	93	-0.3	3.6	12.0	115	209	706	0.00814	0.02578	0.05701
85	7	22	68	2.6	4.6	7.0	167	179	206	0.03007	0.03539	0.04493
86	4	17	93	1.3	3.1	6.9	201	247	405	0.02975	0.03601	0.05072
87	4	29	86	3.6	4.5	5.4	220	260	617	0.03557	0.04162	0.05701
88	5	20	55	2.3	3.7	4.4	184	204	240	0.03203	0.04069	0.05132

Table 3B-4. Minium (min), average (avg), and maximum (max) values for turbidity, SC, water temperature, and discharge during each event at the RW-Up (near Titlist Drive) site. This site is at the upper extent of the Middle Rosewood Creek Restoration Project. These events represent the entire period of record for this site.

	Turbidity (NTU)			Water Temp (°C)			SC (µS cm^{-1})			Discharge (cms)		
#	min	avg	max	min	avg	max	min	avg	max	min	avg	max
62	3	6	202	3.0	5.3	12.6	100	129	1112	0.00926	0.01529	0.02793
64	4	7	20	6.3	6.9	7.6	111	112	113	0.01353	0.01432	0.01740
65	5	90	419	7.2	8.3	10.5	117	134	147	0.00972	0.01429	0.05572
69	3	31	205	7.8	8.3	9.0	65	79	121	0.00855	0.01391	0.02979
70	6	47	464	4.9	6.1	7.5	44	79	152	0.00966	0.01889	0.04489
71	5	20	185	3.1	4.3	5.3	101	130	193	0.00915	0.01610	0.02880
72	3	7	65	2.1	3.8	5.4	99	108	140	0.01019	0.01324	0.02759
73	4	7	207	1.6	4.6	9.7	103	115	385	0.00921	0.01295	0.02917
74	5	18	90	3.2	3.8	4.7	111	150	239	0.00966	0.01422	0.02127
77	6	35	207	4.1	5.3	6.1	121	163	243	0.01503	0.01894	0.02917
78	5	13	139	4.2	6.2	8.1	101	112	141	0.01110	0.01506	0.02509
79	5	18	209	3.9	5.6	7.6	85	105	110	0.01305	0.01946	0.03969
80	7	55	506	9.3	9.9	10.7	97	100	109	0.01013	0.01403	0.03202
82	7	32	426	5.7	6.7	7.5	75	83	93	0.01213	0.02719	0.05654
83	4	8	27	2.7	4.2	5.5	104	123	414	0.00921	0.01007	0.01445
84	4	8	266	1.0	4.5	9.6	100	122	907	0.00887	0.01459	0.03233
86	10	18	87	2.3	4.0	6.1	105	134	213	0.01395	0.01722	0.02281
87	7	26	266	3.6	4.5	5.4	105	117	151	0.01748	0.02120	0.03158

Table 3B-5. Average monthly and yearly discharge for all sites during the period of observation. See Table 2-5 for data prior to October 2007.

Site	Month	Average Discharge (cms) 2007	2008	2009	2010
RW-Up: Rosewood Creek Upland Site	1	--	0.0097	0.0101	0.0094
	2	--	0.0101	0.0098	0.0099
	3	--	0.0158	0.0128	0.0119
	4	--	0.0176	0.0134	0.0171
	5	--	0.0121	0.0116	0.0152
	6	--	0.009	0.0093	0.0124
	7	--	0.0075	0.0095	--
	8	--	0.0072	0.0078	--
	9	--	0.0075	0.009	--
	10	0.0097	0.0082	0.0095	--
	11	0.0102	0.0086	0.0098	--
	12	0.01	0.0086	0.009	--
	annual	--	0.0102	0.0101	--
RW-Abv: Above Rosewood Creek Restoration	1	--	0.0093	0.01	0.0104
	2	--	0.0109	0.0106	0.0153
	3	--	0.0262	0.0259	0.0231
	4	--	0.0298	0.0238	0.031
	5	--	0.0167	0.0145	0.022
	6	--	0.0099	0.0095	0.0176
	7	--	0.0045	0.0073	--
	8	--	0.0031	0.0074	--
	9	--	0.003	0.0077	--
	10	0.0108	0.0062	0.0109	--
	11	0.0098	0.006	0.0093	--
	12	0.0093	0.0075	0.0081	--
	annual	--	0.0111	0.0121	--
RW-Blw: Below Rosewood Creek Restoration	1	--	0.0113	0.0123	0.0147
	2	--	0.0131	0.0133	0.0197
	3	--	0.0368	0.0317	0.0353
	4	--	0.0315	0.0286	0.0452
	5	--	0.0194	0.0199	0.032
	6	--	0.0098	0.0115	0.0235
	7	--	0.0035	0.0072	--
	8	--	0.0038	0.0065	--
	9	--	0.0074	0.0082	--
	10	0.0097	0.0094	0.0145	--
	11	0.0106	0.0098	0.0138	--
	12	0.0118	0.0091	0.0135	--
	annual	--	0.0137	0.0151	--
Third: Third Creek	1	--	0.0682	0.0711	--
	2	--	0.0733	0.0838	--
	3	--	0.0804	0.0855	--
	4	--	0.1679	0.1586	--
	5	--	0.4644	0.5324	--
	6	--	0.2076	0.1634	--
	7	--	0.0464	0.0456	--
	8	--	0.053	0.0357	--
	9	--	0.0253	0.0306	--
	10	0.034	0.0323	--	--
	11	0.0413	0.0564	--	--
	12	0.0561	0.0541	--	--
	annual	--	0.1108	--	--

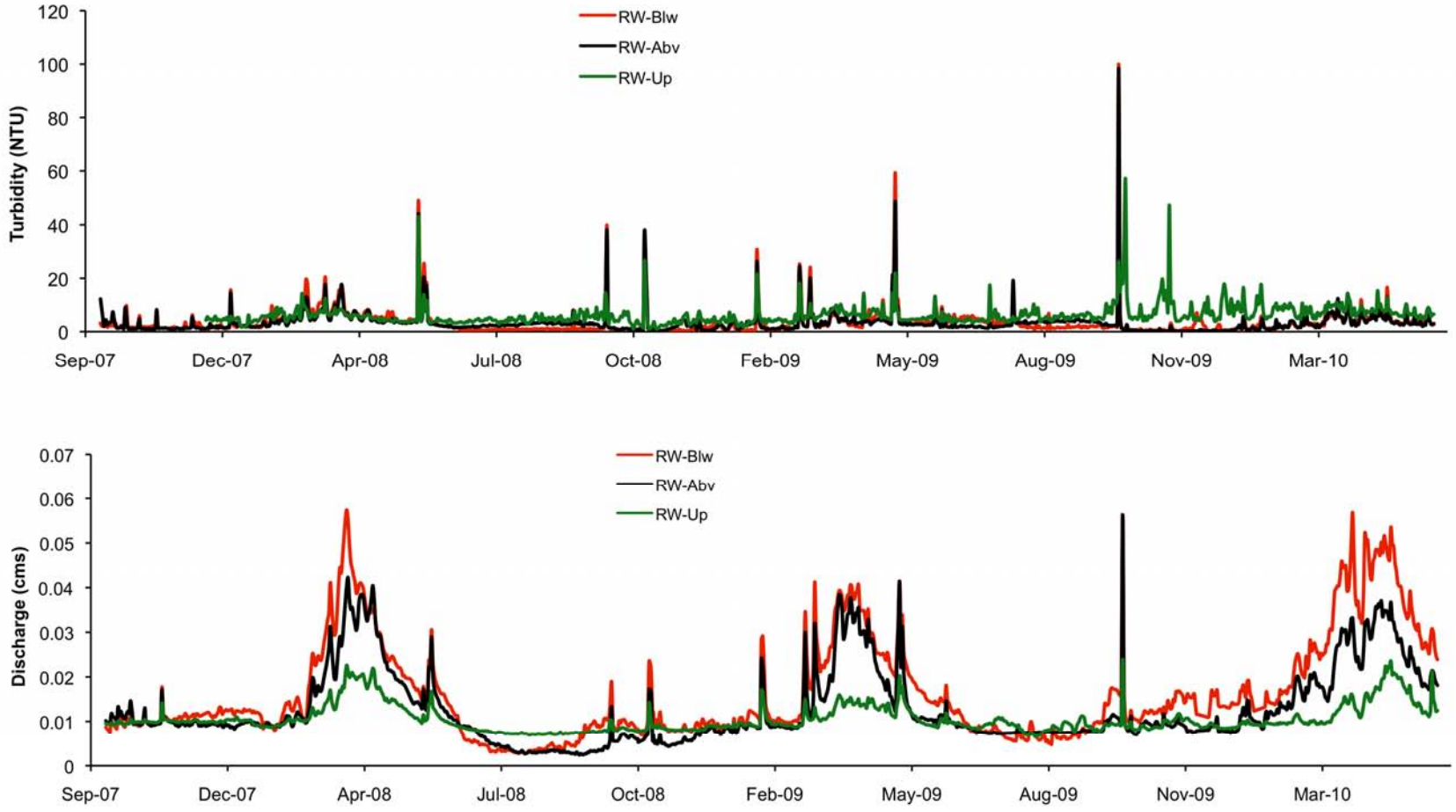

Figure 3B-2. Six-hour average turbidity (top) and discharge (bottom) for all three sites. Data for RW-Up include the entire period of record whereas data from previous years for RW-Abv and RW-Blw are presented in Figure 2-5.

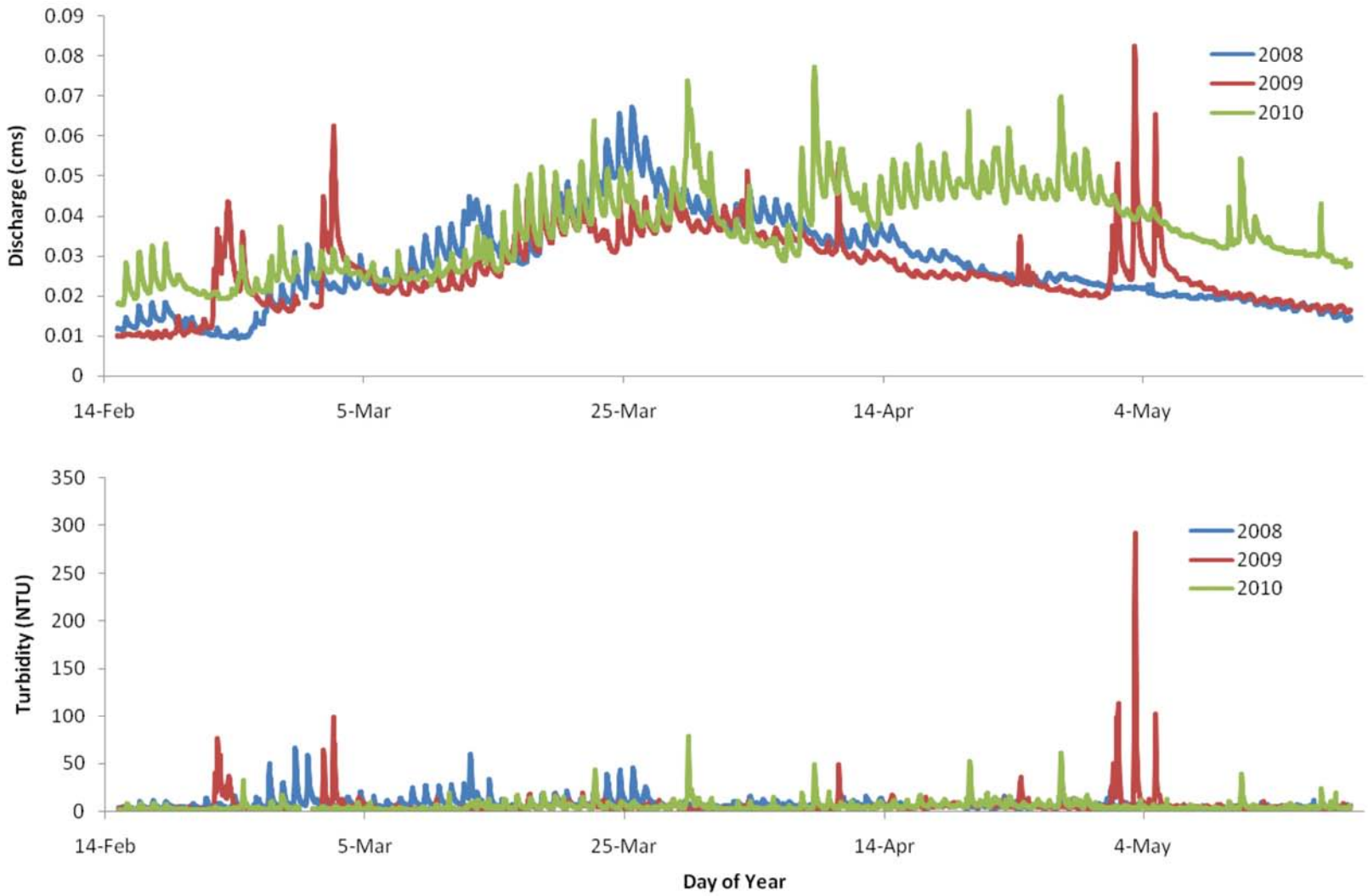

Figure 3B-3. Discharge and turbidity at RW-Blw during the snowmelt season of WYs 2008 through 2010. Compare against previous water years presented in Figure 2-14. Three rain events occurred during later February, early March and early May in WY 2009.

Summary statistics for turbidity, water temperature, specific conductance (SC) and discharge are presented on an event basis in Tables 3B-2 through 3B-4. For turbidity, the mean of event means for WYs 2008 through 2010 ranged from 25 to 33 NTU at the three Rosewood Creek monitoring sites. This was consistent with the 29-34 NTU mean of means previously observed at the two sites active prior to WY 2007. There was a change in the mean of *maximum* event turbidity values as RW-Blw dropped from 279 to 152 NTU and RW-Abv dropped from 340 to 156 NTU for periods WY 2003-2007 and WY 2008-2010, respectively. This decrease in maximum event turbidity levels was likely a result of the lower peak flows present during WYs 2008 - 2010. There was less water load and, thereby, less energy delivered to the system in these WYs. The construction of several water quality BMPs above RW-Abv and the maturing of vegatation within the Lower Rosewood Creek Restoration Project are also likely factors contributing to these observed decreases in the later years of monitoring. Specific conductance of the creek water continued to be dependent on season, with higher values occurring during water stormwater runoff (reflecting dissolved road salts) and lower values observed during the snowmelt season when water input to the creeks was dominated by forested uplands.

A calculated index, called the Turbidity per Unit Flow Index, was used to compare the ability of sediment (as measured by turbidity) to be mobilized by a unit of water flow (Figure 3B-4). This index was calculated by dividing average event turbidity by the average water volume of the same event. Therefore, higher indices represent a greater mobilization of sediment mass per unit volume of water. Rainfall events had greater intensities and kinetic energy over shorter time periods that resulted in rainfall events with a greater index compared to less intense, longer-duration snowmelt events. There was no apparent difference in turbidity index between the monitoring sites for a given event type.

The median suspended sediment concentration (SSC) during events was similar at all sites, but the variability about the median was less at RW-Blw than they other sites (Figure 3B-5). SSCs collected in WY 2008-2010 were much less variable than those collected in prior years. Coupled with the observation that there was no change in the SSC variability at RW-Abv, this indicates that the mature Lower Rosewood Creek Restoration Project was capable of attenuating SSC within the creek, under these hydrologic conditions. This reduction in total SSC was most likely a result of a diminution of particles having a diameter greater than 100 μm at RW-Blw relative to that observed at RW-Abv and RW-Up (Figure 3B-6). Figure 3B-6 presents particle size on a relative percent basis; therefore, a decrease in one size category must be offset by an increase in other size categories, as observed by a greater percentage of finer-sized particles. The shift from larger to smaller particle sizes at RW-Blw from WYs 2003-2007 (Figure 2-8) versus WYs 2008-2010 (Figure 3B-6) and at RW-Blw relative to the particle size distribution observed at RW-Abv for WYs 2008-2010 suggests that the restoration is working well to reduce the delivery of larger particle sizes.

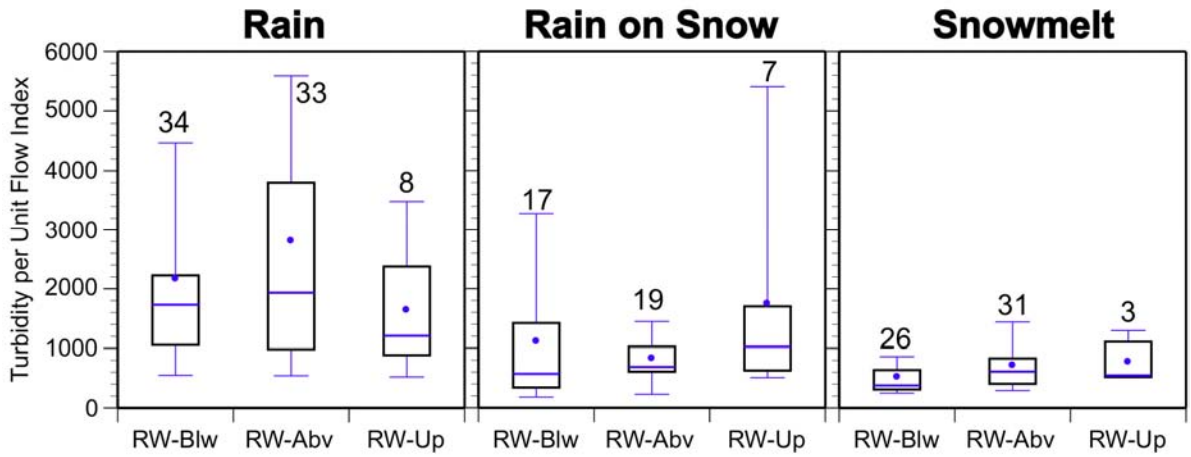

Figure 3B-4. Box plot of the Turbidity per Unit Flow Index for rain, rain-on-snow, and snowmelt events. This index was created by dividing the average turbidity by the average water load for each delineated event (Events 1-88). Values are the number of events contributing to each box plot and represent all data collected for the specific period of record at each site. See Figure 3B-5 for definition of box plot symbology.

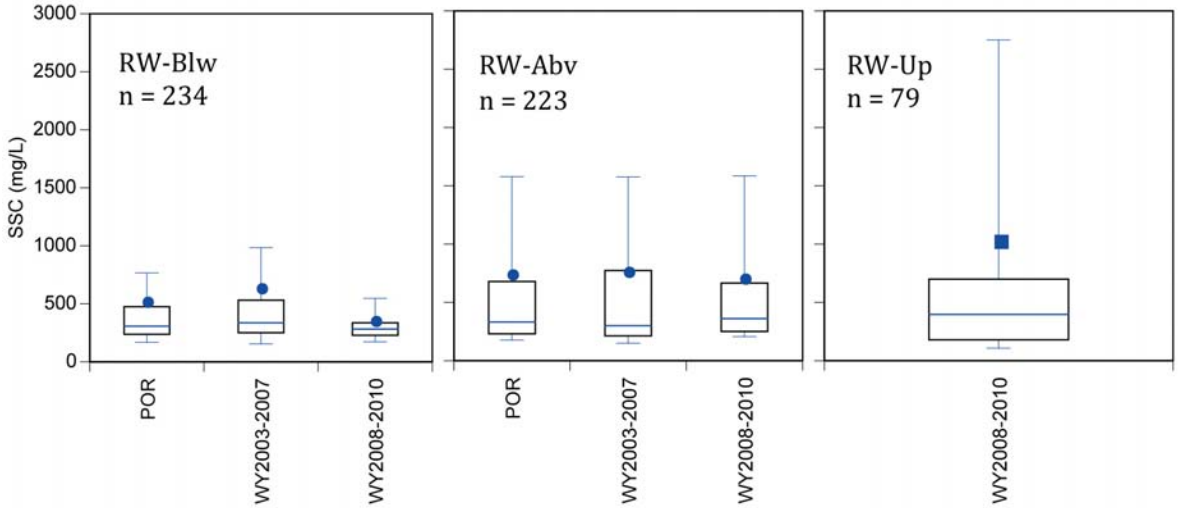

Figure 3B-5. Suspended sediment concentration box plot for the period of record (POR), during WY2002-2010. The top, bottom, and middle line of the box correspond to the 75th, 25th, and 50th percentile (median), respectively. The whiskers extend from the bottom 10th percentile and the top 90th percentile. The filled circle within the box represents the mean for the data range.

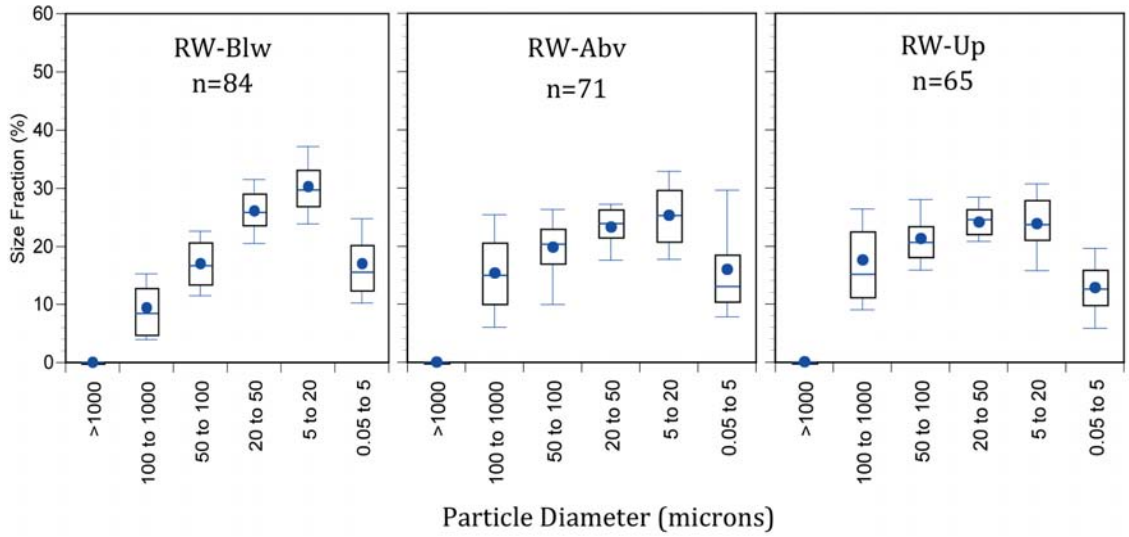

Figure 3B-6. Particle size distribution box plot for all suspended sediment samples collected by site for WYs 2008 to 2010. See Figure 3B-5 for definition of box plot symbology. Compare against WYs 2002-2007 samples presented in Figure 2-8.

TURBIDITY SURROGATE RELATIONSHIPS

Development of Surrogate Relationships

Continuous turbidity readings were used as a surrogate for estimating suspended sediment concentrations following the same methodology as presented for the WYs 2003-2007 data. Briefly, water samples collected using a vacuum-assisted autosampler were compared against in-stream turbidity (Figure 3B-7). A series of regression models were created with the linear form:

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

where *SSC* is the predicted suspended sediment concentration in mg L^{-1}, *Turbidity* is the in-stream turbidity measurement in NTU when the sample was collected, *b* is the slope coefficient and *c* is the y-intercept.

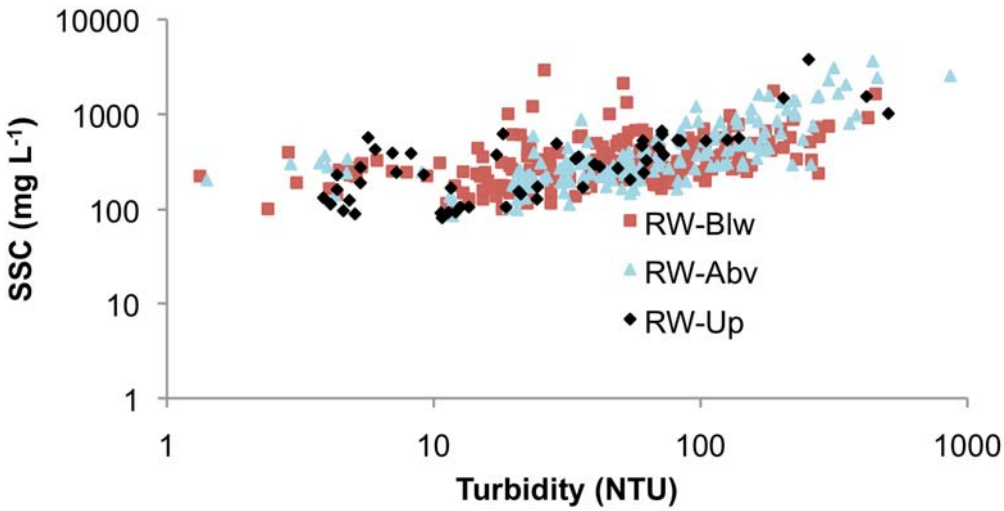

Figure 3B-7. Comparison of SSC from discrete water samples versus turbidity measured in-stream for all Rosewood Creek Sites for the period of record. See Appendix A for tabular form of this data.

Regressions were developed for all sites based on data collected during WYs 2008 through 2010 (Table 3B-6). Turbidity data collected by different sensors were not combined therefore only the turbidity collected after fall 2007 is presented here. WY 2009 turbidity was broken down into snowmelt and non-snowmelt events at RW-Abv and RW-Blw in order to isolate rain events, particularly Event 82 that had a substantially different turbidity surrogate relationship. For RW-Up, WYs 2009 and 2010 were combined due the low number of data points collected at this site during 2010. A graphical comparison of the resulting turbidity surrogate relationships indicates that the relationship at RW-Blw and RW-Up were similar (Figure 3B-8) to each other. In contrast, the equation developed for RW-Abv had a consistently greater slope indicating that water samples collected at this site had a greater suspended sediment concentration for the same level of turbidity as measured at the other two sites.

Table 3B-6. Turbidity-SSC regression equations for RW-Blw, RW-Abv, and RW-Up. See text for definition of regression equations. Regression equations 1-30 for WYs 2004-2007 can be found in Table 2-7.

Period		Reg	Regression Coefficients					Reg	Regression Coefficients				
Start	End	No.	b	c	R^2	p-value	n	No.	b	c	R^2	p-value	n
			Site A: RW-Abv						**Site B: RW-Blw**				
10/1/07	10/1/08	**31A**	5.7471	65.3279	0.76	<0.0001	38	**31B**	2.0580	185.0047	0.56	<0.0001	40
WY2008 Snowmelt		**32A**	5.3030	132.800	0.55	0.0056	12						
WY 2009 Snowmelt		**33A**	1.9550	223.4553	0.78	<0.0001	16	**33B**	3.1470	162.4280	0.33	0.0496	11
WY 2009 Non-snowmelt		**34A**	4.7604	199.2212	0.78	0.0016	11	**34B**	1.0471	192.7453	0.45	0.0013	22
10/1/09	6/1/10	**35A**	6.2750	265.7215	0.83	<0.0001	13	**35B**	1.6041	202.1578	0.81	0.0002	10
			Site C: RW-Up										
10/1/07	10/1/08	**31C**	3.4334	102.2971	0.96	<0.0001	30						
10/1/08	6/1/10	**36A**	2.0260	298.4913	0.45	<0.0001	39						

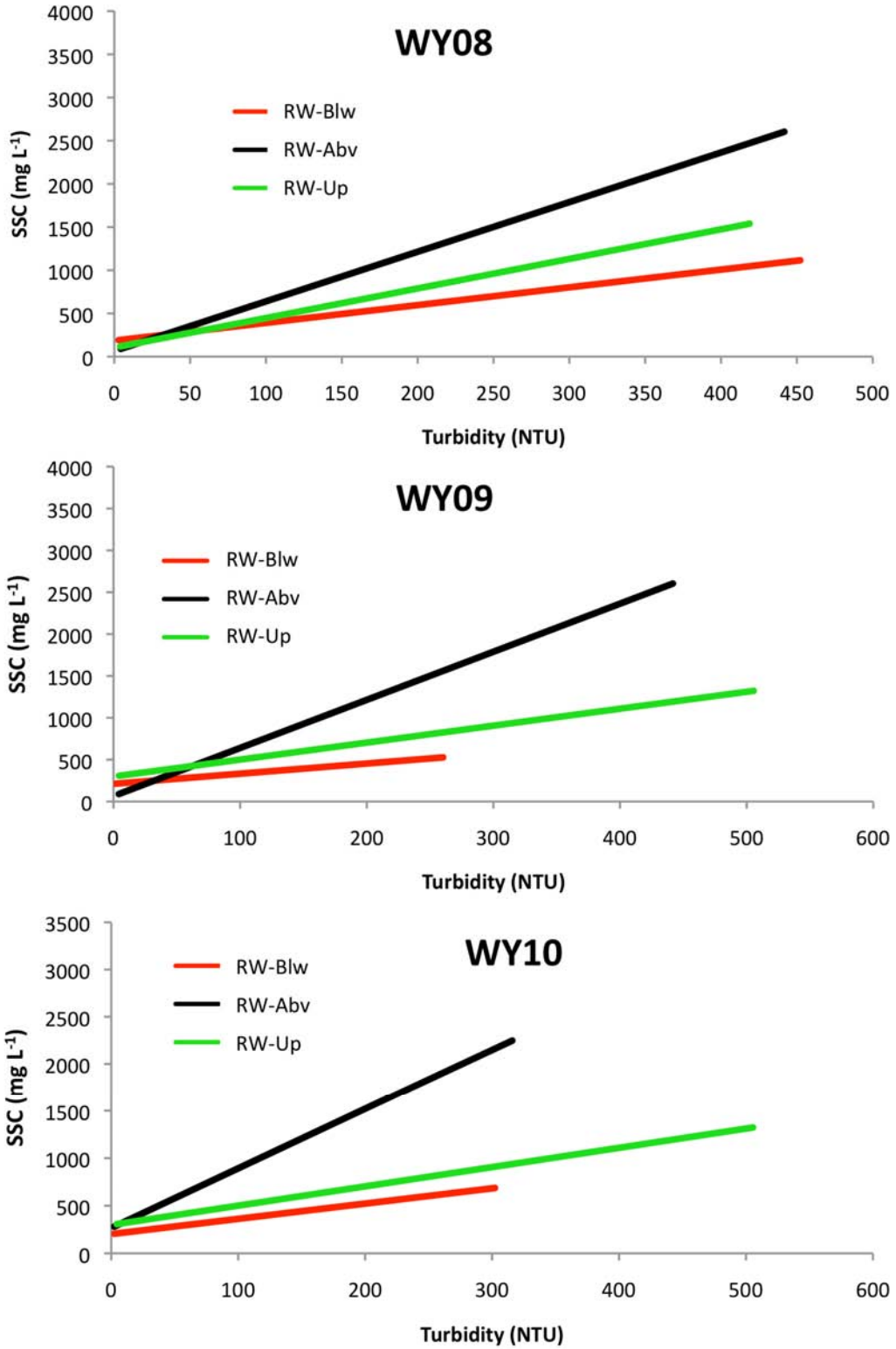

Figure 3B-8. Graphical comparison of regression models (Table 3B-6) used to estimate suspended sediment loading at all three Rosewood Creek monitoring sites for WYs 2008 through 2010.

These figures highlight the need to establish site-specific turbidity surrogate relationships because of differences in water quality, sediment shape and composition, differences in how the sensors are installed at each site, and the type of sensor technology and manufacturer (Lewis, *et al*., 2007). Changing environmental factors can also impact the turbidity surrogate relationship, either by slow changes through time, or quickly when associated with a large hydrologic event. At RW-Blw, for example, results from previous water years (see Chapter 2) indicated a dramatic change in the turbidity surrogate equations with event type and elapsed time since completion of the Lower Rosewood Creek Restoration Project.

Suspended Sediment Loading

Turbidity surrogate relationships were used to estimate suspended sediment loading (SSL) on a 10-minute basis. Total event load estimates were subsequently calculated by summing these 10-minute loads over the course of each event (Table 3B-7). As with previous years, seasonal snowmelt events delivered the greatest loads ranging from 14,000 to 60,000 kg of sediment per snowmelt season depending on water year and site. In comparison, the largest rain events from WYs 2008 to 2010 (Events 74, 78, 79, and 82) delivered only 714 to 2046 kg per event. Figures 3B-9 to 3B-11 present the same data on a daily load basis and are useful in comparing events of such disparate durations. Error bars in these figures represent the 95% confidence interval derived from the turbidity surrogate relationship.

The impact that the Lower Rosewood Creek Restoration Project had on sediment loads were estimated by comparing results measured above (RW-Abv) and below (RW-Blw) the project area. In addition, results are reported for the RW Below Diversion (RW-Bdiv) site, located immediately below the diversion structure that denotes the upper boundary of the restoration project (Figure 2-1). The RW-Bdiv site was used for two reasons relating to the fact that creek flows at the two sites, RW-Abv and RW-Bdiv can be different. First, significant surface water flows can enter the creek below RW-Abv but just upstream of the diversion structure as depicted in Figure 1-2C. These surface flows are the result of overflow from a detention basin and surface runoff from a golf course on the north side of Highway 28 that cross under the road through a culvert. Second, flow within Rosewood Creek can be directed into Third Creek at the diversion structure depending on in-creek flows and the orientation of check boards within the diversion structure. Suspended sediment loads at RW-Bdiv were estimated by: 1) assuming that the entire in-stream sediment load at RW-Abv traveled downstream to the diversion structure; 2) calculating a new estimated SSC of water entering the diversion structure using the RW-Abv sediment load and measured flows entering the structure, and; 3) calculating the sediment loading of water exiting the diversion using the estimated SSC of water entering the diversion with continuously measured flows of water exiting through the Rosewood Creek side of the diversion structure. We also assumed that the SSC of overland flow entering the creek was negligible, as verified through the collection of several grab samples. Results for both the RW-Abv and RW-Bdiv results are presented here, however, the discussion will revolve primarily around results from RW-Bdiv.

Table 3B-7. Suspended sediment and water volumes by event for RW-Up, RW-Abv, RW-Bdiv, and RW-Blw. RW-Bdiv water loads represent the volume of water actually entering the Lower Rosewood Creek Restoration Project as measured using a stage recording device stage/discharge measurements. Suspended sediment loads at this site were calculated using the suspended sediment load from RW-Abv, but accounting for incoming surface water above the diversion and for the percentage of that water that actually exited the Rosewood Creek side of the diversion. See Table 2-8 for results prior to Event 61.

				Total Suspended Sediment Load (kg event^{-1})				Water Load (10^6 L event^{-1})			
Event #	Event Type	Event Start	Avg. Duration (Days)	RW-Up	RW-Abv	RW-Bdiv	RW-Blw	RW-Up	RW-Abv	RW-Bdiv	RW-Blw
61	Rain	10/19/07	0.3	--	254	--	170	--	0.7	--	0.6
62	SM	2/25/08	85.3	13842	30515	27183	44479	112.4	180.7	186.2	220.2
63	ROS	3/13/08	0.3	--	209	284	257	--	0.8	1.1	1.0
64	Rain	5/4/08	0.3	49	--	1115	--	0.4	--	1.0	--
65	Rain	5/20/08	0.5	367	1071	--	584	0.6	0.9	--	1.2
66	Rain	5/24/08	0.7	--	380	421	415	--	1.6	1.8	1.6
67	Rain	5/25/08	0.3	--	216	240	205	--	0.7	0.8	0.7
68	Rain	5/26/08	0.3	--	367	438	--	--	1.1	1.3	--
69	Rain	10/3/08	0.8	310	--	764	445	0.8	--	1.2	1.7
70	Rain	11/1/08	0.5	432	--	143	565	1.0	--	1.8	1.8
71	ROS	1/21/09	1.1	584	--	785	589	1.7	--	2.4	2.5
72	ROS	1/23/09	3.1	1404	--	929	976	4.5	--	4.7	4.7
73	SM	2/22/09	68.0	23857	33157	29718	31103	76.0	141.1	126.5	172.5
74	ROS	2/22/09	1.7	714	1093	1146	1135	2.1	4.0	4.2	4.6
75	ROS	3/1/09	1.8	--	1178	1257	1394	--	4.5	4.8	5.7
76	ROS	3/17/09	2.7	--	1967	1708	--	--	8.1	7.1	--
77	ROS	4/10/09	0.4	196	469	431	--	0.5	1.7	1.5	--
78	Rain	5/1/09	1.5	661	1240	1233	1041	2.0	3.1	2.9	4.6
79	Rain	5/3/09	1.4	765	2217	2533	1220	2.2	4.1	4.7	4.6
80	Rain	6/1/09	0.2	86	167	138	99	0.2	0.4	0.3	0.4
81	Rain	7/28/09	0.3	--	165	112	64	--	0.3	0.2	0.3
82	Rain	10/13/09	0.8	742	6506	--	2046	2.0	4.5	--	4.4
83	SM	2/2/10	19.5	5430	6950	3203	6597	17.2	24.6	11.8	32.1
84	SM	2/24/10	86.6	34419	56160	--	60090	109.1	187.0	--	283.7
85	ROS	3/22/10	0.5	--	568	399	618	--	1.4	1.0	2.7
86	ROS	3/29/10	1.1	438	1443	1617	1543	1.3	3.7	4.1	6.7
87	Rain	4/20/10	0.4	290	511	513	414	0.8	1.1	1.1	1.7
88	Rain	4/27/10	0.6		827	--	785	--	2.1	--	3.2

The ability of restoration project to alter the flow of water or composition of sediment in the creek was variable, depending primarily on the event type, source of the water, and the magnitude of event. Sediment loads exiting the project (RW-Blw) during some events were found to be either lower or equivalent to the estimated loads entering the project. For example, the load of suspended sediment exiting the project during rain Events 65 and 79 was only about 50% of that entering the project while the volume of water remained nearly consistent. Other events, such as rain Events 78 and 86, exhibited a marginal sediment reduction through the Lower Restoration Project despite increased water volumes of 58 to 63%. This indicated that the large flux of water entering the creek from within the project area did not contribute significant sediment loads either through carrying sediment directly into the creek or by mobilizing sediment already present within the lower

reach. However, it appears that the sediment mobilized by the large influx of water was enough to offset that lost to deposition in flood spreading areas, resulting in the marginal loss.

Hydrologic events that originated above the project area in the middle to higher elevations of the Rosewood Creek watershed, such as Event 79, represented the best events from which to assess the potential impacts that the restoration project may have on water quality. During these events, nearly all the runoff entered the creek in the upper reach and traveled the full length of the middle and lower reaches through the various flood spreading zones and sediment reducing mechanisms. When surface runoff enters the creek from within the restoration project (i.e., a more urbanized area), it does not have a chance to travel the entire length of the restoration project and confounds loading comparisons as the load and particle size distribution of this additional sediment cannot be adequately quantified.

In general, WYs 2008 to 2010 rain events typically exhibited the greatest daily event loadings, ranging between 160 and 2,400 kg day^{-1} with the exception of 8,000 kg day^{-1} at RW-Abv during Event 82 (Figure 3B-9). Median daily loadings were higher in the middle of the watershed, 831 kg day^{-1} at RW-Abv and 716 kg day^{-1} at RW-Bdiv, and lower at the top and bottom of the watershed, 589 kg day^{-1} at RW-Up and 601 kg day^{-1} at RW-Blw. Daily sediment loadings for rain-on-snow events in WYs 2008 to 2010 were generally low, ranging from 421 to 1,345 kg day^{-1} (Figure 3B-10). Median sediment loading at RW-Up for rain-on-snow events was considerably lower at 483 kg day^{-1} compared to 787, 720, and 791 kg day^{-1} at RW-Blw, RW-Bdiv, and RW-Abv, respectively. Snowmelt events were characterized by the lowest range of the three types of events, from 162 to 630 kg day^{-1}, with median values of 521, 322, 488, and 351 kg day^{-1} for RW-Blw, RW-Bdiv, RW-Abv, and RW-Up, respectively (Figure 3B-11).

Load Comparison with the Event Mean Concentration Approach

A common approach used to estimate event loading is the use of event mean concentration (EMC) method where numerous water samples are collected during an event and subsequently proportionally composited using flow-weighting to produce a single water sample for analysis. This method is widely used because it is cost-effective, especially if a large suite of chemical analyses is to be performed. This method is highly dependent on both the collection of a sufficient number of samples to be included in the composite, as well as a sampling regime that represents all hydrologic aspects encountered during an event. Events comprised of either short-lived high discharge spikes may not be adequately represented by the EMC method. This can be especially true for suspended sediment, where a portion of sediment mass delivered during an event can predominately occur during these high flow spikes.

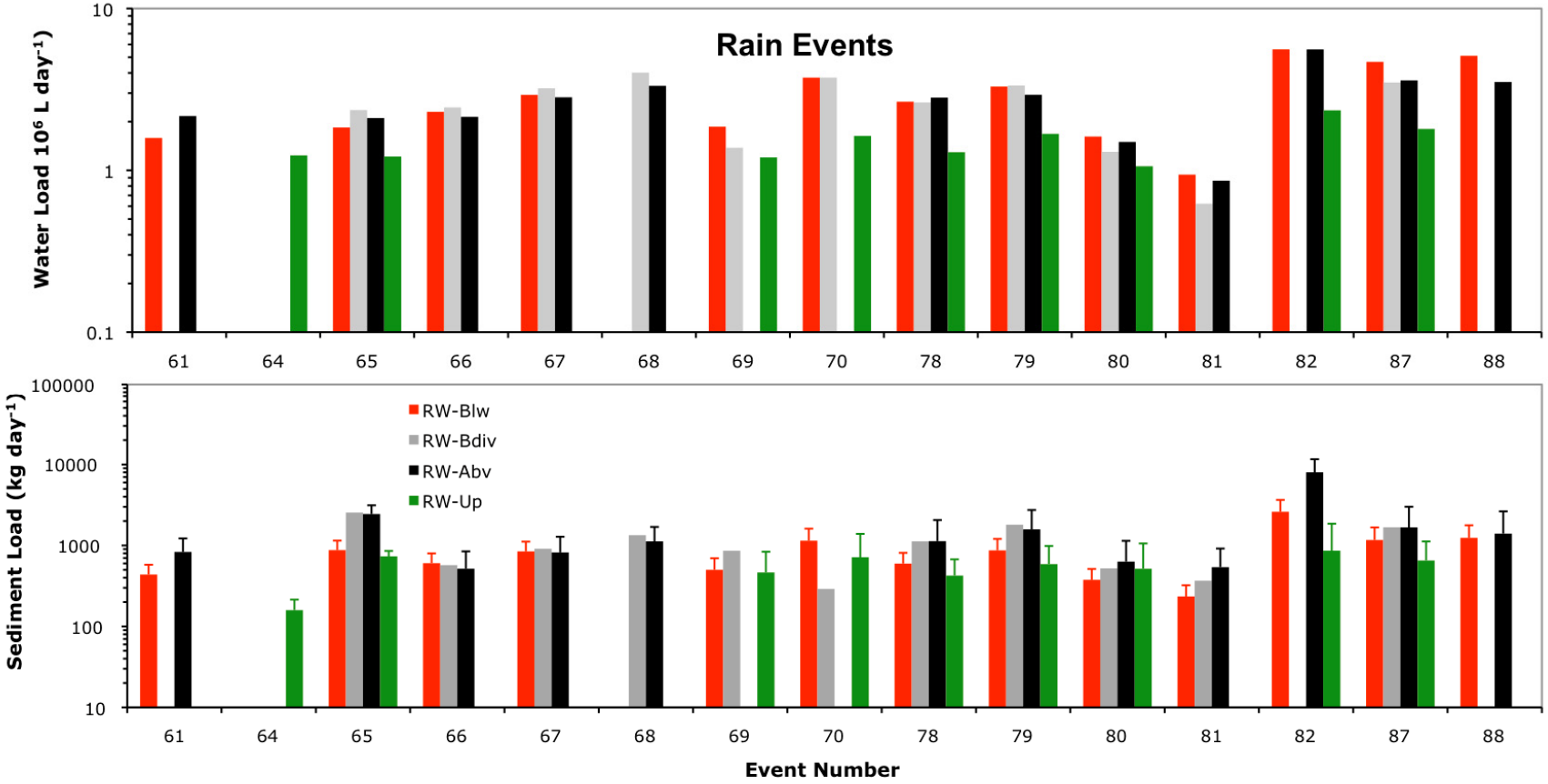

Figure 3B-9. Average daily water loading (top) and suspended sediment loading with error bars (bottom) for all rain events in WY08 through WY10. RW-Abv reflects conditions above the diversion structure whereas RW-Bdiv represents conditions below the structure on Rosewood Creek. Error bars represent the upper 95% confidence interval from the turbidity surrogate equation. See Figure 2-15 for events prior to WY08.

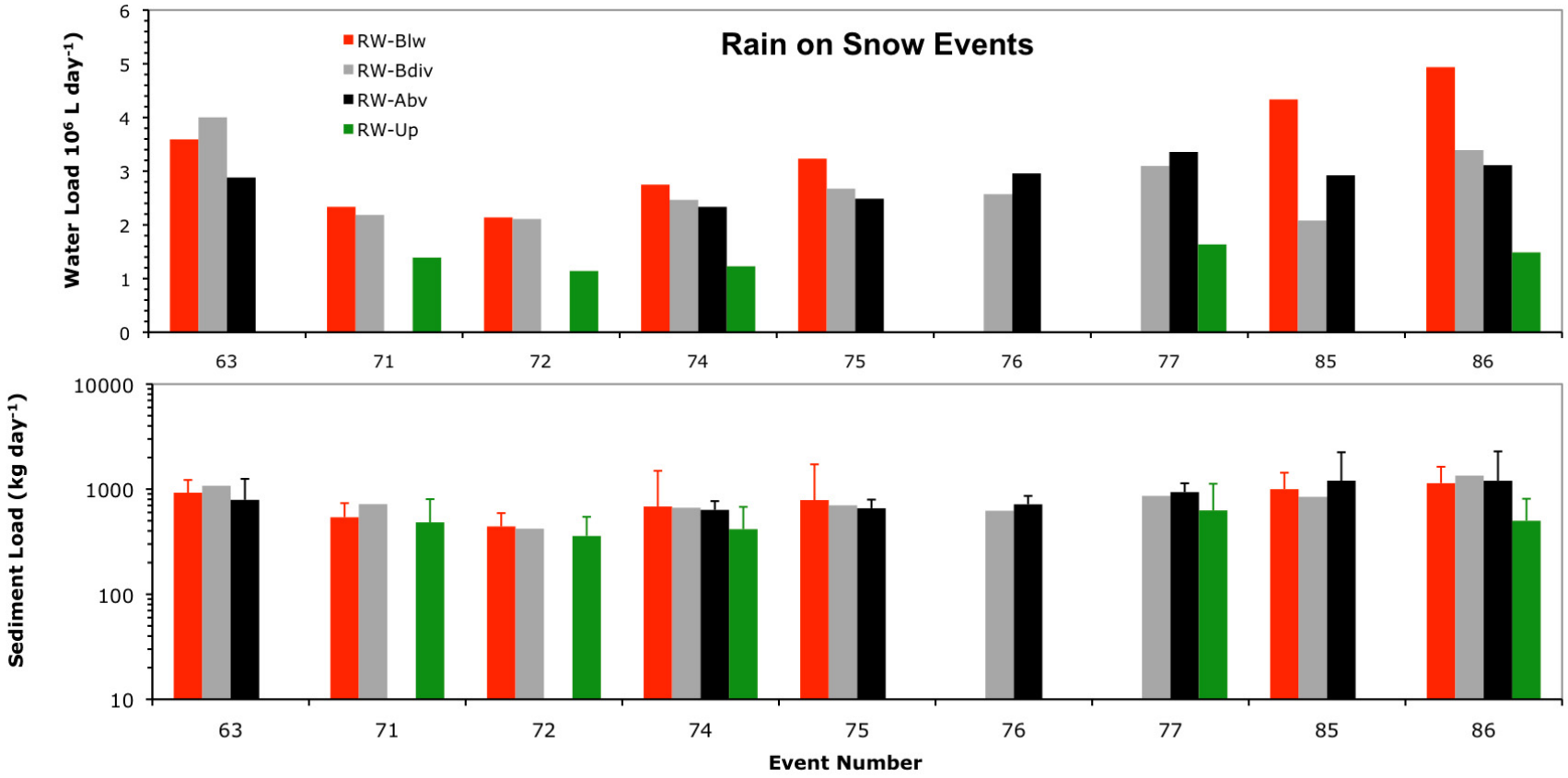

Figure 3B-10. Average daily water loading (top) and suspended sediment loading with error bars (bottom) for all rain-on-snow events in WY08 through WY10. RW-Abv reflects conditions above the diversion structure whereas RW-Bdiv represents conditions below the structure on Rosewood Creek. Error bars represent the upper 95% confidence interval from the turbidity surrogate equation. See Figure 2-18 for events prior to WY08.

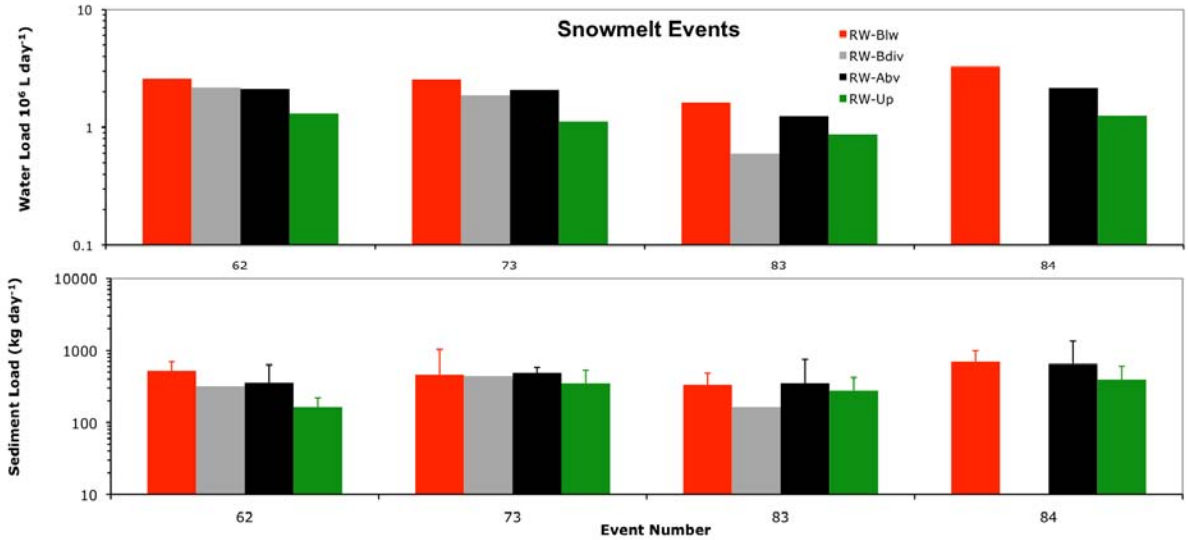

Figure 3B-11. Average daily water loading (top) and suspended sediment loading with error bars (bottom) for all snowmelt events in WY08 through WY10. RW-Abv reflects conditions above the diversion structure whereas RW-Bdiv represents conditions below the structure on Rosewood Creek. Error bars represent the upper 95% confidence interval from the turbidity surrogate equation. See Figure 2-21 for events prior to WY08.

The turbidity surrogate method used during the second phase of this project (WYs 2008 through 2010), in comparison, relied on the collection and analysis of a smaller number of discrete samples per event (typically up to 10). Samples from a number of events were combined to produce either seasonal or yearly relationships between turbidity and SSC. The benefits of this approach include the ability to quantify changes in the turbidity surrogate relationship over time, and to estimate suspended sediment loading (SSL) on a 10-minute basis. Although not necessarily recommended, this method can also be used to estimate SSL in the absence of physical sample collection as long as a continuous turbidity record is present. As this approach measures turbidity increases associated with short-term spikes, it is better able to reflect SSL during these conditions compared to the EMC approach. To obtain the best estimates, however, physical samples must still be collected during high turbidity events because of the dynamic nature of the relationship between elevated discharge and suspended sediment delivery.

A comparison of SSL by the turbidity surrogate and EMC methods for selected WYs 2008-2010 events are shown in Figure 3B-12. Overall, SSLs estimated by the turbidity surrogate method were an average of 48% higher than that calculated by the EMC method. Compared to other studies, this difference between methods is relatively minor. On the middle Truckee River, suspended sediment load averages using the turbidity surrogate method were up to 6 orders of magnitude greater than discharge-based estimates taken several years earlier (Dana *et al*., 2006). In contrast, turbidity surrogate loading estimates on Incline and Third creeks were found to be over a magnitude lower than previously determined discharge-based estimates (Susfalk; unpublished data). The limitations of these comparisons, however, are that the two methods were conducted during different time periods and were therefore unable to reflect any changes in sediment delivery due to a

difference in the magnitude of flows during the different time periods or natural and anthropogenic changes in the mobilization of sediment within the watersheds under study. Utilizing datasets from the same time period, Susfalk *et al*., (2008) found that discharge-based load estimates from the upper Carson River were generally lower than turbidity surrogate estimates. The differences could, however, be up to several orders of magnitude depending on both location and water year.

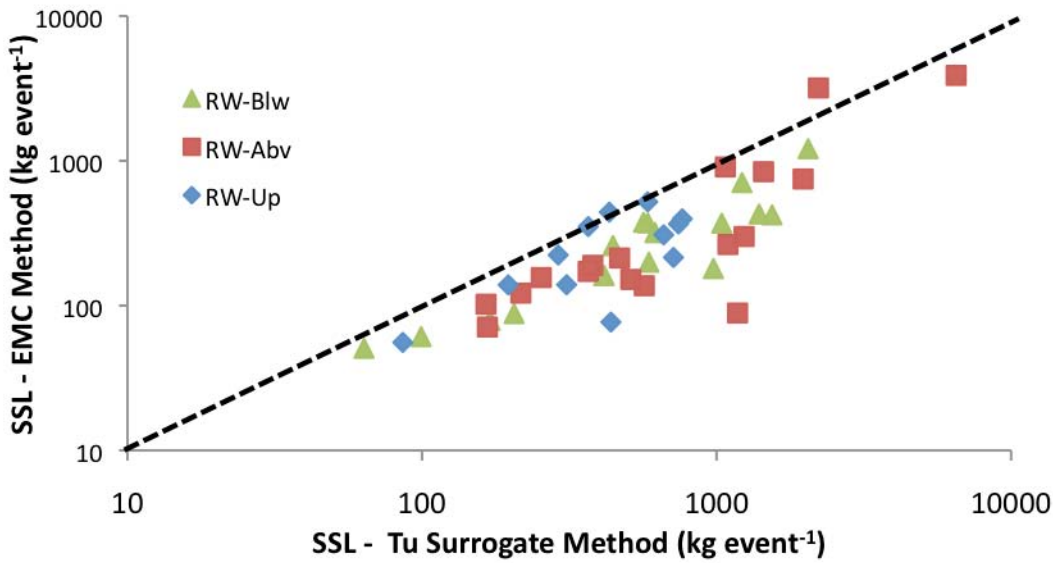

Figure 3B-12. Comparison of SSL calculated by the turbidity surrogate method and the EMC method. The black dashed line is the 1:1 line. Data were collected from all three Rosewood Creek sites during WYs 2008 through 2010. A linear regression fit (not shown) resulted in a slope of 0.622, and intercept value of -70.46, and a coefficient of variation of 0.76.

PARTICLE SIZE RELATIONSHIPS

Particle size analysis was conducted on the water samples because of its importance in affecting the clarity of Lake Tahoe. Particles of less than 20 µm in diameter, once they are discharged to the lake, tend to stay in suspended in the water column longer than those of a greater diameter or mass. The smaller, lighter particles absorb and refract light, thereby reducing the clarity of Lake Tahoe (Jassby, *et al*, 1999). On an event basis, particles of less than 20 µm in diameter comprised 39% (± 8% based on one standard deviation) of the samples at RW-Abv and 53 ± 12% at RW-Blw. This difference was statistically significant (paired t-test, α=0.05), with no influence of the different event types. This increase in percent fines between the entrance and exit of the restoration project was expected for several reasons. First, the slope of the creek decreases from 6.3% above the project area to 3.4% within the project area. As a result, the creek will drop some percentage of coarser particles near the upper boundary of the lower restoration project. Second, coarser particles entrained in the flow will be more likely to be removed by settling in the flood spreading zones of the lower reach compared to finer particle sizes. Lastly, overland flow into or within the lower reach (as previously discussed) will typically be comprised of a greater proportion of finer particles due to its slower velocity.

The load of particles less than 20 µm in diameter are presented in Table 3B-8 on an event basis. Trends for this finer size fraction were consistent with bulk suspended sediment loads. An increase in the load of fine particles within the lower restoration project was observed for snowmelt and rain-on-snow events whereas loading within the project area during rain events were observed to both increase and decrease. Specifically, loadings increased from 306 ± 121 kg day^{-1} at RW-Abv to 430 ± 133 kg day^{-1} at RW-Blw for rain-on-snow events, and from 176 ± 63 kg day^{-1} at RW-Abv to 274 ± 89 kg day^{-1} at RW-Blw for snowmelt events. Of the 11 rain events in WY 2008 through 2010 having sufficient data for accurate calculation, the load of sediment with less than 20 µm diameters decreased in six events (mean = -284 ± 349 kg day^{-1}) and increased in five events (mean = 69 ± 20 kg day^{-1}). When the load of fine sediment decreased through the restoration project, it was highly variable, ranging from -33 up to -972 kg day^{-1}. There was no obvious relationship between fine sediment loading rates and the volume of water entering or exiting the project area.

Table 3B-8. Less than 20 µm diameter particles as percent of PSD and as suspended sediment loads by event. See Table 3B-7 for results for the total sediment loadings for these events.

		Less than 20 µm diameter			
		RW-Abv		RW-Blw	
Event #	Event Type	Percent of PSD	Sediment Load (kg event^{-1})	Percent of PSD	Sediment Load (kg event^{-1})
61	Rain	33	85	43	73
62	SM	37	11346	45	19829
63	ROS	34	71	43	111
64	Rain	--	--	--	--
65	Rain	32	347	41	240
66	Rain	34	130	43	179
67	Rain	34	73	43	88
68	Rain	34	123	--	--
69	Rain	--	--	62	277
70	Rain	--	--	60	336
71	ROS	--	--	66	389
72	ROS	--	--	69	675
73	SM	30	9931	77	24095
74	ROS	48	522	60	678
75	ROS	45	525	61	847
76	ROS	34	669	--	--
77	ROS	51	238	--	--
78	Rain	46	574	67	695
79	Rain	51	1139	63	765
80	Rain	47	79	66	65
81	Rain	53	88	64	41
82	Rain	21	1369	29	603
83	SM	43	3002	50	3309
84	SM	42	23326	49	29485
85	ROS	35	196	46	285
86	ROS	36	516	46	711
87	Rain	32	165	44	181
88	Rain	35	291	44	348

The daily loads of fine sediment above and below the restoration project are graphically compared in Figure 3B-13. Symbols above the black 1:1 line indicate events where there was an increase in the loading of fine particles through the restoration project. These events include all the snowmelt and rain-on-snow, and approximately half of the rain events. Rain events below the 1:1 line included Event 82 (-973 kg day^{-1}), Event 79 (-273 kg day^{-1}), Event 65 (-201 kg day^{-1}), Event 81 (-164 kg day^{-1}), Event 80 (-60 kg day^{-1}), and Event 61 (-33 kg day^{-1}). These events encompassed both small events with water volumes of less than 1 x 10^6 L as well as medium events (Events 79 and 82) with water volumes greater than 4 x 10^6 L. Calendar year 2009, comprised of the snowmelt season and a series of rain-on-snow and rain events (Events 74 through 82) provides an interesting example. The lower restoration project was a net source of fine sediment during the snowmelt season, four rain-on-snow events, and during the first rain event (Events 74 through 82). After May 3rd, 2010, the lower project area became a net sink of fine particles during each of the four remaining rain events (Events 79 through 82).

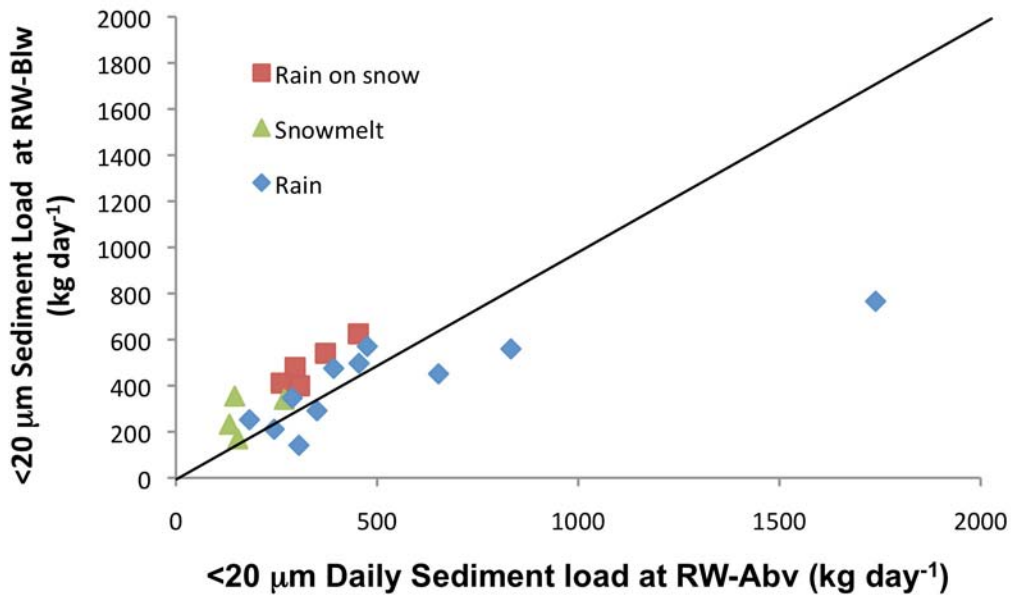

Figure 3B-13. Comparison of the <20 µm diameter suspended sediment load by event. The solid black line is the 1:1 line. Events below the 1:1 line represent a reduction in the load of <20 µm diameter suspended sediment.

In conclusion, results for the investigation of fine particles during WYs 2008 through 2010 indicate that they are more likely to comprise a greater percentage of bulk suspended sediment loads during snowmelt and rain-on-snow events relative to rain events. The lower restoration project was capable of reducing fine and bulk sediment loads during some rain events, but not generally during rain-on-snow, and never during snowmelt events. Within each type of event, there was no correlation between sediment deposition/generation and the volume of water entering or leaving the lower restoration project area. Rather, as calendar year 2009 data suggest, the project is more effective at capturing sediment and reducing water volume during short-term rain events rather than longer term, lower water velocity rain-on-snow and snowmelt events.

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CHAPTER 3: LOWER AND MIDDLE ROSEWOOD CREEK RESTORATION PROJECTS: 2007-2010

PART C: CHEMISTRY AND WATER TEMPERATURE

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INTRODUCTION

NTCD secured an Erosion Control grant with the USDA Forest Service, Lake Tahoe Basin Management Unit in April 2007. The match for the federal funds was obtained by DRI using NDSL License Plate Grant funds. These two grants provided funding for all three sites from April 2007 through June 2010 and both grants had similar objectives. First was to evaluate the effectiveness of the restoration along the lower reach of Rosewood Creek (constructed in 2003). The second objective was to provide flow and water quality data to support design of sections of the middle reach of Rosewood Creek. Previously, only flow, turbidity, and sediment size analysis data had been collected, but these grants added an additional sampling site (RW-Up) and water quality nutrient analysis to the data set for all three sites.

NTCD and DRI collaborated in managing the three sampling sites with DRI taking the lead role in programming and day to day operations. Data collected included in-situ information (SC, water temperature, turbidity, and stage) and discrete 1-liter water quality samples triggered on turbidity (for RW-Blw and RW-Abv) or stage (for RW-Up). Multiple samples collected for an event were composited and analyzed to produce an event mean concentration (EMC).

Analysis is provided for in-situ data, SC, and temperature (with turbidity having already been discussed in previous sections), nutrient concentrations for all water quality samples, event EMCs (overall, rain, and rain-on-snow), and event loads (overall, rain, and rain-on-snow). Finally, two individual events are discussed in detail.

RESULTS

Specific Conductance

Washoe County and NDOT use traction control material with 25% sodium chloride by volume. As a result, SC generated dramatic spikes during snowmelt events due to dissolution and transport of road salt. Beginning in mid November through mid March, of each year, there are several SC spikes at all three sites, but none outside of winter months. An illustration of this phenomenon is presented in Figure 3C-1 where autumn storms did not result in high SC values, but winter melt events have dramatic SC spikes. This observation is consistent with that noted on Incline Creek, where SC spikes from urbanized stations were

associated with snowmelt events, but these spikes were not observed from the forested and undeveloped upper Incline watershed (Dana *et al*, 2008).

In addition, summer SC measurements exhibit a diel pattern that becomes more distinct with distance downstream. For example, looking at early June 2008 (Figure 3C-1), SC exhibits a daily increase of 17% measured at RW-Abv (compared to a 6% diel increase at RW-Up and 45% at RW-Blw for the same period). Out of phase with the SC pattern is discharge with minimum flow occurring between 4 and 5 pm and maximum flow (double the minimum) 14 hours later likely due to evapotranspiration (ET) (discharge has 11% differential at RW-Up, and 100% at RW-Blw). The change in SC may be due to ET removing groundwater from the root zone, but leaving cations in the soil resulting in a higher concentration of cations captured by the creek during the day.

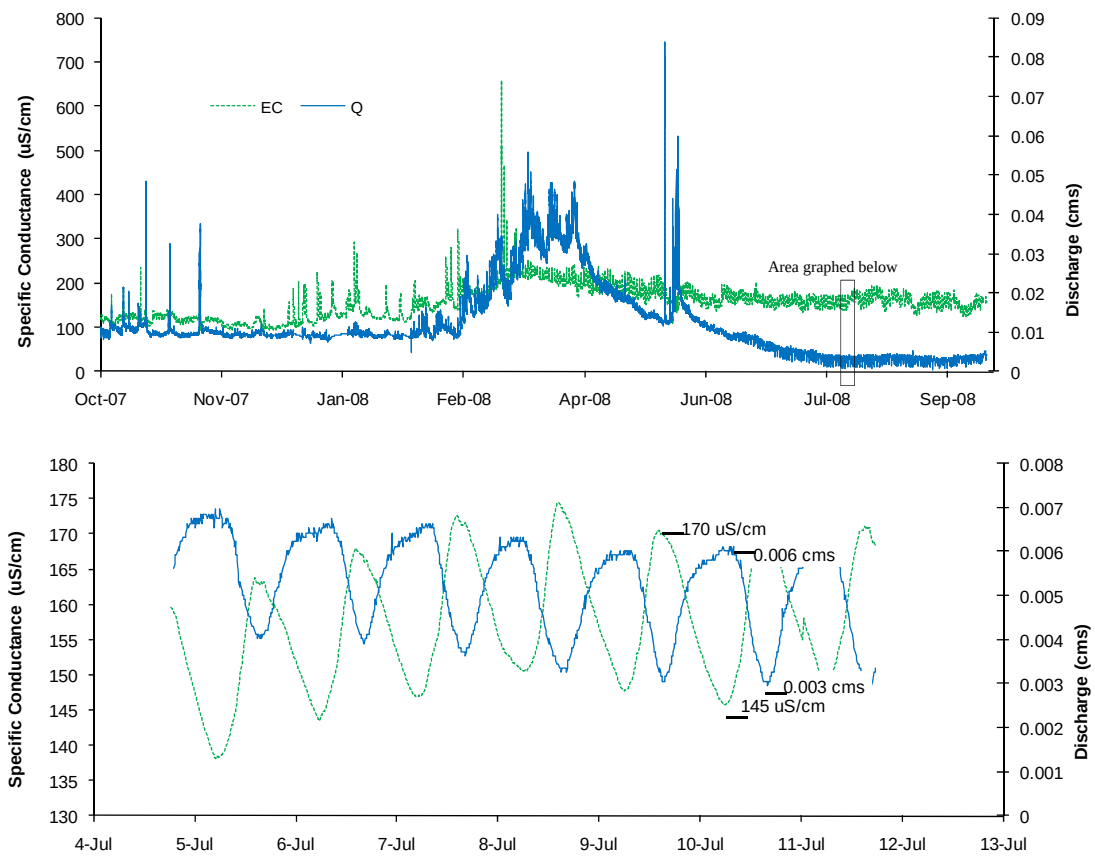

Figure 3C-1. SC and flow graphed for RW-Abv for WY08 (above) and an exploded view of the diel cycle in early July 08 (below).

Temperature

Maximum water temperature at RW-Blw was 30.1°C, 19.2°C at RW-Abv, and 13.8 °C at RW-Up. Average summer temp at RW-Up was 9.5, 11.3 at RW-Abv, and 18.2 °C at RW-Blw. The peak temperature at RW-Blw raises concerns for the viability of fish species in the lower reach; this concern is compounded by on-going fuels reduction efforts along the creek and the restoration of Area A of the middle reach both of which will dramatically

reduce riparian overstory vegetation for a period of years and likely increase water temperatures.

Water Quality Concentrations

From 2006 through 2010, 139 water quality samples were analyzed for nutrients and TSS from individual grab samples (23), composite samples (i.e., EMCs) (52), and discrete samples selected from event sample sets (64). A box and whisker plot was generated for each constituent concentration based on all samples collected at each site (Figures 3C-2 and 3C-3). As expected the data is highly variable with 20 to 25% of the concentrations outside the decile whiskers of the box plot. In general, the median concentrations were similar at all three sample sites with a slight tendency to decrease downstream. Mean concentration were more variable with mean TSS concentrations and most particulate constituents highest at RW-Up. Both the mean and median concentrations tended to be lowest at RW-Blw.

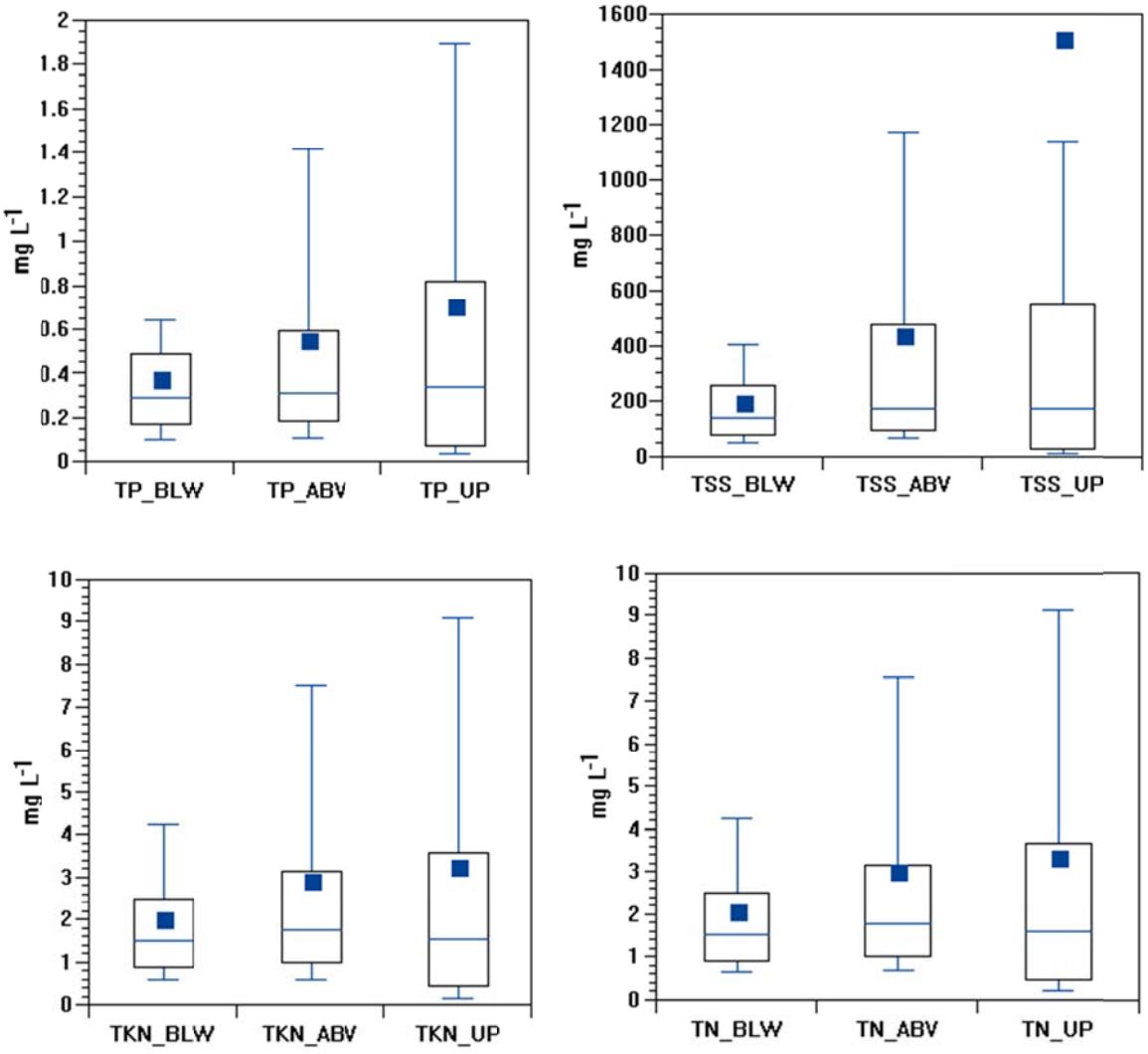

Figure 3C-2. Box and whisker plot of constituent concentrations at RW-Blw (BLW), RW-Abv (ABV), and RW-Up (UP) for total phosphorus (TP), total suspended sediment (TSS), total Kjeldahl nitrogen (TKN), and total nitrogen (TN).

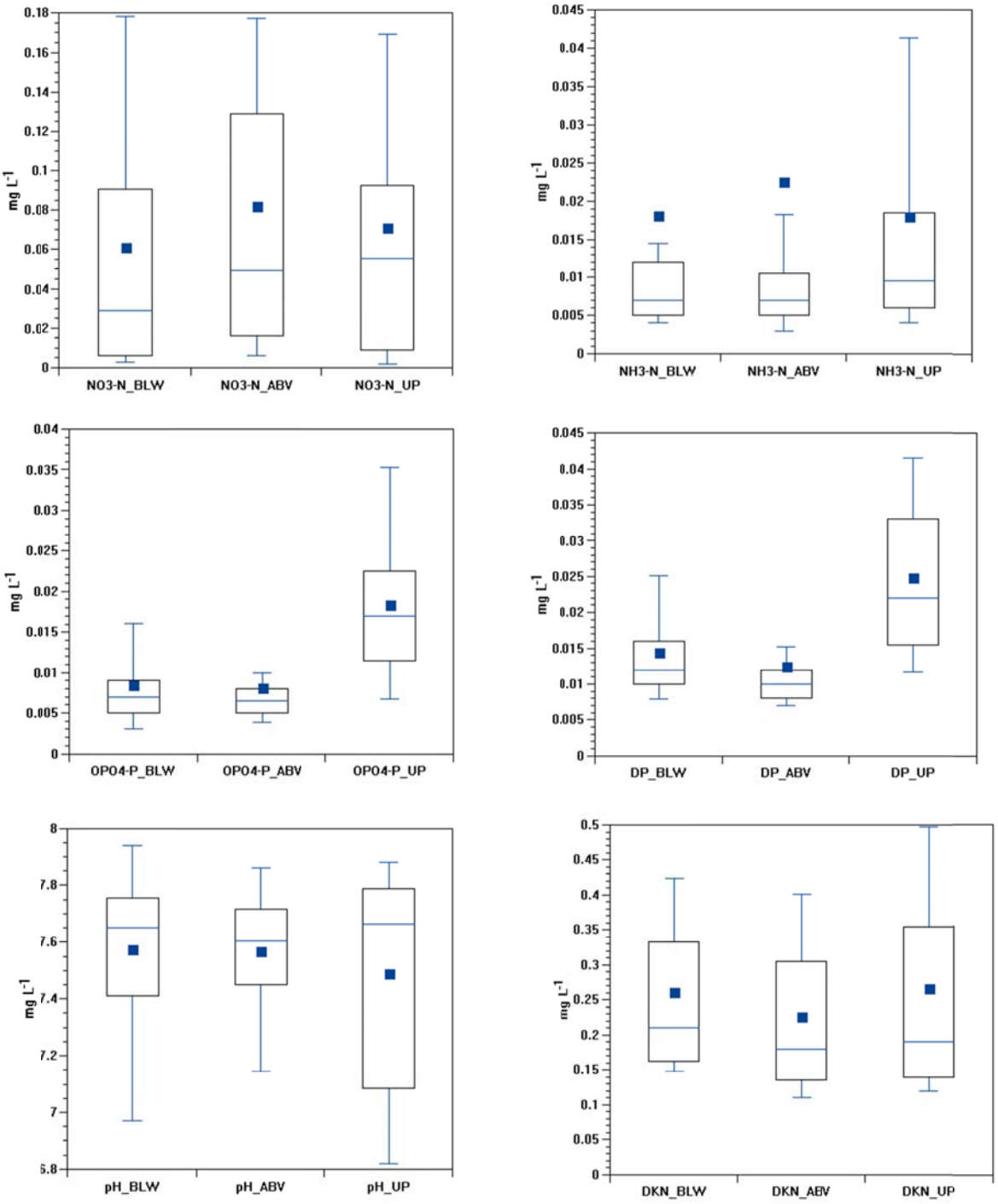

Figure 3C-3. Box and whisker plots of constituent concentrations at the three water quality sample sites for nitrate (NO3-N), ammonia (NH3-N), ortho-phosphate (OPO4-P), dissolved phosphorus (DP), pH, and dissolved Kjeldahl nitrogen (DKN).

Concentration Comparison

NTCD monitored similar water quality parameters at two sites in Lake Forest, CA in the Lake Tahoe basin near Tahoe City from 2007 through 2010. The sites in Lake Forest drained an area and land use similar to RW-Blw. All concentrations were the same order of magnitude except TKN, TN, and TSS which were an order of magnitude greater in the Rosewood Creek system (Table 3C-1). The difference in concentrations of these particulate constituents is attributed to the degraded section of creek above RW-Abv, one that is scheduled for restoration in 2011.

Table 3C-1.Summary statistics for EMCs at the three monitoring sites. Units are grams.

		NO_3-N	NH_3-N	DKN	TKN	TN	OPO_4-P	DP	TP	TSS	pH
RW-Up	Minimum	0.002	0.004	0.08	0.13	0.20	0.005	0.009	0.03	5.4	6.77
	25% quartile	0.02	0.01	0.14	0.74	0.78	0.01	0.02	0.14	83	7.55
	Median	0.06	0.01	0.19	1.5	1.6	0.02	0.02	0.34	178	7.74
	75% quartile	0.11	0.02	0.30	2.6	2.7	0.02	0.03	0.51	287	7.82
	Maximum	0.17	0.16	1.2	12.1	12.1	0.04	0.05	2.10	577	8.04
	Mean	0.07	0.02	0.29	2.3	2.3	0.02	0.02	0.43	202	7.61
	Standard Deviation	0.06	0.04	0.27	2.8	2.8	0.01	0.01	0.49	158	0.36
	C.V.	84%	172%	92%	122%	118%	55%	50%	114%	78%	5%
	n	17	17	17	17	17	17	17	17	16	16
RW-Abv	Minimum	0.004	0.003	0.090	0.580	0.676	0.003	0.007	0.150	66	7.22
	25% quartile	0.019	0.005	0.133	1.140	1.165	0.005	0.008	0.218	119	7.59
	Median	0.06	0.01	0.17	1.37	1.45	0.01	0.01	0.31	161	7.63
	75% quartile	0.12	0.01	0.31	2.11	2.25	0.01	0.01	0.41	350	7.79
	Maximum	0.18	0.59	0.58	7.50	7.51	0.08	0.08	1.40	1140	7.99
	Mean	0.08	0.04	0.23	2.34	2.41	0.01	0.01	0.44	331	7.66
	Standard Deviation	0.06	0.14	0.14	2.16	2.17	0.02	0.02	0.38	349	0.19
	C.V.	84%	341%	60%	93%	90%	166%	115%	86%	105%	3%
	n	18	18	18	18	18	18	18	18	18	18
RW-Blw	Minimum	0.003	0.004	0.13	0.40	0.45	0.002	0.007	0.10	40	6.91
	25% quartile	0.01	0.01	0.17	0.88	0.94	0.01	0.01	0.19	80	7.62
	Median	0.02	0.01	0.21	1.14	1.23	0.01	0.01	0.23	124	7.65
	75% quartile	0.08	0.01	0.26	1.93	1.97	0.01	0.02	0.32	157	7.75
	Maximum	0.15	0.39	0.42	3.64	3.65	0.03	0.03	0.62	303	8.03
	Mean	0.05	0.03	0.23	1.53	1.58	0.01	0.01	0.29	137	7.63
	Standard Deviation	0.05	0.10	0.09	0.91	0.91	0.01	0.01	0.15	73	0.31
	C.V.	104%	296%	37%	60%	58%	72%	52%	52%	54%	4%
	n	17	16	16	16	16	17	17	17	17	17

Event Type (EMCs)

Concentrations from composite samples were divided into Rain and Rain-on-Snow (ROS) events. Snowmelt was considered a multi-week event and no EMCs were generated for Snowmelt. The general trend was decreasing median and mean concentrations for both Rain and ROS events as a function of distance downstream. One interesting exception was median and mean NO_3 concentration for ROS events that were highest at RW-Abv. Median and mean ROS event concentrations for NO_3 were approximately twice that of Rain events, but the opposite was true of TSS, TKN, and TN concentrations, that is, median and mean Rain concentrations were twice that of ROS and generally increased downstream (except for TSS that was highest at RW-Abv). Mean Rain event concentrations were lowest at RW-Blw, except for NH_3 that was the lowest at RW-Up.

EVENT LOADS

Event loads were calculated from the 52 EMCs and summarized for each WQ constituent in Figures 3C-4 and 3C-5. Median and mean event volumes doubled between RW-Up and RW-Abv, and increased approximately 20% more down to RW-Blw. Median constituent loads increased downstream with the highest load at RW-Blw except for NO_3 (highest at RW-Abv). Mean constituent loads were more variable with TSS and most particulate bound constituents, and NO_3 were highest at RW-Abv. RW-Up had a lower mean and median load and was less variable possibly due to the lack of urban influence.

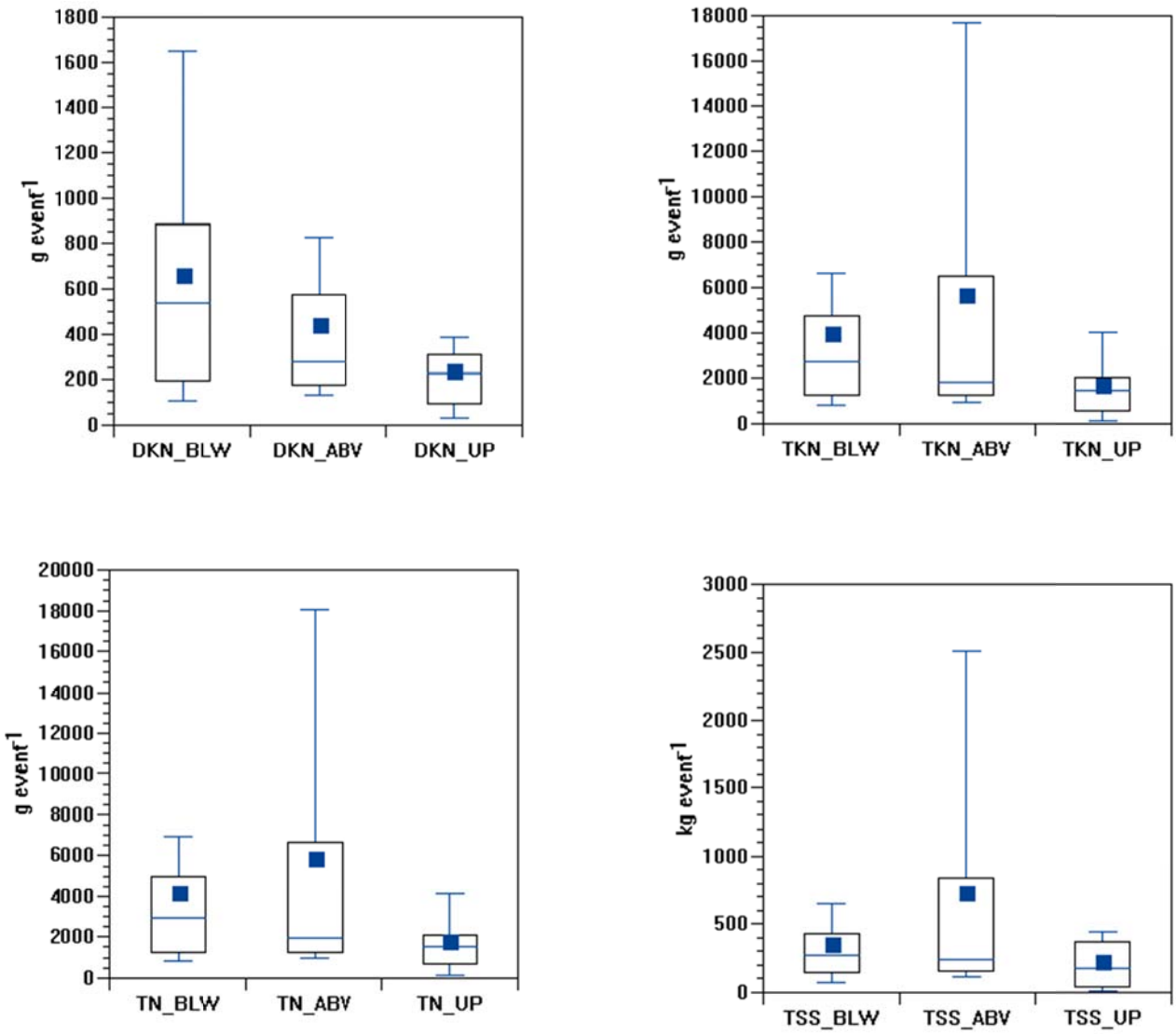

Figure 3C-4. Box and whisker plots for constituent loads of DKN, TKN, TN, and TSS at the three monitoring sites.

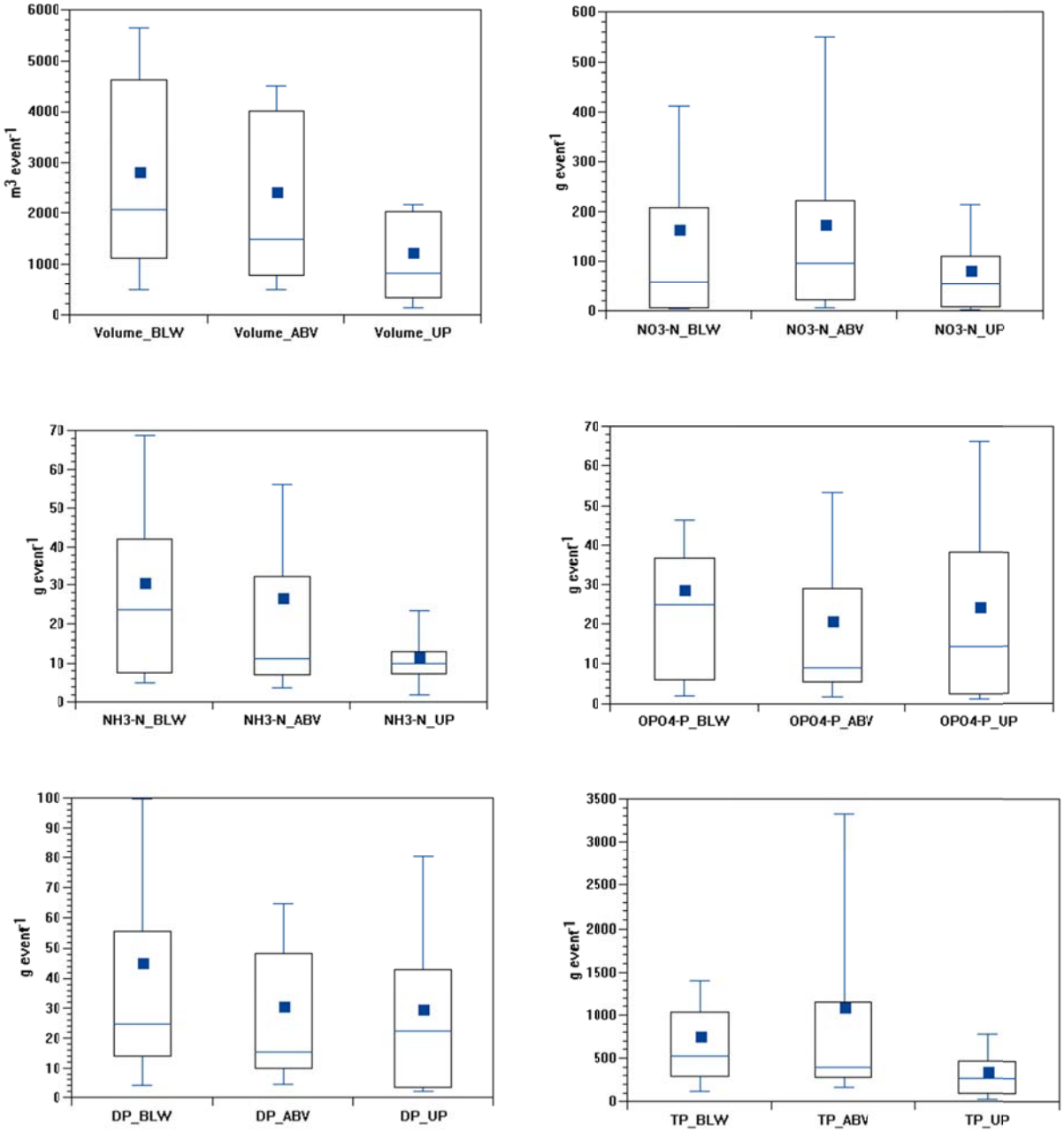

Figure 3C-5. Box and whisker plots for constituent loads of DKN, TKN, TN, and TSS at the three monitoring sites.

The most significant stormwater inputs between RW-Up and RW-Abv were observed at Harold Drive and SR28/Northwood Blvd. Inputs above Highway 431 were likely to be small as they are small and steep county roads that are lightly traveled. Stormwater inputs below RW-Abv were minimal consisting mostly of Incline Way. Salt and sand application on Highway 431 and State Route 28 are extensive, but the county only sands at intersections.

Event Type (Loads)

For Rain events, median loads were generally similar at RW-Up and RW-Blw, but were generally lower at RW-Abv (except for NO_3). Mean Rain loads tended to be highest at RW-Abv especially TKN, TN, and TSS. Median and average constituent loads for ROS generally increased downstream except TSS that was highest at RW-Abv (indicating possible erosion from the area of creek upstream of RW-Abv).

Individual Event Concentrations

Fifty-two EMCs were generated from runoff events, 17 from RW-Up, 18 from RW-Abv, and 17 from RW-Blw, although only eight events resulted in EMCs at all three sites. Three of those eight events included additional analysis of discrete samples in addition to the EMCs. Two of those events are discussed in more detail below.

Table 3C-2. Summary statistics for event volumes and water quality loads for the three monitoring sites. All values are in grams unless noted otherwise.

		Volume (m^3)	NO_3-N	NH_3-N	DKN	TKN	TN	OPO_4-P	DP	TP	TSS (kg)
RW-Up	Minimum	48	0.62	1.34	0.33	1.6	19.3	21	94	105	5.9
	25% quartile	386	10	8	3	3	100	104	582	731	49
	Median	814	53	10	15	22	271	228	1432	1519	179
	75% quartile	2022	104	13	37	39	446	296	2002	2051	358
	Maximum	4479	318	27	85	90	855	650	4461	4522	524
	Mean	1205	78	11	24	29	323	224	1582	1660	207
	Std. Dev.	1135	89	7	25	28	272	163	1358	1354	173
	C.V.	94%	114%	63%	107%	99%	84%	73%	86%	82%	84%
	n	17	17	17	17	17	17	17	17	17	16
RW-Abv	Minimum	268	2.68	2.30	1.21	2.4	123.7	96	880	906	72
	25% quartile	816	30	7	5	10	281	177	1274	1315	160
	Median	1492	96	11	9	15	398	274	1792	1942	240
	75% quartile	3962	216	31	27	48	1099	574	6072	6213	822
	Maximum	8132	639	158	85	91	6366	1546	34106	34128	3897
	Mean	2382	170	26	20	30	1071	428	5554	5725	712
	Std. Dev.	2089	197	37	23	27	1622	365	8739	8749	1077
	C.V.	88%	116%	140%	112%	89%	151%	85%	157%	153%	151%
	n	18	18	18	18	18	18	18	18	18	18
RW-Blw	Minimum	260	2.86	2.92	1.35	3.1	102	65	598	601	52
	25% quartile	1237	6.6	8.1	6.4	15	325	202	1357	1386	163
	Median	2077	59	24	25	25	521	533	2727	2908	272
	75% quartile	4637	199	39	35	56	1027	881	4491	4823	424
	Maximum	6799	999	102	157	197	3059	1890	18103	18133	1373
	Mean	2775	160	30	28	45	733	649	3864	4034	333
	Std. Dev.	2053	250	28	37	49	719	559	4251	4289	319
	C.V.	74%	156%	92%	130%	110%	98%	86%	110%	106%	96%
	n	17	17	16	17	17	17	16	16	16	17

20 May 2008

The 0.76 cm rain event on 20 May 2008 generated runoff at all three sites. Composite samples were analyzed along with several discrete water quality samples from each site. Below are four sets of graphs; the first shows the hydrograph with the samples that were composited for the EMC, the discrete samples, and the event SC (Figure 3C-6). The next three graph sets show the hydrograph, the EMC concentration, and the concentration for each of the discrete samples for TSS (Figure 3C-7), ortho-phosphate (ORP, a.k.a. OPO_4-P) (Figure 3C-8), and dissolved inorganic nitrogen (DIN) (NH_3 + NO_3) (Figure 3C-9). Table 3C-3 provides the event concentration, volume, and load for each constituent.

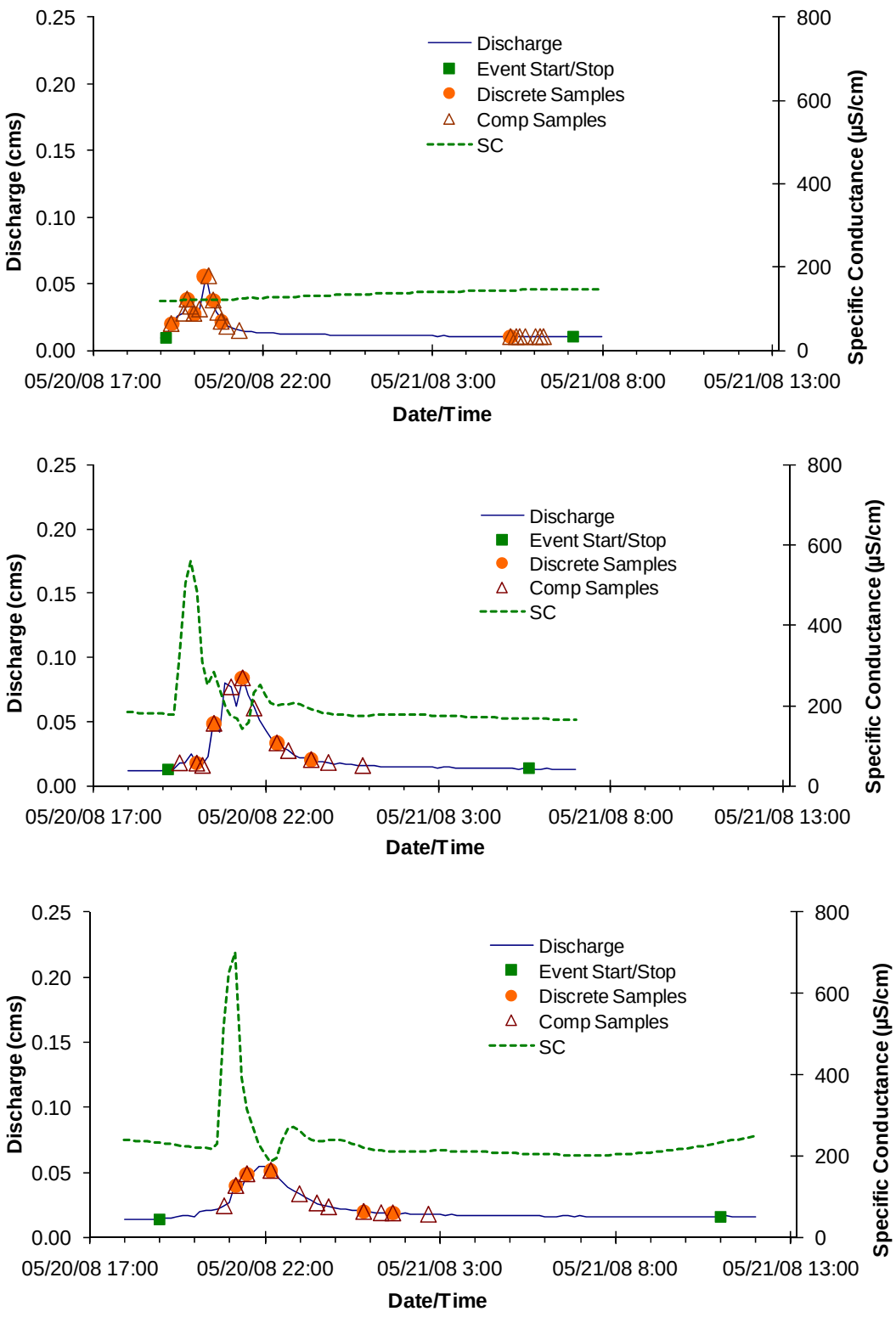

Figure 3C-6. Event hydrographs, samples, and SC for the rain event on 20 May 2008 at RW-Up, RW-Abv, and RW-Blw, respectively.

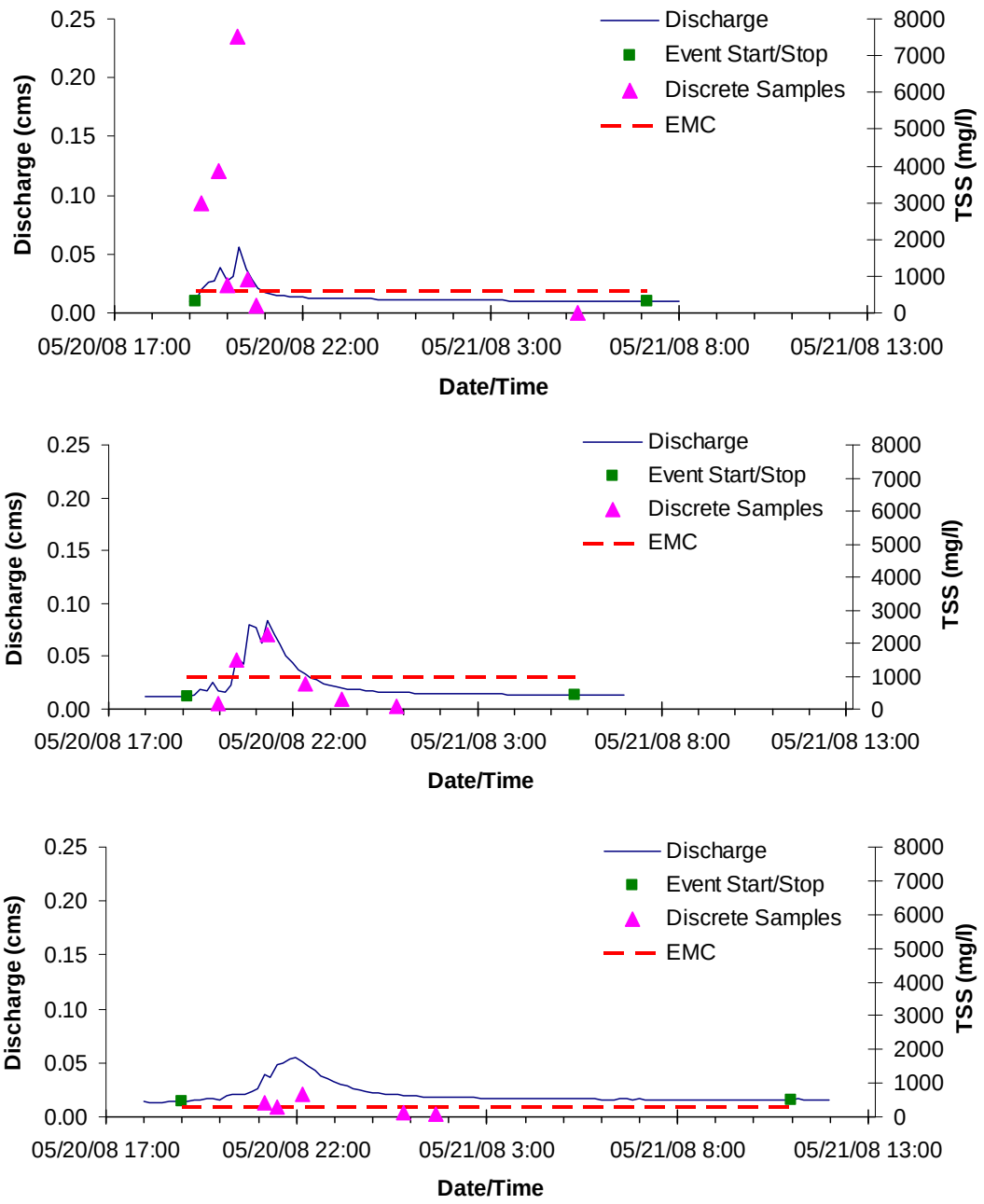

Figure 3C-7. Event hydrographs and TSS concentrations for the EMC and discrete samples at RW-Up, RW-Abv, and RW-Blw, respectively.

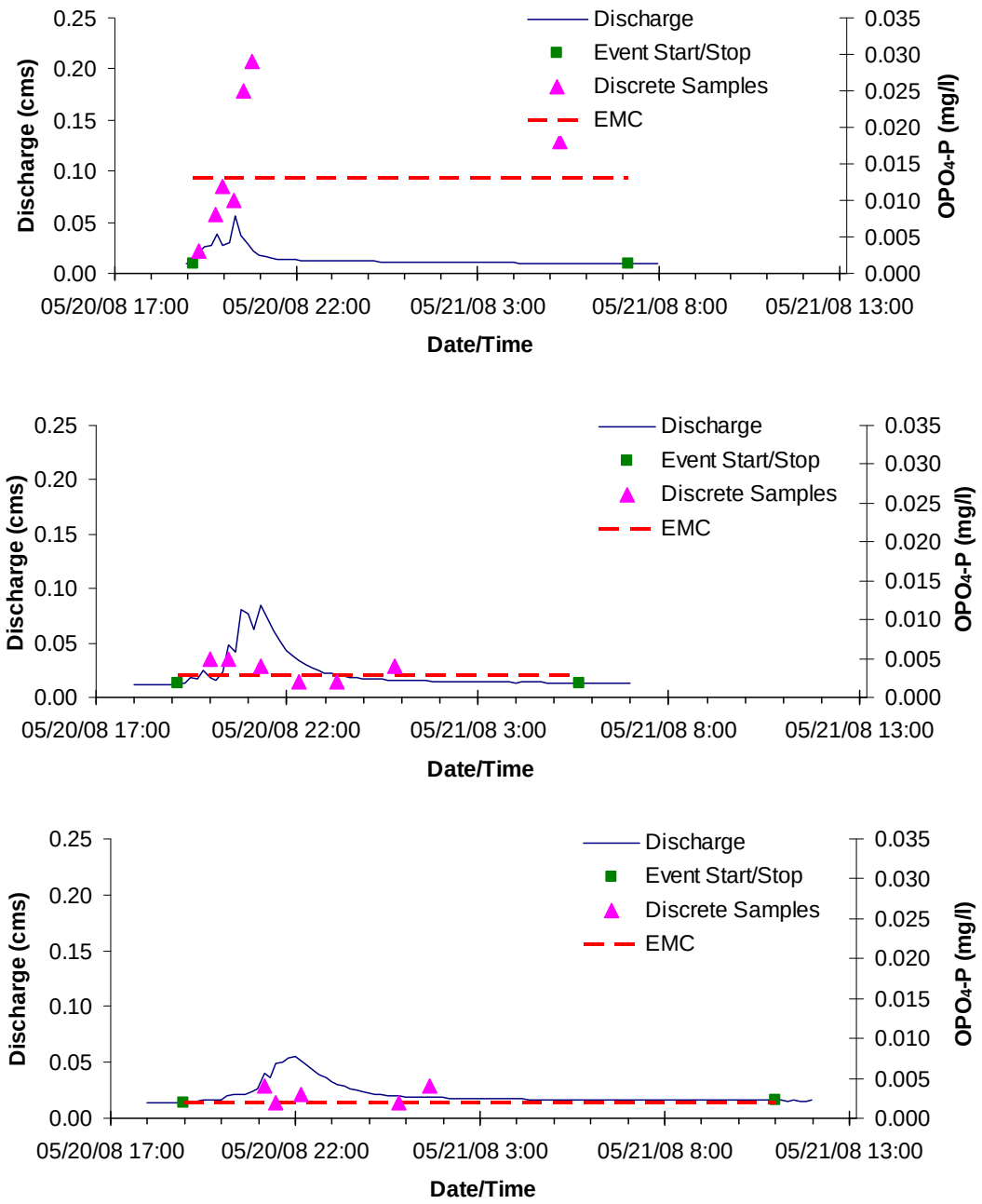

Figure 3C-8. Event hydrographs and ORP concentrations for the EMC and discrete samples at RW-Up, RW-Abv, and RW-Blw, respectively.

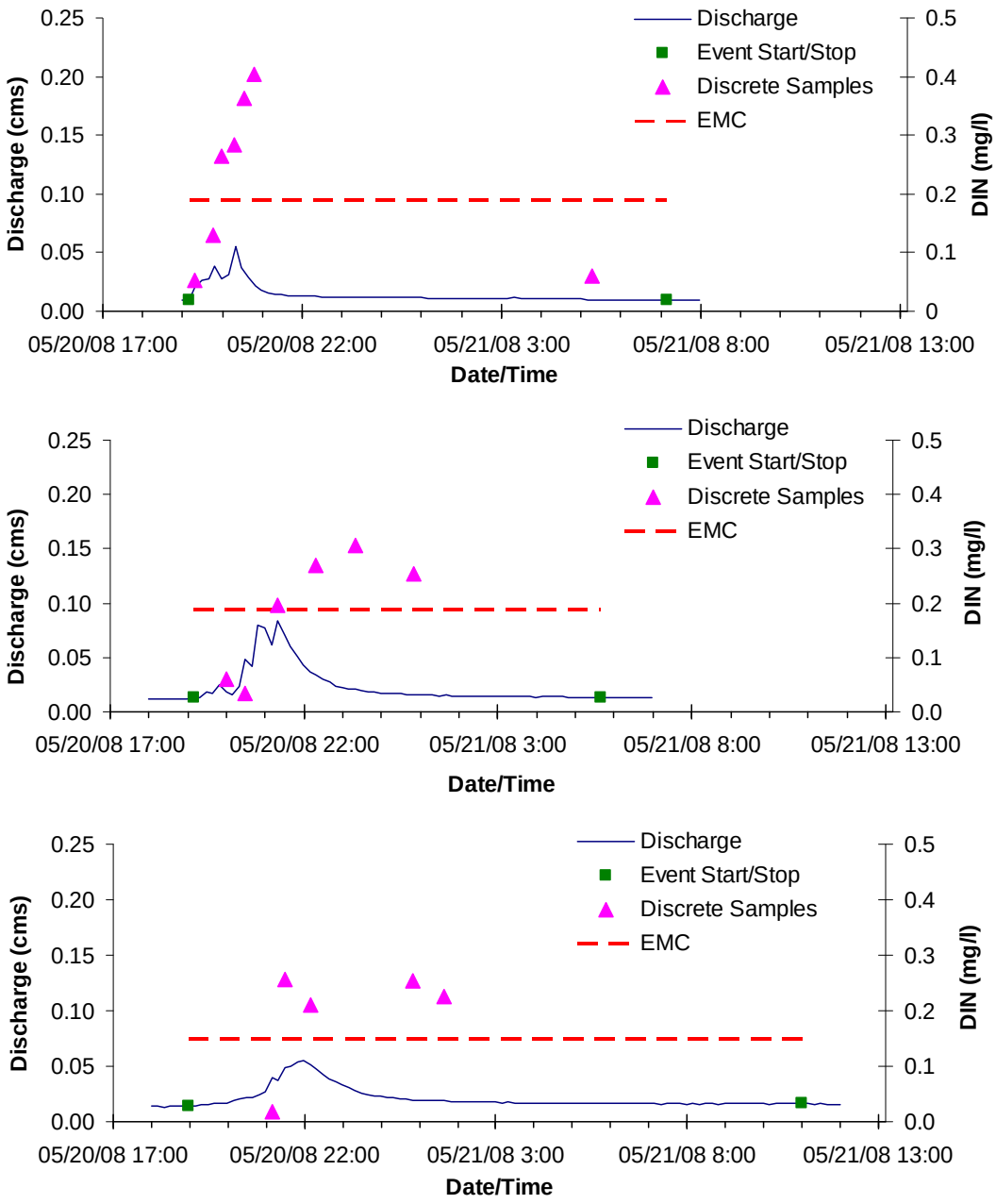

Figure 3C-9. Event hydrographs and TSS concentrations for the EMC and discrete samples at RW-Up, RW-Abv, and RW-Blw, respectively.

Table 3C-3. Event volumes, EMCs, and loads for each constituent at each site for the 20 May 2008 event.

		RW-Up	RW-Abv	RW-Blw	units
	Volume	615	929	1,237	m^3
EMCs	ORP	0.013	0.003	0.002	mg/l
	DIN	0.189	0.189	0.148	mg/l
	TSS	577	985	303	mg/l
Loads	ORP	8	2.8	2.5	g
	DIN	116	175	183	g
	TSS	355	915	374	kg

Figure 3C-6 shows peak flow of the event hydrograph occurs later at downstream sites with the highest peak flow at RW-Abv. Event volume increases downstream (Table 3C-3). The combination of lower peak flow, greatest volume, and a more rounded hydrograph at RW-Blw suggests a degree of hydrologic storage between RW-Abv and RW-Blw.

SC spikes at RW-Abv as stormwater runoff from the predominately urban middle reach enters the creek and becomes more pronounced at RW-Blw. Assuming SC is a result of road salt suggests the drainage between RW-Up and RW-Abv is well connected to impervious surfaces because of the difference in SC response at each site. The late date of this event casts doubt on the cause of the SC response, but only 0.38 cm of precipitation had fallen the previous two months and likely had not completely washed the roads of road salt.

EMCs were lowest at RW-Blw and nutrient concentrations decreased downstream (Figures 3C-7, 8, and 9). Comparing the concentrations of the discrete samples to the EMCs indicate a first flush response at RW-Up for all three constituents. ORP and TSS dramatically decrease concentration from RW-Up to RW-Abv. DIN concentrations were more consistent at each site. Although TSS concentrations for discrete samples were very high in the rising limb at RW-Up, the EMC was highest at RW-Abv. By the time the event was sampled at RW-Blw, most of the variability in the discrete TSS concentrations was gone.

The load of TSS and ORP increased from RW-Up to RW-Abv, but decrease to RW-Blw indicating a source from connected impervious surfaces or from the creek bed and bank erosion to RW-Abv. Nutrient analysis conducted as part of the sweeper study (Brown *et al*., 2011) shows road runoff in Tahoe is not a significant source of nutrients, but the segment of creek upstream of RW-Abv is highly degraded and is a likely source of erosion.

13 October 2009

A much larger 4.3 cm rain event occurred on 13 October 2009. Peak flow occurred at about the same time at all three sites (Figure 3C-10) and a discrete sample was analyzed at peak flow for all three sites. Event volume more than doubled between RW-Up and RW-Abv, but increased only 9% from RW-Abv to RW-Blw. Unlike the 20 May 2008 event, this autumn event generated no spike in SC (Figure 3C-10). EMC nutrient concentration decreased over 60% from RW-Up to RW-Abv, but remained essentially unchanged from RW-Abv to RW-Blw (Figures 3C-11 and 3C-13). Discrete concentrations at RW-Up were significantly higher than the EMC, but the concentrations at the other sites were essentially equivalent to the EMC (except for DIN at RW-Abv). The TSS EMC concentration spiked at

the RW-Abv site again suggesting a sediment source between RW-Up and RW-Abv, but TSS decreased 68% between RW-Abv and RW-Blw (Figure 3C-11).

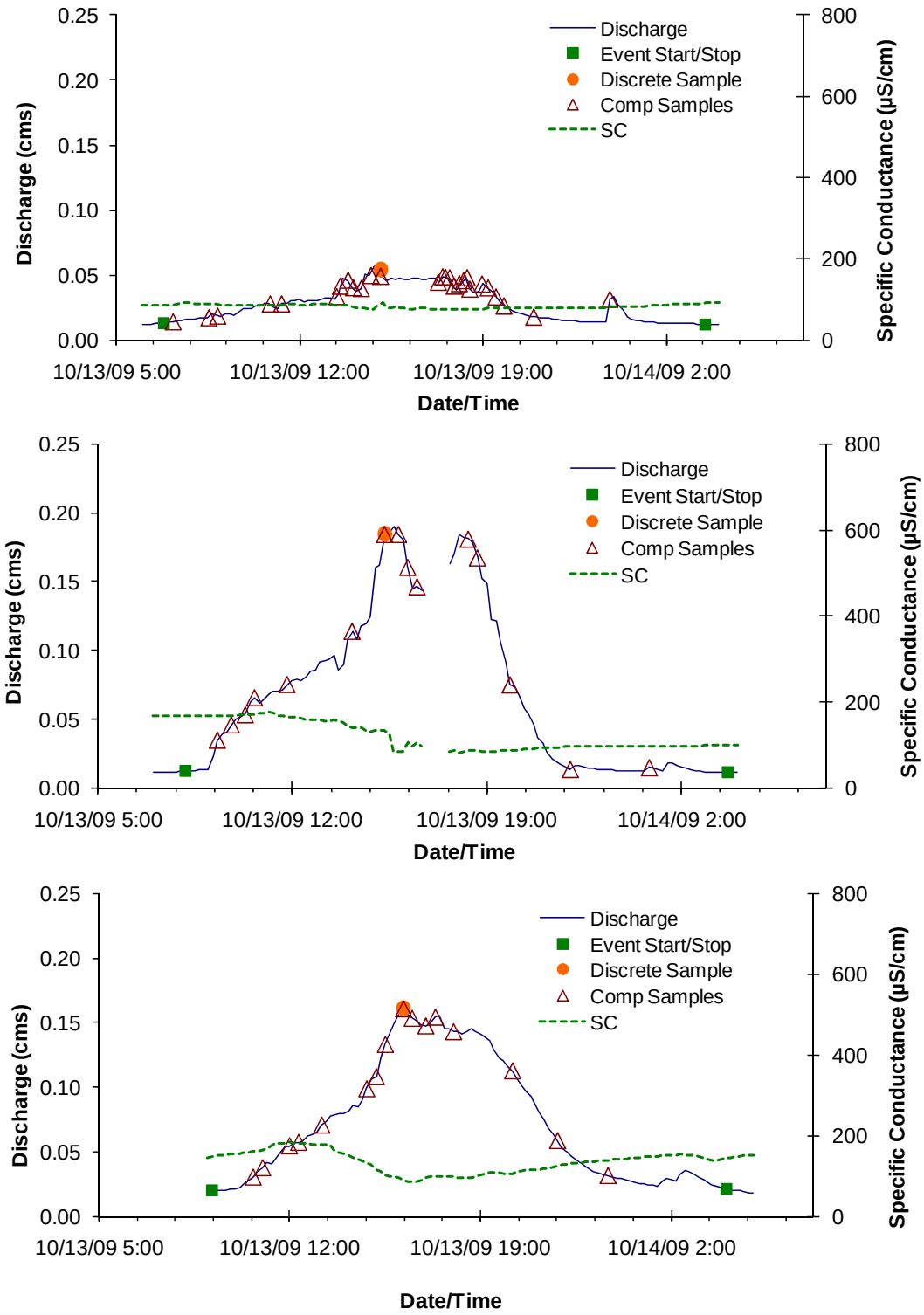

Figure 3C-10. Event hydrographs, samples, and SC for the rain event on 13 October 2009 at RW-Up, RW-Abv, and RW-Blw, respectively.

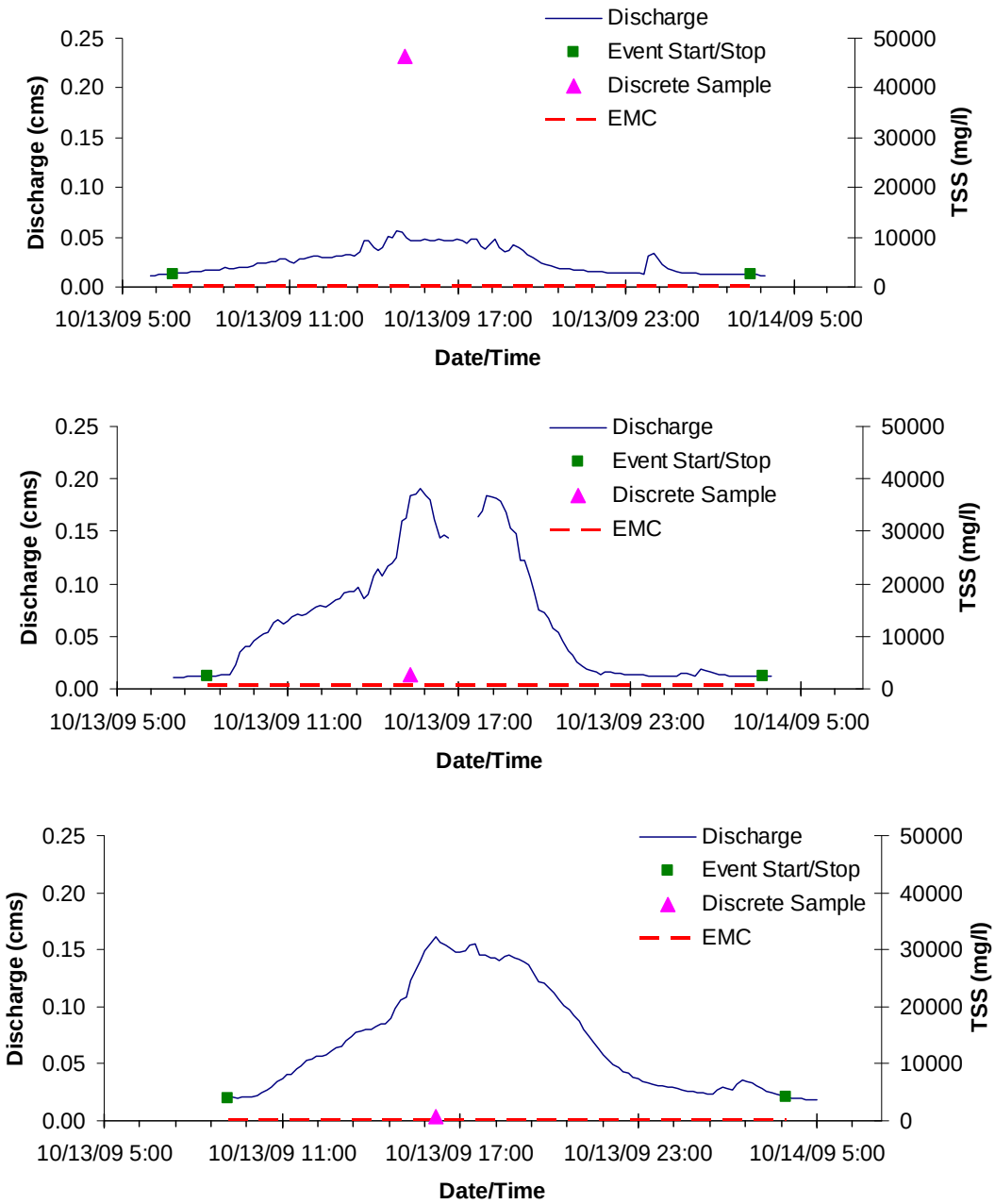

Figure 3C-11. Event hydrographs and TSS concentrations for the EMC and discrete samples at RW-Up, RW-Abv, and RW-Blw, respectively.

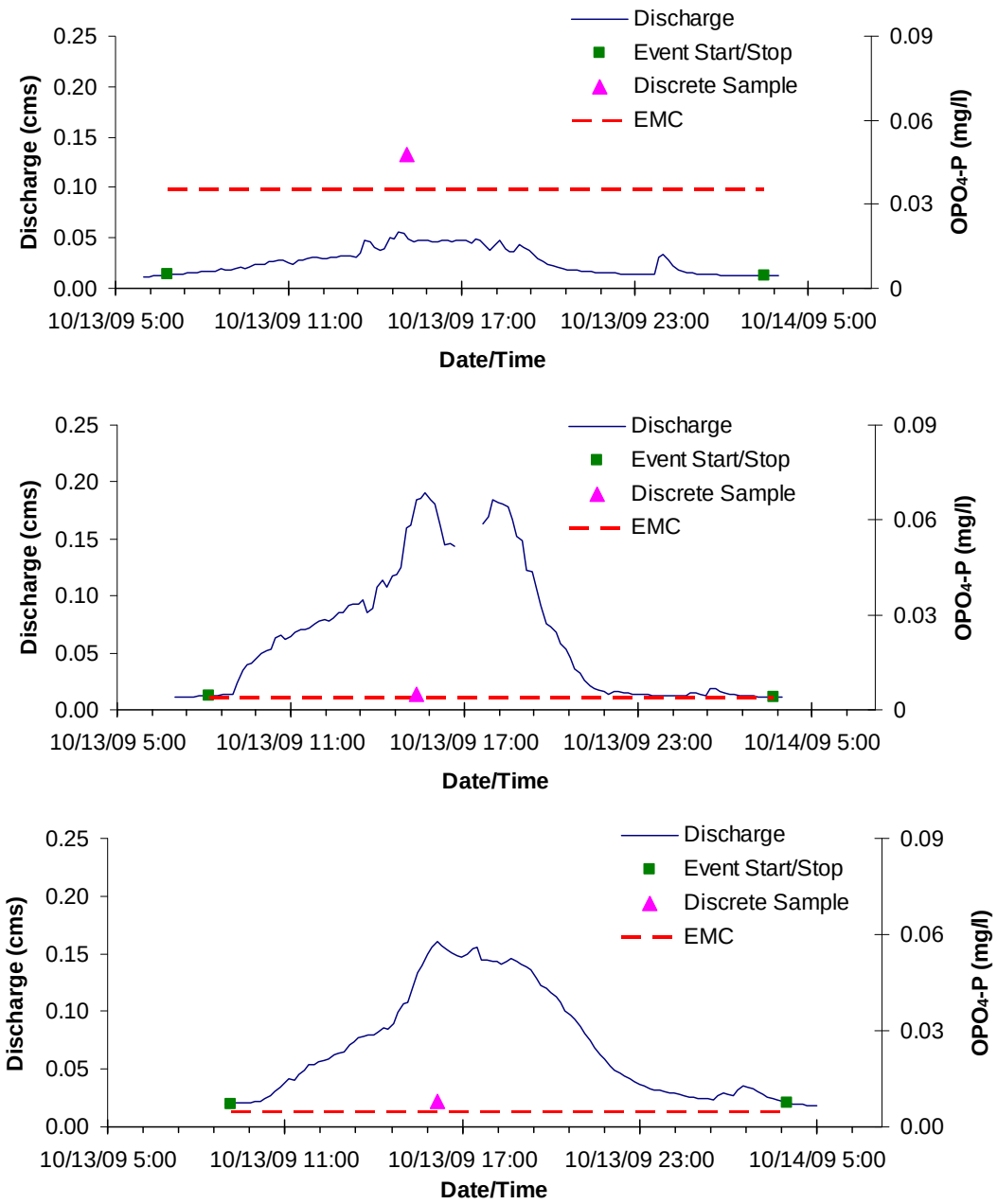

Figure 3C-12. Event hydrographs and ORP concentrations for the EMC and discrete samples at RW-Up, RW-Abv, and RW-Blw, respectively.

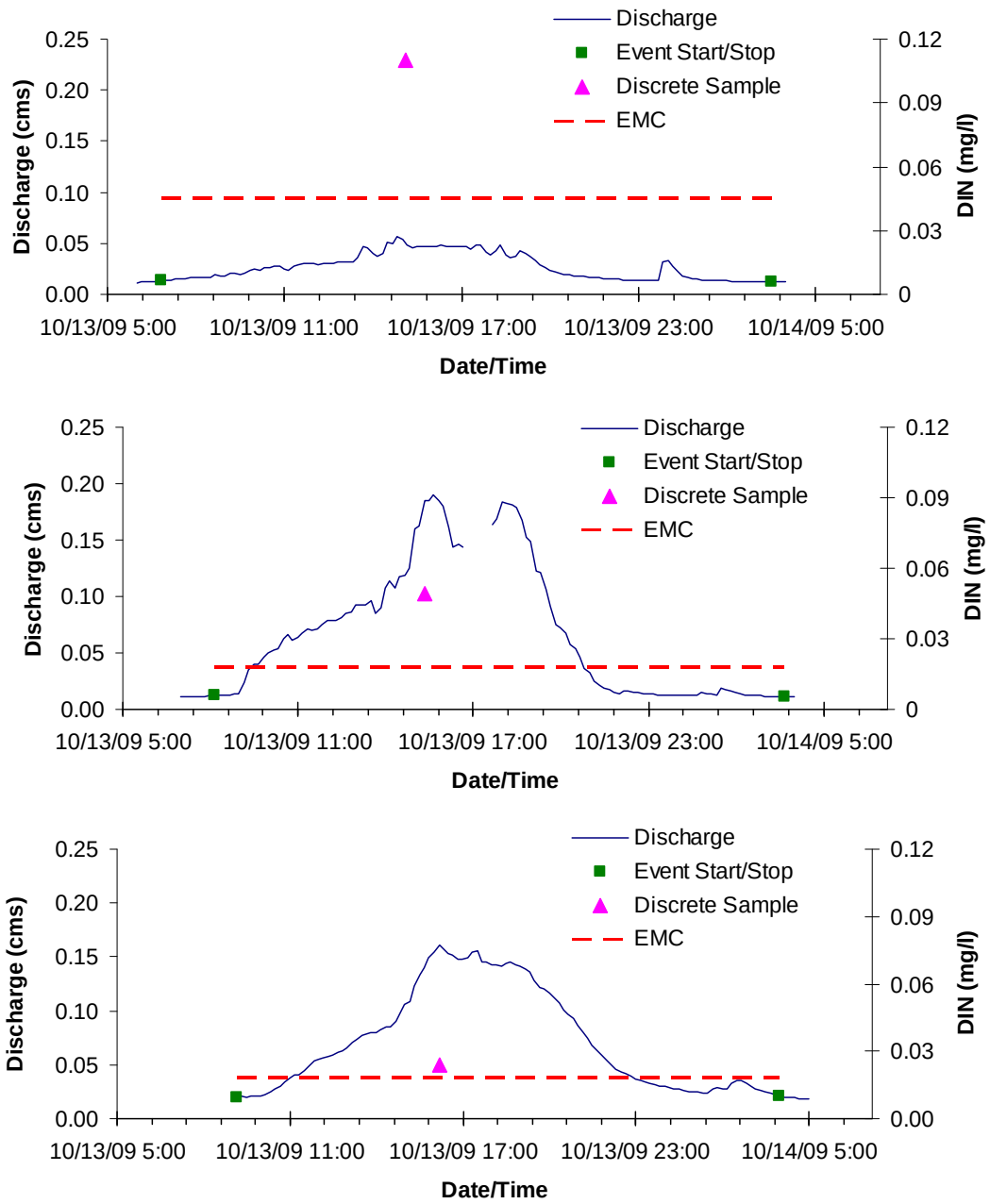

Figure 3C-13. Event hydrographs and DIN concentrations for the EMC and discrete samples at RW-Up, RW-Abv, and RW-Blw, respectively.

Table 3C-4. Event volumes, EMCs, and loads for each constituent at each site for the 13 October 2009 event.

		RW-Up	RW-Abv	RW-Blw	units
	Volume	2,030	4,547	4,973	m^3
EMCs	ORP	0.035	0.004	0.005	mg/l
	DIN	0.045	0.018	0.018	mg/l
	TSS	181	857	276	mg/l
Loads	ORP	71	18	25	g
	DIN	91	82	90	g
	TSS	368	3,897	1,373	kg

Event loads for ORP were highest at RW-Up and lowest at RW-Abv, and DIN was essentially unchanged along the creek. TSS was an order of magnitude higher from RW-Up to RW-Abv, but lost 65% of its mass between RW-Abv and RW-Blw (Table 3C-4). If RW-Abv discharged directly to Lake Tahoe it would have transported nearly 4 metric tons of sediment for this event.

CHAPTER 4: SUMMARY AND MAJOR FINDINGS

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INTRODUCTION

This chapter provides an aggregated review of the major results and findings of these studies with references back to previous chapters for more in-depth review. To facilitate this objective, a brief introduction including project location and methods is presented prior to a discussion of major findings broken down into: 1) a comparison of Rosewood and Third creeks; 2) major monitoring results from the Lower Rosewood Creek Restoration Project, and 3) water chemistry results. This is followed lists of major findings and recommendations.

The Lower Rosewood Creek Restoration Project was constructed in 2003 by adding 975 m of channel length, much of it through historical channels, and restoring its corresponding stream environmental zone in an attempt to capture and retain sediment loads originating from upstream sources. The creek was routed through several flood-spreading basins in an attempt to improve water quality before being discharged into Third Creek and ultimately Lake Tahoe. Monitoring for suspended sediment and some in-stream parameters such as discharge, turbidity, and conductance were initiated prior to the construction in 2002 and continued through early 2010. Monitoring was conducted at two sites located above (RW-Abv) and below (RW-Blw) the restoration project. Further upstream, the Middle Rosewood Creek Restoration Project restored a 215 m reach (Area F) in 2008 with another 730 m reach (Area A) slated for restoration in 2011. These restoration efforts primarily seek to control the introduction of sediment to areas downstream. Monitoring of the middle restoration project commenced in 2007 using the existing RW-Abv site as the downstream boundary and adding the RW-Upland (RW-Up) site as its upstream boundary near Highway 431. Nutrient monitoring for runoff events was initiated at all three sites in 2007 as well. Suspended sediment results were previously presented for all sites in Chapter 2 (WY 2003-2007) and Part A of Chapter 3 (WY 2007-2010). Water chemistry results were presented in Part B of Chapter 3 for WY 2007 through 2010. The majority of the discussion in this chapter will focus on the lower restoration project, however, the data presented here will be important for future consideration of the impacts that the different phases of the middle restoration project have on water quality.

Eighty-eight events were monitored between 2002 and 2010, including 37 rain events, 20 rain-on-snow events, and 31 snowmelt events (Tables 2-1 and 3B-1). Of those, two rain, one rain-on-snow, and 5 snowmelt events were monitored at RW-Abv prior to the construction of the lower restoration project. Average annual flow during this timeframe was 0.0164 cms at RW-Abv and 0.0181 cms at RW-Blw (Tables 2-5 and 3B-5). The average annual discharge at RW-Up was 0.010 cms during the final three years of the project. Water years 2003, 2008, and 2009 were characterized by the lowest average annual discharges,

between 0.0111 and 0.0121 cms. Average annual discharges were highest in 2004 and 2005 and were 97% and 171% greater than that during the low water years.

In-stream turbidity measurements were gathered to assess the quantity of suspended sediment in the creek. Turbidity levels within the creek were a function of event type, characterized by turbidity per unit volume of water greatest during rain events and lowest during for snowmelt events (Figure 3B-4). This trend is commonly observed as rain events are of a shorter duration, are typically more intense and therefore have a greater erosive potential than rain-on-snow or snowmelt events. The turbidity surrogate method was used to estimate suspended sediment loading from continuous, in-stream turbidity measurements. This required developing relationships between suspended sediment concentrations measured in water samples and the prevailing turbidity within the creek when the samples were collected. Once developed, these relationships were used to calculate loading on a 10-minute basis and subsequently summed to provide event-based loading estimates.

The turbidity surrogate relationships were variable, evidenced by the development of different relationships at each site and changing relationships over time. These differences are due to a multitude of factors, including site-specific factors such as how the sensor is installed, the manufacturer and electronic package within the sensor, as well as changes in the sensor's optical response due to changing sediment shape, size, composition, and other water properties (Lewis, *et al*., 2007). The variety of linear turbidity surrogate equations that have been used in the Lake Tahoe basin is shown in Figure 4-1.

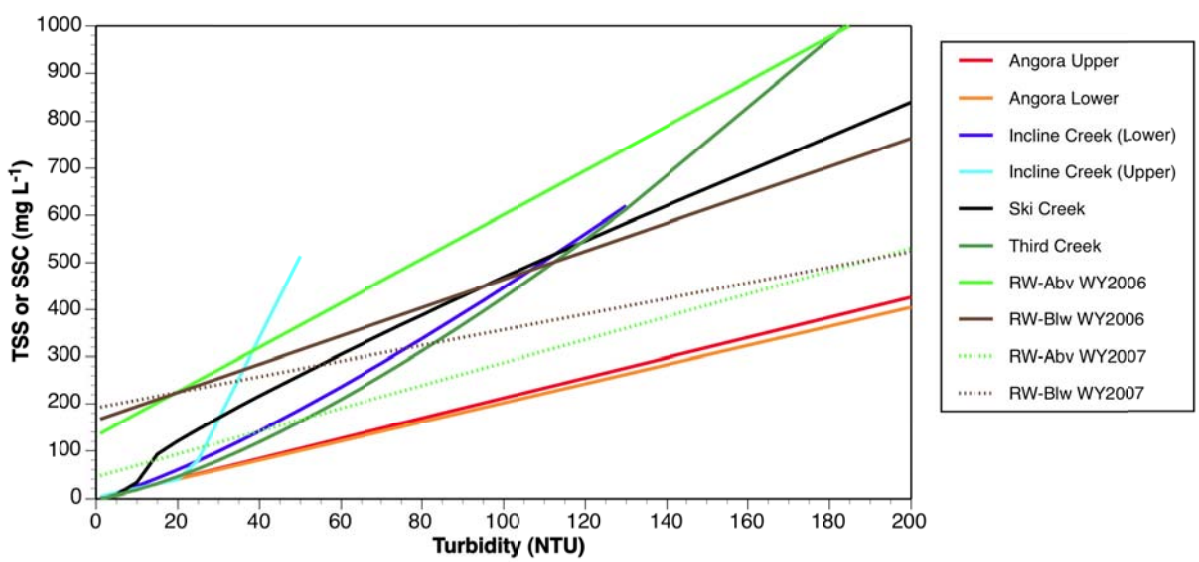

Figure 4-1. Comparison to turbidity and suspended sediment from sites around Lake Tahoe developed between 2003 and 2010. Suspended sediment was measured as either total suspended sediment (TSS) or suspended sediment concentration (SSC) with no conversion factor applied between the two. Angora Creek sites (red and orange color) exhibit the lowest relationship between turbidity and TSS.

ROSEWOOD AND THIRD CREEKS

For the following discussion, the Third Creek watershed is considered to be that part of the watershed above USGS gauge 10336698 and specifically excludes any contribution by Rosewood Creek (that currently occurs below the USGS gauge). Turbidity and suspended sediment concentration within Rosewood Creek can increase rapidly in response to hydrologic events due to its small size and location within an urbanized watershed. In contrast, suspended sediment concentrations within Third Creek are much less flashy and do not reach the high concentrations that are observed in Rosewood. Two factors are responsible for this behavior. First, the volume of water within by Third Creek is, on average, a factor of ten greater than that delivered by Rosewood Creek. Second, Third Creek is a high-elevation watershed (see Figure 2-4) with only 10 percent of its extent in the lower, urbanized watersheds, whereas 53% of the Rosewood Creek watershed is considered impacted, comprised of single and multiple family residences, turf, and roads, for example. Therefore, Third Creek is less impacted by urban runoff and sediment concentrations are diluted by the larger volumes in the creek compared to Rosewood Creek. This helps to explain historical observations where Rosewood Creek was found to be highly turbid whereas Third Creek appeared relatively clear.

These historical observations were also the result of the different timing of hydrologic events in the watersheds. Snowmelt, in particular, occurred two to four months earlier in the lower elevation Rosewood Creek watershed than in the higher elevation Third Creek watershed. If a rain event only impacted either the low elevation or high elevation watershed, then only that creek would respond with elevated turbidity and discharge. For events that were truly watershed-wide, there was a further time lag of several hours for elevated discharge to travel for Third Creek. Therefore, visual comparisons of both creeks at the same time would frequently only catch one watershed having elevated discharge and turbidity. During Event 8 for example, an evening storm caused an immediate, short-term increase in turbidity in both Rosewood and Third creeks with turbidity returning to background conditions in both creeks. Subsequently, another large turbidity increase occurred in Third Creek seven hours later (Chapter 2, pre-project monitoring). This second hydrologic event was only observed to occur in Third Creek and was sourced from above Hwy 431 as verified through a turbidity sensor in Third Creek located upstream of IVGID's Mountain Golf Course. The comparison of event loadings and particularly those during the snowmelt season (Tables 2-8 and 3B-7), were based on different time periods.

A comparison of suspended sediment loads delivered by these watersheds was a focus of the pre-construction monitoring in WY2003. For snowmelt, Rosewood Creek contributed less than 1% of the water volume delivered by Third Creek. However, during this snowmelt season (Event 2 plus Event 6; Table 2-8), 20% of the combined sediment load (247,000 kg) from the Third+Rosewood creek watershed was sourced from the Rosewood Creek (48,600 kg). This is despite the fact that Rosewood Creek delivered only 0.15% of the total water flowing out of the Third+Rosewood creek watersehed. Rosewood Creek was also observed to be a significant source of sediment during some rain events, such Event 8, a whole-watershed thunderstorm that occurred on August 21, 2003. During this event, 13,000 kg of suspended sediment was delivered by Rosewood Creek (measured at RW-Abv) while an additional 22,400 kg was delivered by the upper Third Creek watershed. However, Rosewood Creek was not as productive during other rain events.

LOWER ROSEWOOD CREEK RESTORATION PROJECT

Aggregated results for all four Rosewood sites are presented in Figure 4-3. A fourth site, RW-Bdiv, is introduced in this figure and was located downstream of RW-Abv and just below diversion structure (into Third Creek) at the upper boundary of the Lower Rosewood Creek Restoration Project. This was necessary to account for changes in discharge that occurred below RW-Abv and prior to water entering the restoration project. Suspended sediment loadings (SSL) were estimated using the turbidity as a surrogate method that relies on the development of turbidity-SSC regression models at each site. Loadings at RW-Bdiv were estimated using discharge measured at the site coupled with SSC samples collected at RW-Abv, as described in Part B of Chapter 3. On an event basis, snowmelt delivered two orders of magnitude greater sediment loading (Figure-4-3, top) than rain events, with rain-on-snow events having an intermediate loading rate. There were no differences between sites, however, rain-on-snow events at RW-Up tended to have lower peak flows and be less variable than at the other sites. This could be partly explained by elevation; warmer temperatures at lake level resulted in rain where higher elevations above Hwy 431 could fall as snow. Also the upper watershed had less directly connected developed areas. On an average, snowmelt events (Figure 4-3, middle) typically had lower suspended sediment concentrations than the other two event types due to the large volume of less turbid water during the falling limb of the seasonal snowmelt hydrograph. Lastly, on an average daily basis, the sediment loads resulting from rain and rain-on-snow events were much more variable than that delivered during snowmelt events (Figure 4-3, bottom). The RW-Up site, in particular, tended to deliver less sediment per day for snowmelt and rain-on-snow events compared to the other sites.

Seasonal turbidity-SSC surrogate relationships for RW-Blw were highly variable and had lower seasonal regression coefficients than those for RW-Abv (Tables 2-7 and 3B-6). This was likely a result of the physical disturbance related to project construction and the time needed for vegetation to grow and the stream environmental zone to reach an environmental equilibrium. For example, the SSC-turbidity relationship at RW-Blw during the first year after construction (WY 2004) had not only a poor regression coefficient, but also had a slope three to nine times greater than observed at other sites and during other years. One reason for this poor relationship was the presence of unconsolidated sediment that remained on the bottom of the newly constructed creek bed, and was therefore available to be moved downstream once water entered the creek. In addition, the first heavy thunderstorm (Event 8) caused significant erosion requiring the reconstruction of several sections of the just completed lower RWC restoration. These problems with the restored creek channel were attributed as the source of particles in the 100 to 1000 µm range (Figure 4-4 bottom) and resulted in the mean particle diameter (MPD) to be greater at RW-Blw during the first snowmelt season (Figure 4-4 top). It was not until the third snowmelt season when the MPDs above and below the restoration project were similar. The decline in MPD at RW-Blw could also be attributed to the growth of vegetation within the flood spreading zones that enhanced sediment deposition through a reduction in water velocity and physical entrapment.

In addition to the decline in MPD below the project, there was also a drop in MPD of the particles entering the project between 2006 and 2008. Several factors may have

contributed to this observation. First, several BMP projects were completed in the watershed above the restoration project that may have reduced the likelihood of coarser particles entering the creek. These projects included the Village Blvd and Mill Creek Restoration Project completed in late summer of 2003 and the Fairway Phase 3 project completed in 2006. The most important of these may have been the 2005 NDOT project that installed curb and gutters along Highway 28, just above the RW-Abv monitoring site. Second, the lower average annual flows and discharge during snowmelt after WY 2006 were less likely to entrain coarser material into creek flow. Third, higher flows during water years 2005 and 2006 may have depleted readily available in-stream sources of sediment that would otherwise have been mobilized prior to the low-flow WYs of 2007 and 2008. This has been observed to occur in the Upper Incline Creek watershed (Dana et al., 2008), where significantly less sediment was available to be mobilized during the snowmelt season after a year with large snowmelt runoff and significant rain events. Therefore, there may be an increased MPD of particles entering the restoration project with increased water flow in future years.

Bulk water volumes were also related to the particle-size distribution during the last three years when all three monitoring sites were active (Figure 3B-2). The WY 2008 snowmelt season was characterized by low snowfall throughout the watershed, resulting in similar snowmelt particle-size distributions at the three sites (Figure 4-4 bottom). The following year was similar, but greater snowmelt at lower elevations resulted in a greater contribution of finer particles at RW-Abv and RW-Blw. Lastly, there was significantly more low elevation snowfall in WY 2010 resulting in an increased delivery of finer particles at RW-Blw.

The ability for the lower restoration project to alter net suspended sediment loads and water volume in Rosewood Creek was dependent on event type. Figure 4-2 presents the change in bulk sediment (brown) and water loads (blue) through the Lower Rosweood Creek Restoration Project. The dashed horizontal lines denote the point where the net change is zero -- the load of sediment or water exiting the project at RW-Blw was the same as entering the project at RW-Bdiv. The grey line in Figure 4-2 provides a comparison of the water loads entering the project at RW-Bdiv.

Of all the event types, snowmelt events were the most consistent at increasing sediment loads (Figure 4-2, top) and decreasing the mean particle diameter as water travelled through the restoration project. Whole-snowmelt sediment loads sourced from within the lower project area ranged from an average of 20 kg day^{-1} in 2009 up to 813 kg day^{-1} in 2005. Figure 4-2 also includes a series of discrete sub-events primarily during the first few years of the project. During WY 2004, for example, several of these sub-events were characterized by low sediment loadings (brown line) including Events 13, 15, 16, and 17. These events were comprised of time periods that were either early on the rising limb or on the falling limb of the seasonal snowmelt hydrograph. The largest sediment load was during Event 14, a five-day period that corresponded with peak seasonal discharge. Similar trends were noted in WYs 2005 and 2006. Water year 2006 was the most productive snowmelt season observed and it included a significant contribution of water from low-elevation sources, as indicated by

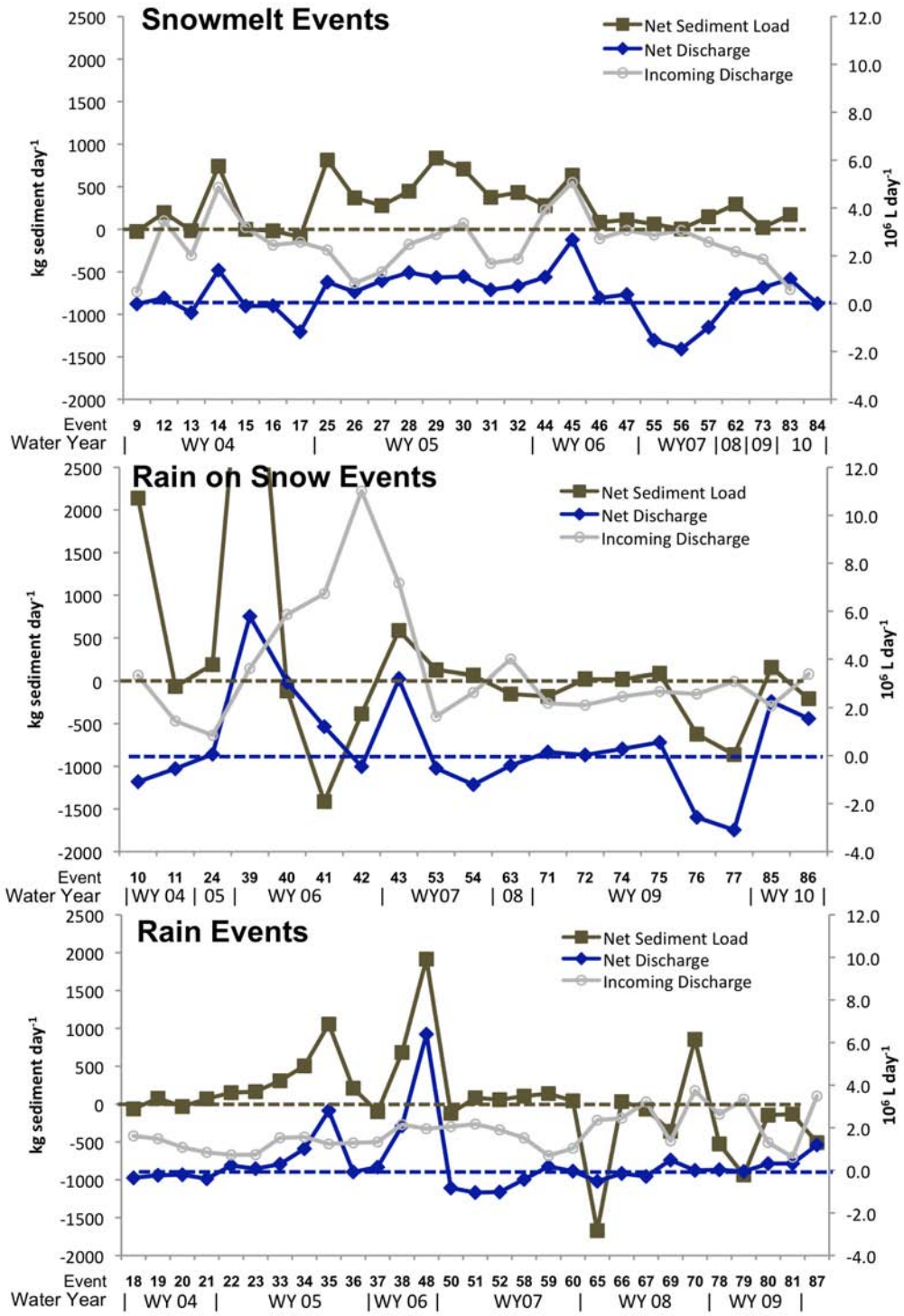

Figure 4-2. Net sediment loading (brown, left axis) and dischage (blue, right axis) for all events measured within the Lower Rosewood Creek Restoration Project. Net loadings were calculated by subtracting RW-Blw loads from RW-Bdiv. The dashed horizontal lines represent where sediment loadings (brown) or net discharge (blue) through the restoration project were zero. Values above the dashed lines represent more load leaving the restoration than entering. The grey line represents the volume of water entering the restoration project and is used to compare the magnitude of each event.

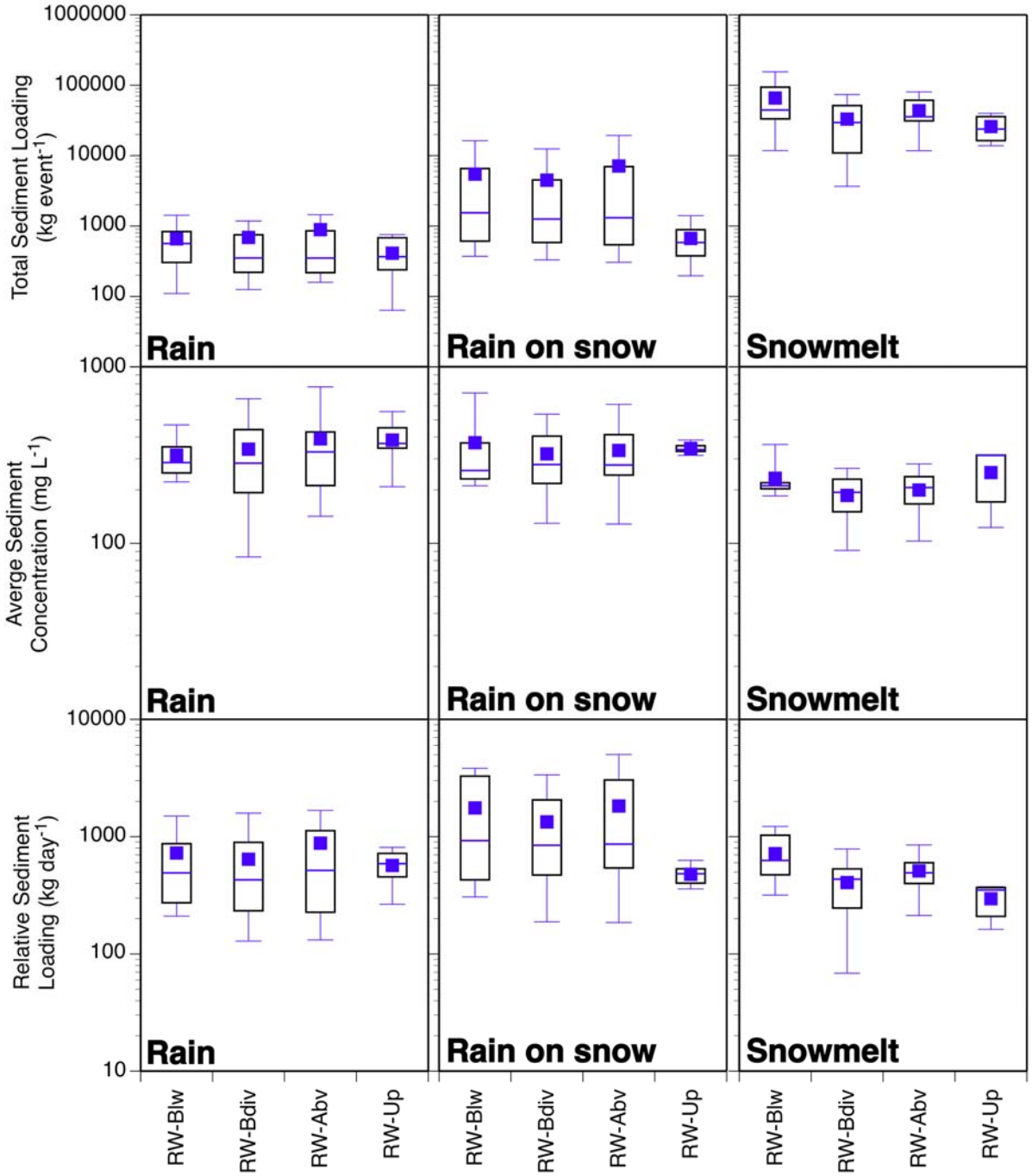

Figure 4-3. Box plots representing total event sediment loading per event (top), average event sediment concentration (middle), and average relative sediment loading (bottom) for all events, by event type. These were calculated using mean values for each event.

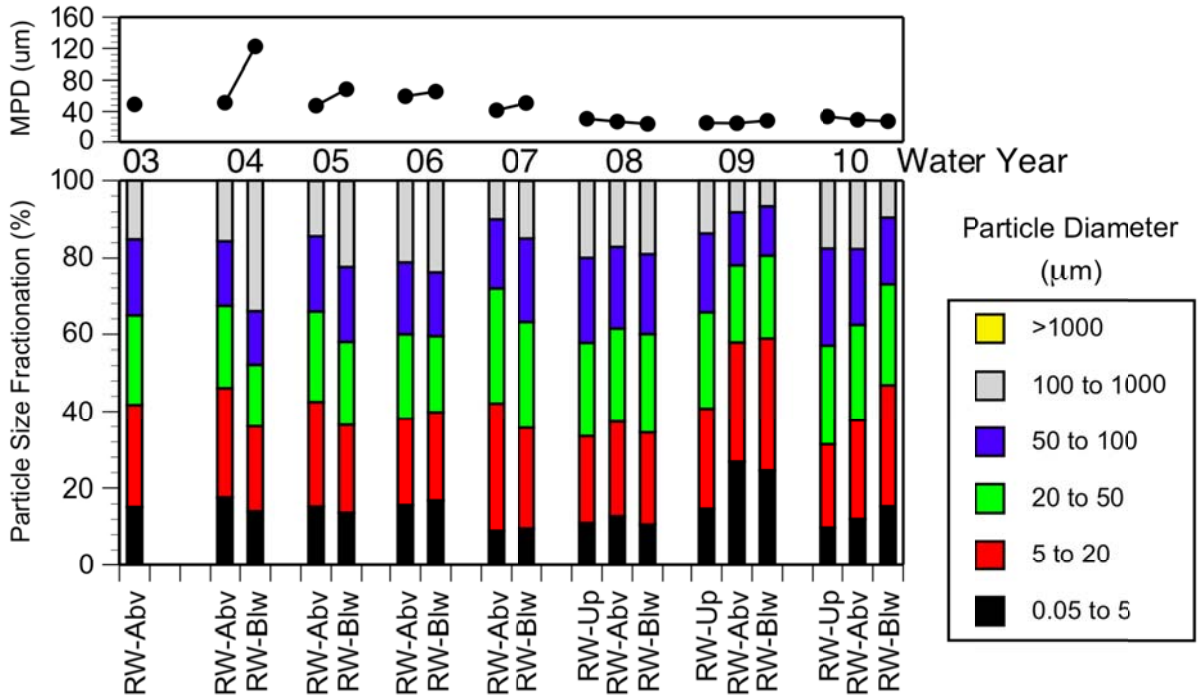

Figure 4-4. Flow weighted average particle size fraction (bottom) and mean particle diameter (MPD, top) for water samples collected during snowmelt events. Sample collection was biased toward higher sediment samples that comprised the bulk of the suspended sediment load. Therefore, these results were higher than for a true average that would include low-sediment concentration samples.

the magnitude of the blue line in Figure 4-2. Despite these greater discharges, the magnitude of suspended sediment loading in WY 06 was only about three-quarters that of the previous two water years. This reflected a greater availability of sediment for mobilization during the first two post-construction years compared to the third year. Water years 2007 through 2010 were characterized as low snowfall years and therefore had low sediment loading and net discharges compared to earlier years.

For rain-on-snow event types (Figure 4-2, middle), seven events deposited sediment in the restoration project (-359 ± 475 kg day^{-1} on average) while sediment was mobilized from the restoration project during the remaining 10 events (850 ± 1631 kg day^{-1} on average). This latter group included two large loading events, a mid-winter event in February 2004 (Event 10) and an early winter event in December 2005 (Event 39). The large positive value for net discharge (blue line in Figure 4-2) through the project for Event 39 indicated a significant contribution of water to the creek sourced from within or adjacent to the restoration project. Although this was a winter storm, air temperatures were relatively warm causing precipitation to fall as either rain or snow throughout the lower restoration project whereas it fell as snow above the project. This caused flows at RW-Abv to remain at background levels while discharge increased at RW-Blw. Alternating cooler periods also caused periods of low elevation snow that subsequently melted, causing this event to be a combined rain, rain-on-snow, and snowmelt event.

For rain event types (Figure 4-2, bottom), 12 events deposited sediment in the restoration project (-494 ± 403 kg day^{-1} on average) while sediment was mobilized from the restoration project during the remaining 18 events (370 ± 488 kg day^{-1} on average). Suspended sediment was more likely to be mobilized from the project during the first three years after construction (Events 33-38, 48), up to 2000 kg day^{-1} (Event 48). Although the volume of water entering the project during these events was not unusual for rain events (gray line), the large increases in net discharge (blue line) indicated that a substantial volume of water entered the creek from within the project area itself. This will most likely occur during intense rainfall events, as indicated in this case by the short event durations. Surface water entering the creek not only carried additional sediment into the creek, but appeared to have also contributed to the mobilization of sediment previously deposited in the creek channel under lower flows. Furthermore, water entering the creek from within the restoration project does not undergo the same "treatment" as it does not travel through all the flood spreading zones in the project. Readily mobilized sediment may have remained in the project from construction, but it may have also been brought into the project during WY 2005 and 2006 snowmelt, which were the two largest snowmelt events during the period of study. Rain events during subsequent years did not have as large of a surface water input from within the project area, resulting in net discharge of between $\pm 1 \times 10^6$ L day^{-1}. Rain events in WYs 2008 and 2009 were typically greater than those of previous years (gray line), however, sediment loads through the project remained neutral or decreased. The only exception was Event 70, that resulted in the greatest average daily water volume observed post-construction.

WATER CHEMISTRY

In-stream specific conductance (SC) and water temperature have been continuously measured since the initiation of the project with event average values presented in Tables 2-2, 2-3, and 3B-2 through 3B-4. Elevated spikes in SC were commonly observed between mid-November and mid-March due to the dissolution, leaching, and transport of road traction control salts. Both Washoe County and the Nevada Department of Transportation use traction control material containing 25% sodium chloride by volume. Near immediate spikes of in-stream SC indicate a connection between imperious road surfaces and the creek. These spikes were not observed outside of the winter months nor have they been observed in creeks draining higher elevation forested watersheds that lack wintertime road operations, such as the Upper Incline Creek Watershed (Dana *et al*., 2008).

Average annual in-stream water temperatures increased from 9.5 °C at RW-Up and 11.3 °C at RW-Abv to 18.2 °C at RW-Blw. Peak summer water temperatures also increased from 13.8 °C at RW-Up to 19.2 °C at RW-Abv to 30.1 °C at RW-Blw, raising concerns for the viability of fish species in the lower reaches of Rosewood Creek. This concern was compounded by the reduction in riparian overstory vegetation through ongoing fuels reduction efforts along the creek during the last two years.

Discrete sampling for water chemistry was primarily accomplished through the analysis of 52 event mean concentration (EMC) samples and augmented by the analysis of grab samples and additional samples from within event sample sets. Water chemistry constituents were highly variable, with 20 to 25% of the observed concentrations outside of the 10th or 90th percentile. Concentrations were typically equivalent to a similar watershed at Lake Forest, CA, except for TKN, TN, and TSS that were an order of magnitude greater at

Rosewood Creek (NTCD, 2010). Median constituent concentrations typically decreased downstream (Figures 3C-2 and 3C-3) indicating relative dilution by the greater volumes of water present in the creek at the downstream sites. Median constituent loads, however, increased downstream (Figures 3C-4 and 3C-5) indicating that while surface water inputs were lower in concentration than creek water, they still carried sufficient concentrations to increase overall loadings. Nitrate and particulate bound constituents did not follow these trends and were typically highest at RW-Abv. For particulate bound constituents, this is consistent with in-channel erosion and mobilization of sediment that is relatively easily transported downstream as a result of the steep slopes of the creek channel within the middle reach. These trends were not observed in mean concentrations and loadings.

Two specific rain events were also compared, including a small event on May 20, 2008 (Event 65) and a much larger rain event on October 13, 2009 (Event 82). Precipitation during the earlier event primarily impacted the middle and upper reaches of Rosewood Creek as there was a delay in the timing of peak discharge between the upper two monitoring sites and the RW-Blw site. Both storms had an increase in TSS concentration and load between the upper two monitoring sites and a decrease in concentration and load between the lower two sites (Tables 3C-3 and 3C-4). The increase between RW-Up and RW-Abv indicates input from either connected impervious surfaces or from erosion of the creek bed or banks. The decrease from RW-Abv to RW-Blw indicates capture of TSS in the lower reach. Although the Washoe County Sweeper Study (Brown *et al*., 2011) has indicated road runoff from Village Blvd between Harold Way and Golfers Pass is not a significant source of nutrients to Rosewood Creek, elevated SC during snowfall events demonstrates there is connection between impervious surfaces and the creek. Precipitation for the second event (#82) was was nearly six times greater than the first event. Although this was a whole-watershed event, nutrient concentrations decreased over 60% between RW-Up and RW-Abv and remained relatively unchanged to RW-Blw indicating dilution between the upper sites (event volume increased 125%). Nutrient loads decreased between the upper sites as well, then increased slightly at RW-Blw.

MAJOR FINDINGS

- Eighty-eight events were monitored between 2002 and 2010 including 37 rain events, 20 rain-on-snow events, and 31 snowmelt events.
- The average annual discharge for Rosewood Creek was about one-tenth of Third Creek. Average annual flow for WY 2003 through 2010 was 0.0164 cms at RW-Abv and 0.0181 cms at RW-Blw. For RW-Up, average annual discharge at RW-Up was 0.010 cms during WY 2008 through 2010.
- Rosewood creek is a typical low elevation urbanized watershed in the Lake Tahoe basin that quickly responds to hydrologic events. In contrast, very little of the Third Creek watershed is urbanized, so the impacts of urban runoff on water quality are much less apparent in Third Creek than Rosewood Creek.
- Specific conductance increased dramatically during snowfall events due to the application of road traction material indicating a connection impervious road surfaces and the creek.
- The maximum creek water temperatures exiting the lower reach was 30.1 °C,

possibly compromising fish habitat in this part of the stream. The high water temperatures may have been exacerbated by ongoing wildfire fuels reduction efforts that have removed shady overstory coverage.

- In general, mean and median constituent concentrations were similar at all three sample sites with a slight tendency to decrease downstream indicating that the contribution from urban runoff from the more urbanized middle and lower reaches did not generally alter in-stream concentrations to a significant degree. This conclusion was also supported by the low nutrient concentrations in road runoff measured during the Washoe County Sweeper Study (Brown *et al*., 2011).
- Median constituent loads of dissolved species typically increased downstream with the highest load at RW-Blw. Exceptions to that were NO_3, TSS and most particulate bound constituents that were highest at RW-Abv. RW-Up were generally characterized by lower mean and median loads that were also less variable, possibly due to the lack of urban influence above this site. The pattern for particulate constituents indicates either a source of sediment between the upper and middle sample location or deposition of particulate matter between the middle and lower sites.
- Rosewood and Third creeks did not often experience elevated discharge or turbidity at the same time due to differences in geography and in the mean elevation of the watershed. Therefore, Rosewood Creek could be visually observed to be highly turbid when Third Creek was not.
- Although Rosewood Creek can contribute significant loads to Third Creek on an event basis, total sediment loading from the Third + Rosewood creeks watershed is dominated by high elevation snowmelt sourced in the upper Third Creek watershed. For example, Rosewood Creek contributed nearly 40% to the total 35,400 kg total sediment loading for rain Event 8 compared to 20% of the total 247,000 kg of sediment delivered by Third + Rosewood creeks during the previous snowmelt season.
- Within the Rosewood Creek watershed snowmelt events also dominated sediment loading typically delivering two orders of magnitude more sediment than individual rain or rain-on-snow events.
- After construction of the Lower Rosewood Creek Restoration Project, the first two snowmelt seasons experienced greater sediment loads and a greater proportion of coarse sediment than in subsequent years. This was attributed to construction disturbance, creating the physical creek channel, and the immaturity of riparian vegetation.
- The fourth snowmelt season (WY 07) started a period of low snowmelt water volumes that has lasted through the end of the study. Therefore, the impacts of normal or higher snowmelt years on sediment mobilization and transport through the restoration project are unknown.
- Deposition of sediment and the storage/infiltration of water within the flood spreading zones of the lower restored area occurred during some rain events, but not

during rain-on-snow or snowmelt events.

- During a given rain event, a minimum volume of water was needed within the project to cause overbanking into the adjacent flood spreading basins. Flooding into these spreading zones was the main feature of the restoration project to reduce sediment loading.
- Sediment deposition was most likely to be observed for low to moderate volume rain events that fell primarily on the upper or mid elevations of the Rosewood Creek watershed. Low elevation surface runoff from within the project itself contributed additional, unmeasured sediment that confounded sediment deposition calculations. Sediment deposition was still likely to occur, but it appeared to be much lower due to these unmeasured inputs.
- Sediment deposition within the lower project was observed during 12 rain events, averaging -494 ± 403 kg day^{-1}. In comparison, sediment was mobilized during 18 rain events, averaging 370 ± 488 kg day^{-1}.

RECOMMENDATIONS

- When using the turbidity surrogate approach to estimate suspended sediment loading in the Lake Tahoe basin, make sure to collect a sufficient number of samples (≥ 6) for each primary event. Temporal and spatial variability require the development of surrogate regressions on the smallest time period possible (e.g. by event, through a given season, events within a give water year). This is especially true of areas that have undergone or are recovering from significant disturbance, such as the Lower Rosewood Creek Restoration Project.
- When using the turbidity surrogate approach, individual regressions must be developed for each monitoring site.
- Additional sediment loading data should be collected during higher water years (e.g., WYs 2005 and 2006) to help determine if the lower sediment loadings and mean particle diameters in WYs 2007 through 2010 were a result of the average to below average water volumes or the maturation of the restoration project (e.g. vegetation growth in the flood spreading areas).
- Additional monitoring at RW-Blw may be cost effective as RW-Abv will be monitored as part of the upcoming Middle Rosewood Creek Restoration Project Area A restoration.
- Construction of the lower restoration project resulted in the confluence of Rosewood Creek into Third Creek to be moved from above the USGS Third Creek Gauging Station to just below it. Therefore, Third Creek data reported by the USGS no longer reflects the influence of Rosewood Creek as it had from 1977 through October 2004. Continued baseline monitoring of the RW-Blw site would assure that the evolution of the Rosewood Creek watershed continue to be assessed in terms of water quality and that comparisons with historical data can be made.

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APPENDIX A. TURBIDITY AND SSC OF WATER

(This currently contains data through WY2007, and will be updated with all data in the final version)

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

Third Creek			RW-Up			RW-Blw			RW-Abv		
	TU (NTU)	SSC (mg L^{-1})		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	2/28/08 13:10	21	155	12/24/03 9:50	56	321	12/11/02 18:50	31	90
12/13/02 21:40	29	33	3/14/08 13:50	17	378	3/7/04 14:10	27	207	12/12/02 23:20	37	11
1/3/03 15:50	6	5	3/28/08 13:40	14	107	3/7/04 15:10	58	337	1/7/03 22:00	17	54
1/3/03 16:40	6	5	4/3/08 14:10	13	106	3/7/04 17:20	45	394	1/10/03 12:50	23	67
1/4/03 11:20	6	6	4/3/08 14:20	12	94	3/8/04 15:00	57	686	1/13/03 15:10	20	150
1/4/03 12:20	6	6	4/4/08 3:40	5	125	3/9/04 16:10	50	221	1/22/03 15:30	55	260
1/8/03 19:30	12	22	4/12/08 14:00	11	93	3/13/04 13:30	21	394	1/22/03 18:40	249	955
1/8/03 19:50	5	8	4/12/08 14:10	11	82	3/13/04 14:30	53	1332	1/22/03 19:00	330	1116
1/12/03 4:20	8	17	4/16/08 5:50	4	114	3/13/04 15:00	46	1006	1/22/03 19:20	277	842
1/22/03 19:00	35	152	4/23/08 13:10	5	97	3/14/04 17:10	41	502	1/22/03 19:50	212	618
1/22/03 19:40	68	186	5/1/08 12:00	4	133	3/15/04 15:30	53	532	1/23/03 1:30	47	323
1/22/03 20:00	90	220	5/4/08 14:40	12	169	3/16/04 15:30	31	175	3/15/03 7:20	154	608
1/22/03 20:30	75	197	5/4/08 14:50	9	234	3/21/04 2:10	17	180	3/15/03 13:10	372	1679
1/22/03 21:40	42	122	5/20/08 19:50	419	1539	3/21/04 2:40	17	176	3/15/03 14:30	133	894
1/23/03 17:20	90	253	5/24/08 4:30	19	106	3/21/04 3:40	15	160	5/3/03 9:20	36	899
1/23/03 17:50	134	338	5/26/08 13:20	5	90	5/27/04 7:50	15	129	5/3/03 10:30	101	786
1/23/03 18:30	106	263	10/3/08 18:00	40	302	5/27/04 8:40	19	150	5/3/03 11:10	41	287
1/23/03 19:20	64	191	10/3/08 20:10	73	379	5/27/04 12:20	13	102	6/23/03 13:10	88	275
3/15/03 11:00	17	180	10/3/08 20:40	42	284	5/27/04 18:40	13	117	6/23/03 15:00	371	1357
3/15/03 14:30	83	106	10/3/08 21:20	72	623	6/9/04 9:40	72	321	6/23/03 17:10	192	677
3/15/03 15:40	43	106	10/4/08 0:40	61	533	6/9/04 10:10	42	223	7/22/03 18:30	557	1583
5/13/03 13:10	21	181	10/4/08 0:50	61	245	6/9/04 11:40	17	138	7/22/03 19:10	285	660
5/13/03 19:30	47	147	10/4/08 1:10	63	329	10/19/04 11:30	23	139	7/23/03 17:50	359	907
5/14/03 18:50	52	196	10/4/08 1:50	205	1482	10/19/04 12:00	60	261	7/23/03 18:20	194	473
5/21/03 6:20	14	167	10/4/08 2:20	54	207	10/19/04 14:10	41	335	8/21/03 15:20	49	289
5/21/03 18:00	75	376	10/4/08 2:30	36	172	10/19/04 17:20	43	319	8/21/03 17:30	510	1740
5/29/03 20:10	112	733	10/4/08 2:40	24	129	10/19/04 20:10	44	333	8/21/03 19:40	95	339
5/30/03 18:00	30	730	10/4/08 3:10	11	92	11/10/04 19:20	51	466	12/24/03 8:50	82	202
6/23/03 15:00	32	75	1/22/09 0:00	8	392	11/10/04 19:40	175	678	2/16/04 12:00	165	464
6/23/03 18:10	55	97	2/22/09 3:00	4	163	11/10/04 19:50	140	358	2/16/04 13:30	384	983
6/23/03 18:40	47	72	2/22/09 13:50	34	344	1/25/05 11:50	51	205	2/16/04 17:40	173	425
7/22/03 19:20	26	226	3/19/09 13:30	21	146	1/25/05 13:20	137	409	3/7/04 12:40	21	176
7/22/03 19:50	86	193	4/10/09 10:20	84	534	1/25/05 13:50	155	294	3/7/04 14:20	57	215
7/22/03 20:50	58	157	4/10/09 11:40	126	542	1/25/05 14:10	149	251	3/7/04 17:10	44	174
8/21/03 10:30	658	1486	4/10/09 11:50	105	532	1/25/05 15:30	49	284	3/8/04 14:00	57	201
8/21/03 11:30	244	8303	4/24/09 11:10	18	630	2/10/05 17:50	36	602	3/9/04 17:10	44	308
8/21/03 20:50	116	347	5/1/09 0:00	4	232	2/12/05 15:00	49	529	3/10/04 12:20	21	206
8/22/03 2:00	221	638	5/1/09 7:50	6	575	2/16/05 12:50	54	654	3/10/04 12:40	23	172
8/22/03 12:30	31	6847	5/3/09 0:00	5	192	2/26/05 15:50	57	299	3/10/04 13:10	30	193
10/6/03 14:10	5	3	5/3/09 6:50	72	677	2/28/05 13:30	61	336	3/13/04 13:10	23	184

Third Creek	TU (NTU)	SSC (mg L-1)	RW-Up	TU (NTU)	SSC (mg L-1)	RW-Blw	TU (NTU)	SSC (mg L-1)	RW-Abv	TU (NTU)	SSC (mg L-1)
11/7/03 13:30	4	1	5/3/09 7:40	82	542	2/28/05 14:40	95	377	3/13/04 13:30	27	222
12/2/03 15:20	3	1	5/3/09 7:50	139	570	2/28/05 14:50	82	322	3/13/04 13:50	30	193
1/5/04 12:50	4	2	5/4/09 20:50	29	497	3/10/05 14:20	59	302	3/16/04 15:30	53	166
2/3/04 13:20	5	1	5/4/09 21:40	60	473	3/10/05 15:20	124	477	3/16/04 15:40	54	341
2/16/04 19:20	30	90	6/1/09 0:00	6	431	3/10/05 17:30	93	501	3/16/04 15:50	55	256
3/2/04 13:30	4	2	6/1/09 18:20	506	1017	3/10/05 20:30	48	478	3/24/04 18:30	21	249
3/9/04 11:10	4	4	10/13/09 0:00	5	279	3/11/05 10:30	19	178	5/27/04 10:00	19	104
3/12/04 16:20	5		10/13/09 7:10	70	451	3/19/05 15:30	18	181	5/27/04 12:20	12	127
3/16/04 10:20	6	7	10/13/09 8:30	35	361	3/19/05 16:30	32	216	5/27/04 18:40	12	86
3/23/04 14:00	11	14	10/13/09 8:50	49	273	3/19/05 17:40	16	202	6/9/04 9:10	126	309
3/30/04 12:10	4	5	10/13/09 13:30	254	3781	3/20/05 17:10	14	239	6/9/04 9:50	88	199
4/5/04 11:00	8	7	3/29/10 0:00	7	246	3/20/05 17:20	15	446	6/9/04 11:00	32	197
4/12/04 10:30	5	9	3/29/10 18:10	24	174	3/20/05 18:30	16	248	1/25/05 11:20	82	164
4/12/04 17:40	6	13	4/20/10 0:00	7	396	3/31/05 14:10	23	493	1/25/05 12:20	144	291
4/21/04 15:00	5	5				4/1/05 14:50	65	308	1/25/05 13:10	97	377
4/28/04 11:40	25	17				4/1/05 15:10	48	262	1/25/05 15:00	47	291
4/28/04 18:10	25	28				4/6/05 15:20	29	399	2/28/05 11:30	54	297
5/4/04 18:30	25	197				4/6/05 23:00	20	266	2/28/05 13:30	104	382
5/6/04 15:30	6	13				4/10/05 13:50	23	507	2/28/05 16:10	45	255
5/20/04 16:50	6	8				4/10/05 15:50	20	620	3/8/05 13:00	30	272
6/1/04 14:10	7	5				4/11/05 14:20	19	306	3/9/05 14:20	56	261
6/16/04 13:40	1	5				4/11/05 19:00	18	315	3/10/05 13:50	62	452
7/6/04 16:30	8	3				4/12/05 15:50	21	615	3/10/05 14:40	107	423
8/2/04 15:30	3	4				4/12/05 20:40	15	361	3/10/05 17:50	95	268
9/9/04 12:00	2	3				4/16/05 14:30	22	1210	3/11/05 12:50	39	238
10/4/04 14:50	4	1				4/16/05 15:50	60	695	3/28/05 12:20	60	206
11/4/04 14:30	2	3				4/16/05 22:20	19	1009	3/28/05 14:50	47	205
12/6/04 15:20	4	1				4/27/05 5:20	59	424	3/31/05 12:50	21	216
1/5/05 14:20	8	24				4/27/05 6:50	124	579	4/1/05 14:10	76	272
2/2/05 13:10	5	3				4/27/05 7:20	89	378	4/1/05 17:10	44	242
3/2/05 15:00	6	5				4/27/05 9:00	49	316	4/2/05 13:40	54	259
3/9/05 14:30	11	7				4/30/05 20:20	35	584	4/2/05 17:10	46	257
4/6/05 16:10	6	5				4/30/05 20:50	65	400	4/6/05 16:50	51	281
4/21/05 12:40	5	4				4/30/05 22:20	42	287	4/6/05 18:40	49	269
4/27/05 7:20	13	119				5/5/05 9:50	27	289	4/11/05 12:30	32	210
4/27/05 11:20	7	14				5/5/05 10:30	58	307	4/11/05 14:50	42	226
5/3/05 14:50	8	7				5/5/05 12:20	44	286	4/12/05 13:20	26	205
5/5/05 15:50	8	12				10/15/05 11:00	188	1761	4/12/05 21:40	20	186
5/13/05 15:50	8	8				10/15/05 11:20	133	763	4/16/05 14:30	51	279
5/14/05 21:30	25	150				12/1/05 6:20	116	332	4/16/05 15:40	85	513
5/16/05 13:50	18	104				12/1/05 7:50	117	364	4/16/05 18:50	48	256
5/17/05 16:00	5	16				12/1/05 10:40	116	342	4/17/05 14:00	52	303
5/19/05 11:40	11	54				12/1/05 19:30	222	893	4/17/05 18:30	46	250
5/20/05 12:30	9	42				12/21/05 2:30	14	129	4/30/05 10:20	12	0
5/23/05 15:30	6	31				12/21/05 2:50	14	130	4/30/05 20:10	69	312
5/24/05 0:00	26	230				12/21/05 16:40	27	151	4/30/05 21:00	84	336
5/31/05 15:30	5	32				12/21/05 17:30	73	258	4/30/05 22:10	43	223
6/8/05 16:40	9	14				12/21/05 18:00	123	387	5/5/05 10:00	70	290
6/15/05 17:50	9	51				12/21/05 18:30	200	713	5/8/05 13:10	67	253
6/22/05 14:40	3	11				12/21/05 18:50	258	589	5/8/05 13:40	142	484
7/8/05 15:10	5	8				12/28/05 12:30	63	634	5/8/05 14:10	126	421
8/1/05 16:20	5	1				12/28/05 13:20	50	328	9/27/05 1:40	264	760
9/12/05 17:40	12	3				12/28/05 18:50	19	290	12/1/05 5:00	127	445

Third Creek			RW-Up			RW-Blw			RW-Abv		
	TU (NTU)	SSC (mg L-1)		TU (NTU)	SSC (mg L-1)		TU (NTU)	SSC (mg L-1)		TU (NTU)	SSC (mg L-1)
						12/30/05 12:00	22	366	12/1/05 7:30	171	576
						12/30/05 17:10	103	548	12/1/05 9:30	194	851
						12/31/05 1:50	204	452	12/1/05 18:50	222	1407
						12/31/05 5:40	104	201	12/21/05 17:40	226	985
						12/31/05 8:00	181	519	12/21/05 19:50	227	1383
						12/31/05 17:30	57	249	12/22/05 6:20	299	296
						2/27/06 8:20	95	516	12/30/05 15:10	138	808
						2/27/06 8:40	126	518	12/30/05 16:20	201	1339
						2/27/06 10:30	90	571	12/30/05 22:50	181	1569
						2/27/06 14:00	103	714	4/3/06 1:00	24	598
						2/27/06 15:00	139	786	4/3/06 2:10	96	1199
						4/3/06 1:50	25	266	4/3/06 3:10	137	477
						4/3/06 2:40	70	429	4/25/06 17:00	112	552
						4/3/06 6:20	44	261	4/25/06 19:00	226	1036
						4/27/06 16:10	77	272	4/25/06 19:20	165	845
						7/21/06 20:20	27	117	4/25/06 19:40	123	635
						2/9/07 12:00	102	514	7/21/06 21:20	16	138
						2/10/07 11:50	178	504	2/9/07 13:30	110	288
						2/10/07 13:00	131	267	2/9/07 13:40	116	292
						3/13/07 16:20	23	264	2/10/07 11:10	154	471
						3/13/07 20:00	13	150	2/10/07 11:50	118	317
						9/20/07 5:20	49	221	3/13/07 15:50	22	133
						9/20/07 6:00	80	246	8/31/07 13:10	56	164
						9/22/07 9:30	62	310	9/19/07 23:50	55	147
						9/22/07 10:50	424	927	9/20/07 4:10	242	547
						9/22/07 11:30	257	518	9/20/07 5:10	180	443
						9/22/07 12:40	110	267	9/20/07 5:30	122	297
						9/22/07 13:20	68	182	9/20/07 8:50	32	113
						10/20/07 0:10	105	323	9/20/07 12:20	21	99
						10/20/07 0:30	72	238	9/22/07 8:30	148	508
						10/20/07 1:30	19	170	9/22/07 9:20	863	2538
						2/28/08 15:00	50	275	9/22/07 10:40	361	807
						2/28/08 15:40	57	258	9/22/07 11:40	163	346
						2/28/08 16:40	60	209	10/19/07 22:30	155	1132
						2/29/08 15:10	45	257	10/19/07 23:30	72	383
						2/29/08 15:50	58	314	10/20/07 0:40	32	210
						2/29/08 19:10	29	210	11/11/07 0:30	25	310
						3/13/08 3:20	56	287	3/9/08 15:20	22	202
						3/14/08 16:10	23	438	3/10/08 16:20	21	189
						3/23/08 16:40	43	460	3/13/08 2:00	37	180
						3/23/08 18:10	25	337	3/13/08 3:10	70	520
						3/30/08 10:30	9	227	3/13/08 4:50	32	447
						4/4/08 9:00	5	276	3/14/08 12:30	22	230
						4/5/08 9:10	4	262	3/14/08 14:40	24	400
						4/11/08 8:00	5	298	3/23/08 17:20	32	288
						4/11/08 14:30	11	311	3/24/08 16:50	39	313
						4/11/08 15:00	8	249	3/25/08 15:10	54	407

Third Creek			RW-Up			RW-Blw			RW-Abv		
	TU (NTU)	SSC (mg L-1)		TU (NTU)	SSC (mg L-1)		TU (NTU)	SSC (mg L-1)		TU (NTU)	SSC (mg L-1)
						4/13/08 8:10	5	308	3/25/08 18:00	36	363
						4/13/08 17:00	12	179	4/23/08 14:00	4	142
						4/30/08 9:50	3	402	5/12/08 22:40	23	227
						4/30/08 18:00	6	330	5/20/08 19:30	38	519
						5/1/08 11:40	40	296	5/20/08 20:30	259	297
						5/1/08 12:20	13	251	5/20/08 21:10	442	3625
						5/19/08 14:10	4	145	5/20/08 21:40	328	1656
						5/20/08 21:00	66	474	5/20/08 22:40	174	668
						5/20/08 21:30	452	1638	5/20/08 23:40	84	318
						5/20/08 23:00	277	242	5/23/08 2:40	26	224
						5/20/08 23:50	184	421	5/24/08 4:20	24	217
						5/21/08 1:20	84	248	5/24/08 9:20	38	330
						5/21/08 2:40	15	161	5/24/08 12:00	32	213
						5/24/08 10:20	62	257	5/24/08 13:00	54	360
						5/24/08 12:10	76	190	5/24/08 14:40	36	222
						5/24/08 14:50	70	237	5/25/08 17:00	21	128
						5/24/08 16:10	37	167	5/25/08 18:00	86	500
						5/25/08 18:10	143	299	5/25/08 18:20	53	351
						5/25/08 19:10	61	244	5/25/08 19:00	32	268
						5/25/08 20:20	18	162	5/26/08 14:00	30	201
						5/26/08 18:40	86	283	5/26/08 14:30	20	181
						10/3/08 23:40	48	206	5/26/08 16:40	35	339
						10/4/08 0:20	138	381	5/26/08 17:30	84	679
						10/4/08 2:10	66	206	5/26/08 18:10	69	526
						10/4/08 3:50	260	334	5/26/08 19:40	36	306
						10/4/08 5:50	85	221	2/22/09 2:00	1	205
						10/4/08 6:20	67	183	2/22/09 10:40	69	380
						11/1/08 20:40	45	285	2/22/09 14:10	62	416
						11/1/08 22:30	137	279	2/22/09 16:30	70	337
						11/2/08 1:50	71	167	2/22/09 20:00	59	284
						11/2/08 3:10	34	138	3/1/09 17:40	21	190
						1/22/09 1:00	3	192	3/1/09 21:10	52	234
						2/22/09 4:00	1	226	3/2/09 0:00	9	248
						2/22/09 12:40	26	332	3/2/09 13:00	200	639
						2/22/09 15:30	41	258	3/2/09 13:20	153	495
						2/22/09 17:20	39	243	3/2/09 13:40	54	256
						2/22/09 20:50	54	208	3/18/09 16:20	21	260
						3/2/09 1:00	15	225	3/21/09 18:10	31	321
						3/2/09 13:50	100	252	4/10/09 10:50	51	376
						3/2/09 14:00	129	972	4/10/09 11:10	40	309
						3/2/09 14:30	99	230	4/10/09 11:30	61	411
						3/2/09 16:30	84	307	5/1/09 0:30	4	310
						4/24/09 13:40	51	552	5/1/09 23:00	113	653
						5/1/09 1:00	4	167	5/2/09 1:20	154	931
						5/1/09 23:10	74	276	5/3/09 7:30	119	834
						5/1/09 23:30	120	379	5/4/09 22:10	88	826
						5/2/09 1:00	65	302	5/4/09 22:30	136	908
						5/3/09 2:00	5	259	6/1/09 1:00	3	303

Third Creek			RW-Up			RW-Blw			RW-Abv		
	TU (NTU)	SSC (mg L-1)		TU (NTU)	SSC (mg L-1)		TU (NTU)	SSC (mg L-1)		TU (NTU)	SSC (mg L-1)
						5/3/09 8:40	217	579	6/1/09 20:00	83	556
						5/3/09 10:40	104	429	6/1/09 21:30	103	525
						5/4/09 22:40	89	305	6/6/09 12:30	39	243
						5/4/09 23:00	113	305	10/13/09 9:20	277	1578
						6/1/09 2:00	7	255	10/13/09 9:50	273	1511
						10/13/09 2:00	2	102	10/13/09 10:20	211	1114
						10/13/09 10:50	158	502	10/13/09 14:10	302	2281
						10/13/09 12:00	272	730	10/13/09 15:50	316	3076
						10/13/09 14:50	229	342	10/13/09 16:30	165	1614
						10/13/09 16:40	302	754	10/13/09 18:40	98	849
						3/22/10 2:00	5	224	10/14/09 0:50	23	232
						3/29/10 1:00	5	239	3/22/10 1:00	5	243
						3/29/10 21:30	83	326	3/29/10 2:00	4	372
						3/29/10 22:20	65	308	3/29/10 21:10	68	556
						4/20/10 2:00	5	283	3/29/10 22:10	36	881
						4/27/10 1:00	5	231	4/20/10 1:00	5	343
									4/27/10 0:00	4	282

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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 coefficient of variation (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 coefficient of variation 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 coefficient of variations had wider PIs that resulted in greater load estimates. Models with coefficient of variations above 0.50, like those for RW-Abv (equations 6A through 10A), have narrower PIs than those with lower coefficient of variations, such as for RW-Blw (Equations 7B through 13B). Water loads and estimated suspended sediment are presented in Tables 2-8, 3B-7 by event, with prediction interval-based errors depicted in the daily loading graphs in the section on rain events (Figure 2-15 and 3B-9).

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 limit of the prediction interval 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, resulting in poor correlation of these regressions.

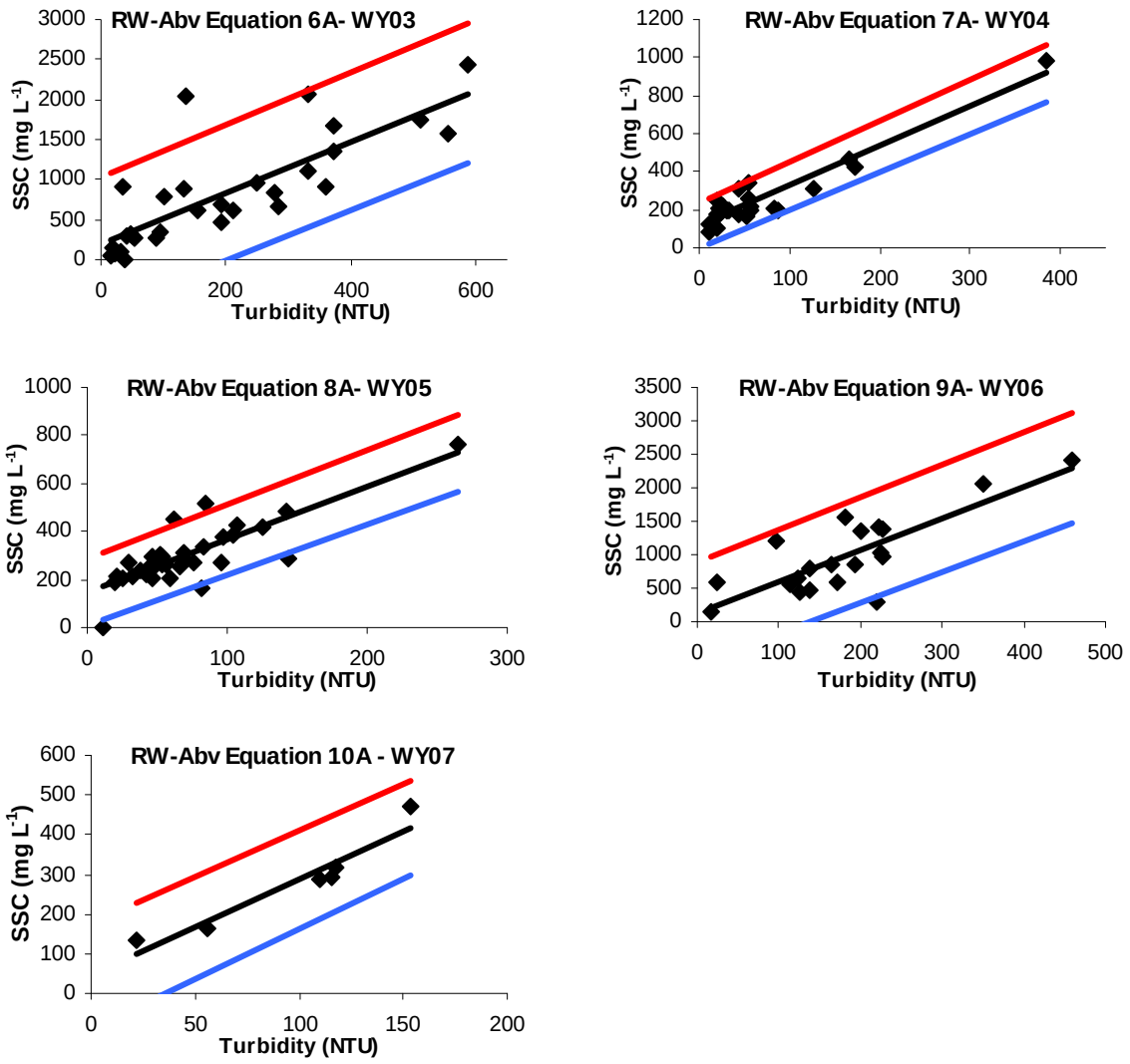

Figure B1. Plots of turbidity and SSC data, regression equations, and 95-percent prediction intervals (red and blue lines) for the State Route 28 (RW-Abv) site.

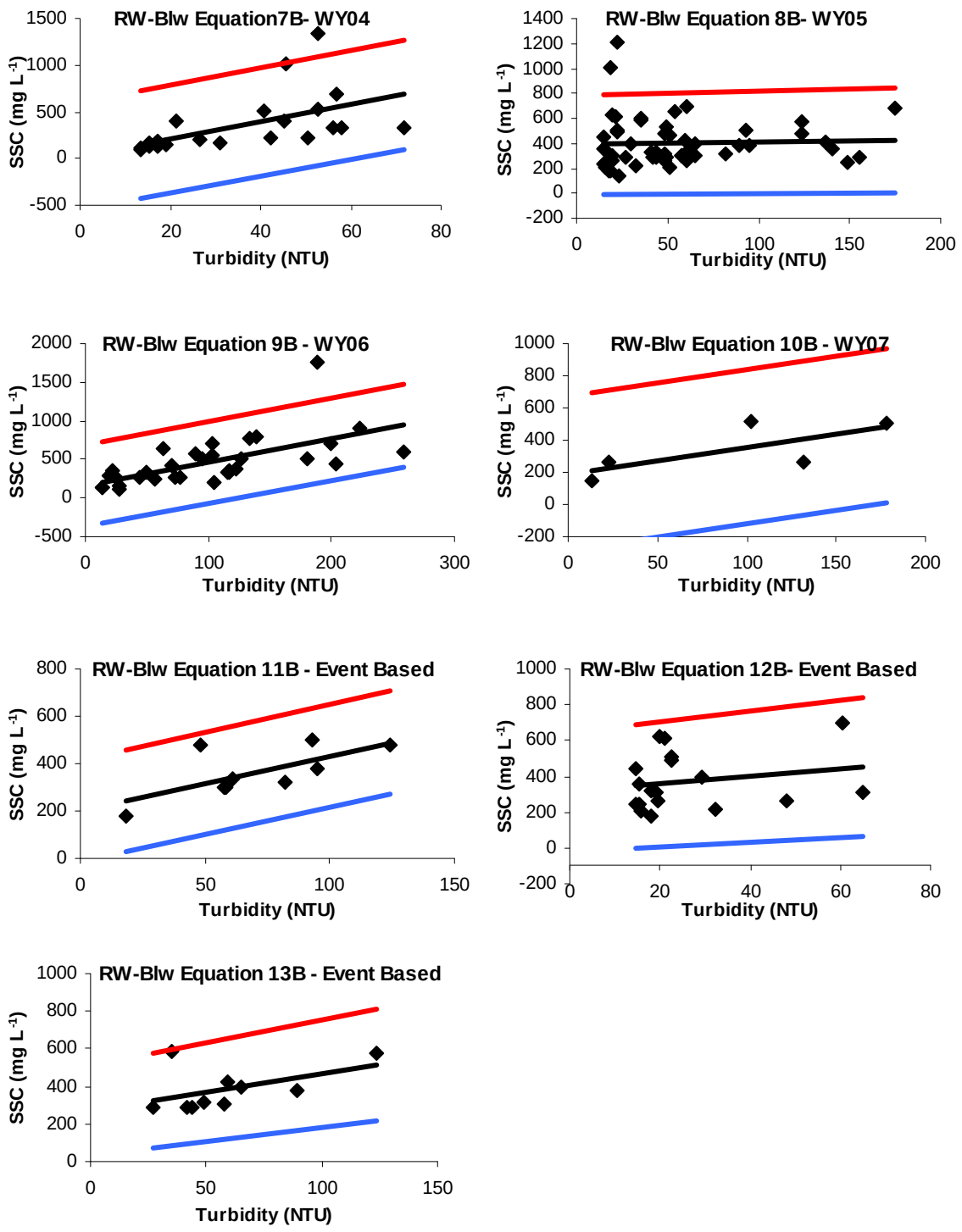

Figure B2. Plots of turbidity and SSC data, regression equations, and 95-percent prediction intervals (red and blue lines) for the RW-Blw (Lakeshore) site.