IMPACT OF THE ROSEWOOD CREEK RESTORATION PROJECT ON SUSPENDED SEDIMENT LOADING TO LAKE TAHOE: PRE-MONITORING AND YEAR 1

Richard B. Susfalk, Assistant Research Scientist, Division of Hydrologic Sciences, Desert Research Institute, Reno, NV, rick.susfalk@dri.edu

Abstract: Rosewood Creek is a small, urban creek in the northeastern part of the Lake Tahoe basin. In 2003, the creek was elongated by 975 linear meters to restore a historically sensitive environmental zone and to mitigate the delivery of suspended sediment from upland sources into Third Creek and ultimately into Lake Tahoe. Strategies to reduce suspended sediment loads included: 1) increasing the length of the channel, thereby increasing the distance that sediments 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; and, 3) routing the creek through five flood-spreading basins.

The objectives of this research are to assess what impacts the Rosewood Creek Restoration Project has on the net transfer and particle-size distribution of suspended sediment. Data collected at each site included near-continuous measurements of water discharge, turbidity, specific conductivity, and water temperature. Discrete water samples were collected by an automated vacuum sampler and were analyzed for suspended sediment concentration (SSC) and particle-size distribution. In-stream turbidity was used as a surrogate for SSC by developing linear and sequential linear regression models to describe the relationship between turbidity and SSC. Particle-size distribution was used to assess the relative importance of suspended sediment loading, as the loading of finer-sized particles have played an important role in the historical decline of Lake Tahoe's optical clarity.

The ability of the restoration project to alter suspended sediment loads the first year after construction was variable and dependent on the type of hydrologic event. For example, suspended sediment loading leaving the restoration zone was half that entering the project during a series of small, low-elevation snowmelt and rain-on-snow events in early 2004. In contrast, sediment loads exiting the project during spring snowmelt were 60% greater than those entering the project. The restoration project did not alter the average particle-size distribution during snowmelt, with particles of less than 20 μm in diameter comprising 40% of suspended sediment samples. However, distinct periods of coarser-grained suspended sediment were observed and were attributed to the presence of unconsolidated sediments remaining from the project construction, and from sediment that had been previously eroded during an earlier, intense thunderstorm. The response of the restoration project during its first post-construction year should not be representative of its future ability to alter suspended sediment delivery due to the recent construction disturbance and the immature status of the newly planted riparian vegetation.

INTRODUCTION

Rosewood Creek is a small, urban tributary located within the Third Creek watershed in Incline Village, NV. 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 an historically 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% 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 the 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; and 3) routing the creek through five flood-spreading basins, and constructing 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 head gate boards allows water to enter Rosewood Creek, or be diverted into Third Creek. Currently, the boards are positioned to restrict peak flows into the project to an estimated 4.1 cfs (Miller, 2004) with water in excess of 4.1 cfs diverted into Third Creek. This operating plan was designed to protect the project from damage from high flows during the establishment phase of recently planted riparian vegetation.

The overall objectives of this research were to: 1) ascertain the ability of Rosewood Creek to deliver suspended sediment into Third Creek; and 2) estimate the ability 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. This monitoring was conducted between November 2002 and May 2004, and included the winter and snowmelt periods prior to and after the construction of the restoration project. Data collected at each site included continuous measurements of water discharge, turbidity, specific conductivity, and water temperature, and discrete measurements of suspended sediment concentration (SSC) and particle-size analysis.

METHODS

Field Sites, Equipment, and Sample Collection: A total of three monitoring sites were established within Incline Village, NV, in the northeastern section of the Lake Tahoe Basin. Two monitoring sites were established before the restoration project, with the third installed after completion of the restoration project. The Rosewood Creek site was installed above (RW-Abv) the restoration project area, 130 m prior to the creek’s discharge into Third Creek. The Third Creek (3^{rd}) site was another 0.8 km downstream near its outfall into Lake Tahoe. The 2003 restoration project extended the length of Rosewood Creek by 975 linear meters and moved the creek's confluence downstream to a point just below the existing Third Creek monitoring site. A new monitoring site near the lower extent of the restoration project was added on Rosewood Creek (RW-Blw) prior to its discharge into Third Creek. Each site was equipped with an in-stream turbidimeter (OBS-3, D&A Instrument Co., Port Townsend, WA), conductivity and water temperature sensor (Campbell Scientific, Logan, UT), and pressure transducer (KPSI, Hampton, VA) to monitor stage. A datalogger (Campbell Scientific) collected data from these sensors every 10 minutes. An automated vacuum sampler collected discrete water samples when triggered by a modified version of the Turbidity Threshold Program (Lewis, 1996).

Suspended Sediment Concentration and Laser Particle Size Analyses: A subset of the samples collected by the automated vacuum samplers was analyzed for SSC by the Soil Characterization Laboratory at the Desert Research Institute following the ASTM D 3977-97 method. Laser particle-size analysis (LPSA) was conducted using the Micromeretics Saturn DigiSizer 5200® laser particle size analyzer following a procedure based on ASTM C 1070 – 01 for the particle-size determination of alumina and quartz powders by laser light scatter (ASTM, 2002). The DigiSizer 5200® determined the percentage of specific size-class fractions between 0.02 µm and 1,500 µm in diameter in a sediment sample (Gee and Or, 2002) based on the Mie theory of light scattering by a spherical particle.

Load Calculation: The instantaneous suspended sediment load (SSL) was the product SSC (in mg L^{-1}) and discharge Q (in L s^{-1}) summed over each 10-minute interval. Load calculations were done on a hydrologic-event basis. When in-stream turbidity exceeded the turbidimeter maximum (1,000 NTU), SSL was calculated using hourly SSC measurements collected during the events. Suspended sediment loads by particle-size group were calculated by multiplying the percentage particle-size fraction determined by LPSA by total SSL.

RESULTS AND DISCUSSION

The relationships used to estimate suspended sediment concentrations from in-stream turbidity are presented in Table 1. The predictive ability for RW-Blw was poor due to the limited number of samples since and the impacts of disturbance from the recent project construction. The predictive ability of this model should improve as more samples are collected while the restoration zone matures toward an ecological equilibrium. The 3rd model was stratified by turbidity value to reduce overestimation of SSC at lower turbidities that occurred in non-stratified models. The correlation between log(SSC) and the fitted log(SSC) was 0.71 for RW-Abv, 0.39 (P =0.0225) for RW-Blw, and 0.87 ($P \leq 0.0001$) for 3rd. These regression models are preliminary, and will be adjusted as new data are collected over the next two years.

Pre-restoration Project Monitoring: The objective of pre-project monitoring was to establish background data prior to construction and to assess the impact that suspended sediment delivery by Rosewood Creek had on Third Creek. Four events were monitored during this period including low- and high-elevation snowmelt events, and two rainstorms (Table 1). The geography of the two watersheds played an important role in the timing and magnitude of suspended sediment loading. The Rosewood Creek watershed is a low-elevation, urbanized watershed that responds rapidly to low-elevation/lake-level snowmelt and storm events. Approximately 55% of the 2.3 km^2 watershed lies within urbanized areas above lake level (1,800

m) to 2,300 m in elevation. The Third Creek watershed is larger in area, with a higher mean elevation, and responds primarily to high-elevation hydrologic events. Only 10% of this 13.3 km^2 watershed lies within lower-elevation urban areas.

Table 1 Relationships between suspended sediment concentration (SSC), turbidity (TU), water temperature (WT), and discharge (Q).

Site	Equation	R^2	P value
RW-Abv	$\log(SSC) = 0.0580 * \sqrt{TU} + 1.9313$	0.72	(TU) ≤0.0001
RW-Blw	$\log(SSC) = 0.7909 \times \log(TU) + 0.0924 \times WT + 0.9109$	0.56	(TU) 0.0197 (WT) 0.0378
3rd	$\log(SSC) = 0.6823 \times \log(TU < 12) + 0.0138 * Q + 0.3758$ $\log(SSC) = 0.6824 \times \log(TU \geq 12) + 0.0138 * Q + 0.9611$	0.88	(TU) ≤0.0001 (WT) 0.0007

Total suspended sediment delivered to Lake Tahoe from these watersheds was dominated by high-elevation, seasonal snowmelt originating from the upper Third Creek watershed (Event 2, Table 2). On an event basis, however, Rosewood Creek was capable of contributing significant suspended sediment loads to Third Creek during low-elevation events (Events 1 and 4).

Table 2 Suspended sediment loadings (SSL) and water discharge on an event basis.

Event	SSL (kg/event)			Water (10^6 L/event)			Duration
Description	RW-Abv	RW-Blw	3rd	RW-Abv	RW-Blw	3rd	(hours)
1. Low-elevation snowmelt (1/22-2/50/03)	6,922	--	3,694	41.6	--	155.7	351
2. High-elevation snowmelt (5/11-6/20/03)	7,056	--	339,877	33	--	2,346	960
3. Rainstorm (7/22-7/24/03)	236	--	867	0.9	--	10.7	41
4. Rainstorm (8/21-8/24/03)	9,966	--	12,530	5.6	--	19.4	73
5. Early season snowmelt (1/20-2/10/04)	3,419	1,651	6,033	24.2	27.14	313.4	522
6. Rain on snow (2/16-2/18/04)	2,700	1,345	764	6.3	3.67	16.8	47
7. Low-elevation snowmelt (3/1-4/27/04)	31,745	50,837	15,532	178.3	183.2	--	1,368

Particle-size analysis revealed that only 35% of the suspended sediment from Rosewood Creek was less than 20 µm in diameter, whereas over 85% of the suspended sediment from Third Creek was less than 20 µm in diameter (Figure 1). The delivery of fine-grained suspended sediment has important consequences to the clarity of Lake Tahoe, as fine-grained particles not only remain suspended in the water column for longer periods, but also have a greater potential to be a source of limiting nutrients, such as phosphorus. As a result, fine-grained particles adversely affect both near-shore clarity (Taylor et al., 2004) and long-term clarity at mid-lake (TRG, 2001). Regulatory agencies within the Lake Tahoe basin have placed a strong emphasis on the reduction of suspended sediment input to the lake as a way to restore Lake Tahoe's famed clarity.

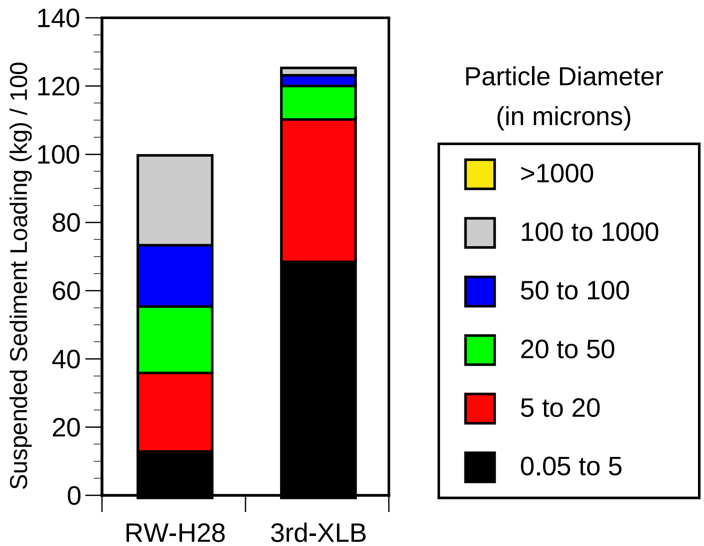

Figure 1 Total suspended sediment loading (SSL) by particle-size group for Event 4, a series of summer thunderstorms.

Post-Restoration Project Monitoring: The restoration project was constructed in the summer of 2003 and added 975 linear meters to the length of Rosewood Creek's channel. This resulted in the movement of the creek's confluence 800 m downstream to a point just below the existing Third Creek monitoring site. Three hydrologic events were monitored: early season snowmelt (Event 5), a rain-on-snow event (Event 6), and a low-elevation snowmelt (Event 7).

The effectiveness of the restoration project to reduce suspended sediment loading was judged by comparison of the calculated loadings entering (RW-Abv) and exiting (RW-Blw) the restoration project. During the two mid-winter events (Events 5 and 6), the restoration project acted as a sediment sink, reducing suspended sediment loads by about 50%. This was likely due to the relatively low water velocities resulting from flooding within the designed spreading zones that occurred due to the presence of snow and ice dams that partially blocked several sections of the restored creek.

The larger, low-elevation snowmelt event occurred between March 1 and April 27, 2004. During this time, the restoration project was a source of 335 kg/day of suspended solids and the total loading from Rosewood Creek comprised 77% of the suspended sediment delivered to Lake Tahoe by Rosewood and Third creeks. Hysteresis curves and particle-size analyses data were used to gain insight on the possible sources of suspended sediment within the restoration project during the most intensive days in early snowmelt. For example, the concentration of suspended sediment entering the restoration project was found to be unimodal in distribution, elevated between 1.1 to 1.8 cfs (Figure 2). Although suspended sediment concentrations were elevated, the observed mean particle diameters between 35 and 53 μm were consistent with mean diameters observed during other hydrologic events at this site.

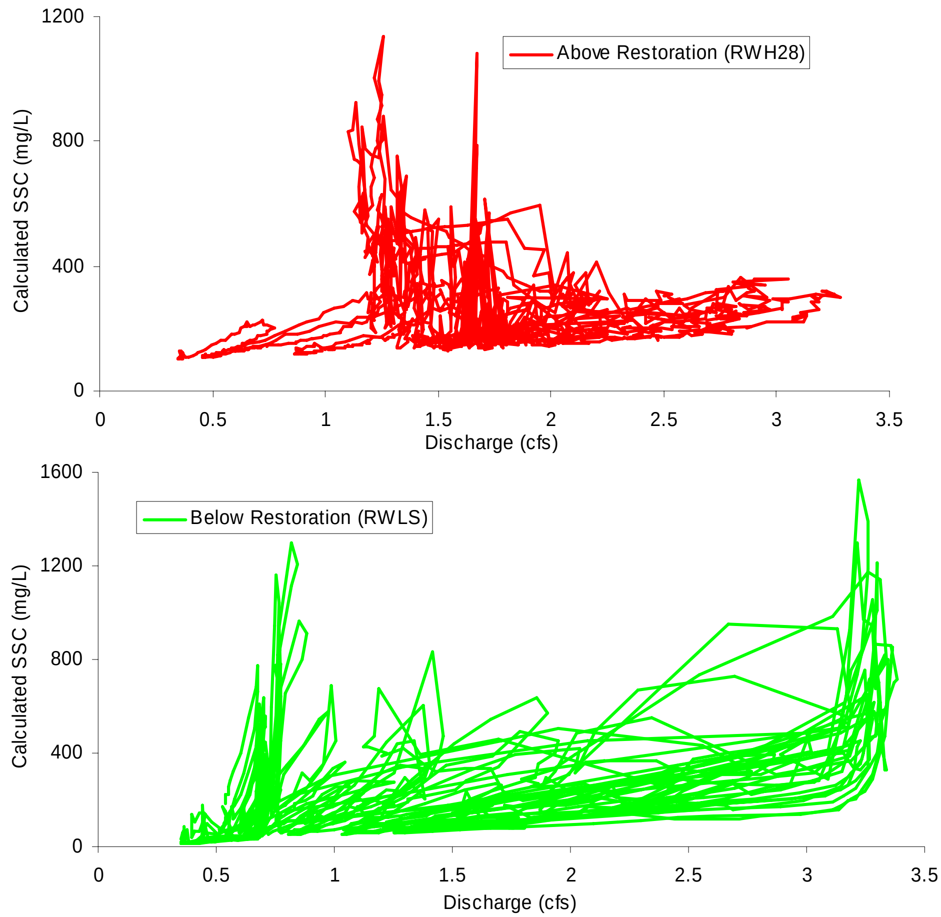

Figure 2 Hysteresis relationships above (top) and below (bottom) the Rosewood Creek Restoration Project observed between March 9 and March 16, 2004.

In contrast, the suspended sediment leaving the restoration project was observed to be bimodal in distribution, with elevated sediment concentrations between 0.5 to 0.9 cfs, and above 3.2 cfs. Mean particle size was found to vary, primarily during the early part of snowmelt when particles greater than 100 μm in mean diameter were mobile during relatively low flows (0.5 to 0.9 cfs). This suggested an easily mobile sediment source within the restoration project that was short lived, presumably as the source of this material was depleted. This coarser, mobile material was likely residual, unconsolidated material that remained from the project's construction and from severe erosion that occurred in response to an intense series of rainstorms on August 21, 2004, prior to the completion of the project. If this hypothesis is correct, then this pulse of coarse material should not be observed in subsequent years.

SUMMARY

The objectives of this project were to ascertain the ability of Rosewood Creek to deliver suspended sediment into Third Creek and to estimate the ability of the Rosewood Creek Restoration Project to alter the quantity and composition of suspended sediment delivered by Rosewood Creek into Third Creek. The data presented here included several months of pre-construction data and the first winter season following the completion of the restoration project.

The ability of Rosewood Creek to significantly increase suspended sediment loads in Third Creek was due to the geographical differences between the watersheds. Events such as lake-level snowmelt and low-elevation rainstorms resulted in the mobilization of sediment from the low-elevation Rosewood Creek watershed, but not from the higher-elevation Third Creek watershed. For example, lake-level snowmelt in 2003 resulted in Rosewood Creek transporting 6,922 kg of suspended sediment compared to just 3,694 kg in Third Creek. These values were dwarfed by the 339,877 kg of suspended sediment transported by Third Creek during spring thaw at higher elevations. However, Rosewood Creek was able to mobilize significant amounts of suspended sediment during summer thunderstorms, such as contributing 44% of the combined 22,496-kg load entering Lake Tahoe from the Third Creek watershed. However, suspended sediment delivery from Third Creek itself was more important, as suspended sediment from Third Creek had a finer particle-size distribution (85% < 20 μm diameter) than observed in Rosewood Creek (35% < 20 μm diameter).

The ability of the Rosewood Creek Restoration Project to alter the delivery of suspended sediment to Third Creek was mixed. Suspended sediment loading was reduced by approximately 50% during a series of small, low-elevation snowmelt events in January and February 2004, and during a rain-on-snow event in mid-February 2004. In contrast, suspended sediment loading within the project increased by 60% during low-elevation spring thaw. The restoration project did not affect the average particle-size distribution, as about 42% of the suspended sediment above and below the project was less than 20 μm in diameter. However, distinct periods were observed where the particle-size distribution of suspended sediment was skewed by the substantial presence of particles greater than 100 μm in diameter. This transport of coarser particles was attributed to the presence of unconsolidated sediments remaining from the construction, and from sediment remaining in the project that had eroded from the banks and channel failures during a previous thunderstorm. The response of the restoration project during its first post-construction year should not be representative of its future ability due to the disturbance caused by recent construction and the immaturity of recently planted riparian vegetation. Monitoring to determine the effectiveness of the restoration project will continue for at least two more years.

ACKNOWLEDGEMENTS

The author would like to thank the Nevada Division of State Lands' Lake Tahoe License Plate Program for funding the project. Additional funds for equipment were provided by the Desert

Research Institute, and the National Science Foundation's RING-TRUE Incline Creek Watershed Project.

REFERENCES

ASTM, 1999, "D 3977-97 Standard test method for determining sediment concentration in water samples," Annual Book of Standards, Water and Environmental Technology, 1999, Volume 1 I .02, pp 389-394.

ASTM, 2002, C 1070 – 01 Standard test method for particle size distribution of alumina and quartz powders by laser light scattering. http://www.astm.org.

Gee, G.W., and Or, D. (2002). "Particle-size analysis," in Dane, J.H. and G.C. Topp (eds.), Methods of Soil Analysis, Part 4, Physical methods, Soil Science Soc. Am., Inc., Madison, WI, pp 255-293.

Jassby, A.D., Goldman, C.R., Reuter, J.E., and Richards, R.C. (1999). "Origins and scale dependence of temporal variability in the transparency of Lake Tahoe, California-Nevada," Limnol. Oceanogr. 44(2) pp. 282-294.

Lewis, J. (1996). "Turbidity-controlled suspended sediment sampling for runoff-event load estimation," Water Resources Research 26, pp 2069-2077.

Miller, D. (2004). "Rosewood Creek Restoration Project: Operations and Maintenance Plan," Mainstream Restoration, Inc. March 23, 2004.

Rowe, T.G., Saleh, D.K., Watkins, S.A., and Kratzer, C.R. (2002). "Streamflow and water-quality data for selected watershed in the Lake Tahoe Basin, California and Nevada, Through September 1998," United States Geological Survey Water-Resources Investigations Report 02-4030.

TRG (Tahoe Research Group) (2001). "Annual Progress Report. Water Quality, Air Quality and Watersheds," Tahoe Research Group, Dept. of Civil and Environmental Engineering, Center for Ecological Health Research, Delta Group, Dept. Land, Air, and Water Resources. University of California, Davis, August 7, 2001.

Taylor, K., Susfalk, R., Shanafield, M. and Schladow, G. (2004). "Near-shore clarity at Lake Tahoe: Status and causes of reduction," Desert Research Institute Publication No. 41193.