Fine sediment load rates of a restored, and unrestored reaches of the Upper Truckee River, Lake Tahoe CA.

Abstract

The water quality differences between a restored and unrestored reaches of the Upper Truckee River were monitored during the 2012 peakflow conditions in an attempt to measure the surface water quality benefits of a restoration project. Turbidity samples were collected at reference sites above and below the project area and reference reaches for a period of 12 days. The intent of the sampling was to capture the diurnal, rise, peak and falling hydrograph variability for the 2012 peakflow. The relationship between discharge and turbidity was then applied to the spring flow record to estimate the mass of fine sediment transported to Lake Tahoe during the spring 2012 peakflow condition. The restored reach resulted in a greater rate of fine sediment loading per mile relative to all three unrestored reference reaches.

Background

The Upper Truckee River (UTR) is the greatest contributor of suspended-sediment and fine-grained sediment in the Lake Tahoe Basin (Simon, 2003). Inorganic terrestrial sediment is the dominant cause of Lake Tahoe's long term clarity decline (Swift, 2006). The restoration of the UTR is based on the re-establishment of natural geomorphic processes and functions and it is believed that a geomorphically stable channel will improve many important ecological functions and at the same time, reduce impacts to water quality (UTRWAG, 2008). Determining the total suspended sediment load in rivers is critical for establishing science-based criteria for the maximum daily amount of sediment so that erosion management and pollution control strategies may be developed (Gao, 2008). However, few riparian ecosystem restoration monitoring efforts in the Lake Tahoe basin have included both pre-restoration and post-restoration project effectiveness, and previous evaluations have not been able to attribute changes in ecosystem conditions to riparian ecosystem restoration project actions (2NDNATURE, 2010). The turbidity of the UTR was measured by Michael Alexander and Russell Wigart during 2012 spring snowmelt flooding at sample sites above and below three unrestored reference reaches, as well as above and below the newly restored airport reach to determine if the channel restoration reduced water quality impacts as hypothesized by the UTRWAG.

The direct approach to monitoring water quality involves measurement of suspended sediments, solids, and nutrients at the upstream and downstream ends of the project reach (UTRWAG, 2008). Sediment sampling by turbidity is an indirect means where turbidity serves as a surrogate for suspended sediment concentration and has been increasingly adopted by researchers for sediment estimation in surface waters (Gao, 2008). Using turbidity data from the UTR is a reliable and valid sediment monitoring technique (2ND Nature, 2006). Furthermore, there is an excellent correlation between suspended sediment and turbidity for Lake Tahoe basin tributaries, including the UTR (Stubblefield, 2006). Particles of different sizes impact turbidity differently and 0.2 to 5 micron for mineral sediment and 1 to 20 micron for organic grains are the most sensitive to turbidity (Gao, 2008). One of the difficult aspects of water quality monitoring is that the pollutant loads entering the lake are very small compared to other systems and the expected change is small, and the signal of a load reduction is if the volume of sediments and nutrients is lower at the downstream station (UTRWAG, 2008).

In 2012 a total of five sample locations were established above and below the new airport restoration reach and along three unrestored reference reaches (See Figure 1). Sample location A was located in Meyers at the Highway 50 Bridge, B was at Elks Club Drive, C was upstream of the restored airport reach, D was downstream of the restored airport reach, and E was in South Lake Tahoe at the Highway 50 Bridge.

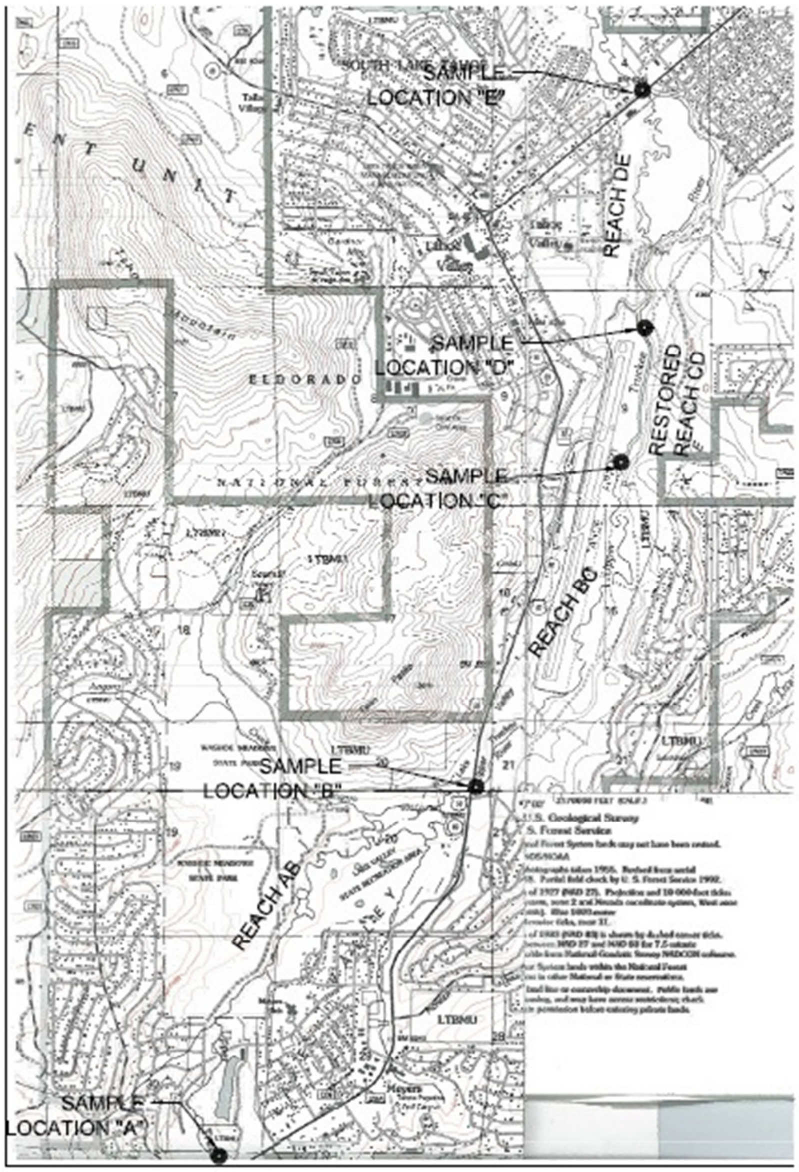


FIGURE 1 - Sample Locations

Reach AB is located between the Highway 50 Bridge in Meyers and Elks Club Drive and is typically gravel bedded with 1.5 to 3 meter-high banks of silt and fine sand layers overlying layers of coarse sand and gravel. Short grass is the dominant vegetation and the outside bends of non-cohesive materials have become undercut and are sloughing off (Simon, 2003).

REACH AB @ 110 cfs on June 2, 2012

Reach BC is located between Elks Club and the South Lake Tahoe airport and is a sinuous reach with 1.5 meter high grassed banks composed of silt and fine sand. The outside bends are being undercut, and the upper portions are sloughing off. As woody vegetation levels increase in the upstream part of the reach, the frequency of sloughing cut-banks drops off, indicative of the potential role of woody plants in strengthening streambanks (Simon, 2003).

REACH BC @ 110 cfs on June 2, 2012

Reach CD is adjacent to the airport and was relocated as part of the original airport construction in 1958, and was further modified during the airport expansion of the late 1960s into a straightened planform, deeper and wider channel cross-section with rip-rapped banks (Entrix, 2008). The old channel form was a 1.2 km reach with 20 cm diameter rip-rap lining the banks with alders, grass, and small pines covering the banks (Simon, 2003). Between 2008 and 2011 Reach CD was restored using a relatively low width-to-depth channel ratio, steeply dipping point bars, and remnant channel features on the fine-grained floodplain (Entrix, 2008). The old channel required a flow of about 1,300 cfs to overbank and through analyses of the effective discharge, flood frequency analysis, and bankfull geomorphic indicators, the channel-forming flow for the restored channel was set at 450 cfs (Entrix, 2008). The new channel depth and slope were established to pass the estimated bedload of a 450 cfs channel-forming flow while maintaining channel stability, and the new floodplain was designed to be inundated beginning around 450 cfs (Entrix, 2008). The hypothesis for this restoration reach was that a properly functioning floodplain will store more water and one of the goals of the project was to improve functionality of floodplain for improving water quality (UTRWAG, 2008).

REACH CD @ 110 cfs on June 2, 2012

Reach DE is located between the airport and Highway 50 in South Lake Tahoe and is a meandering reach with streambanks that are typically 1.5 meters high and composed of silt and fine sand. The stream meanders near the east valley wall thereby creating occasional escarpments. The escarpments contain a mix of materials including cohesive clays, cemented sands, and loose sand and gravel. Vegetation consists of grasses and alder on the flat meadow banks and sagebrush and pine on the escarpment banks (Simon, 2003).

Below sample location E the sediment retention characteristics of the Truckee Marsh reflect floodplain connectivity, the UTR is highly incised, with two meter high banks preventing movement of snowmelt flows out into the marsh and constrained flows result in the reach acting like a pipe, directly transmitting suspended sediment with little retention. (Stubblefield, 2006).

REACH DE @ 110 cfs on June 2, 2012

During the spring of 2012 bankfull flows entered the newly restored Reach CD for the first time and flow peaked at a discharge of 678 cfs as measured by the United States Geological Survey (USGS) at sample location E near the highway 50 Bridge in South Lake Tahoe. The turbidity of the UTR was measured during these spring snowmelt high flows because high values of suspended sediment concentration are often associated with high annual flows (Gao, 2008). Furthermore, spring snowmelt was selected as a test of the UTRWAG water quality hypothesis for Reach CD because spring snowmelt represents the bulk of sediment loading for subalpine Sierra watersheds (Stubblefield, 2006). The turbidity measurements were collected to determine if water quality improvements could be detected as a result of the channel redesigned to be inundated at 450 cfs where the old channel was expected to be inundated at 1,300 cfs.

REACH CD @ 673 cfs on April 26, 2012

Methods

The indirect approach to monitoring water quality was used by measuring turbidity at the upstream and downstream ends of each reach as a surrogate for fine sediment. Water samples were collected from the bank from the flowing river at approximately 0.02 meters below the moving water surface in a location free of backwater effects between April 20 through May 2. The vertical fine sediment particles in the water column are well-mixed with respect to concentration, there is no discernible vertical structure to concentrations within the water column and surface grab samples are a reasonable proxy to represent fine sediment particle concentrations in the entire water column in Lake Tahoe streams (2NDNATURE, 2011). 2012 sampling frequency was random with an effort to collect samples on the rising and falling limbs of the diurnal hydrograph before, during and after the 450 cfs channel forming flow rate. The discharge of the UTR was measured at 15 minute time intervals by the USGS at gauging station 103366092 at Highway 50 above Meyers near sample station A, and at gauging station 10336610 at Highway 50 at South Lake Tahoe near sample station E. The turbidity of each water sample was measured using a Hach 2100P turbidimeter within an hour of the collection of the sample. The position of each sample location was recorded using Global Positioning System (GPS). River mile distances between the beginning and end of each of the four reaches were estimated using Google Earth by averaging the left and right banks, with river mile 0 representing the location where the UTR reaches Lake Tahoe.

Five linear models were developed to predict turbidity from discharge and were based on turbidity measured between April 20 and May 2 at each sample location. The linear model was then used to calculate the turbidity for each discharge value. USGS gauging station 103366092 at Highway 50 above Meyers was used for discharge at sample stations A and B, and gauging station 10336610 at Highway 50 at South Lake Tahoe was used for discharge at sample stations C, D and E. The predicted turbidity for each sample location was converted to fine sediment particles (FSP <16 µm) using equation 1.

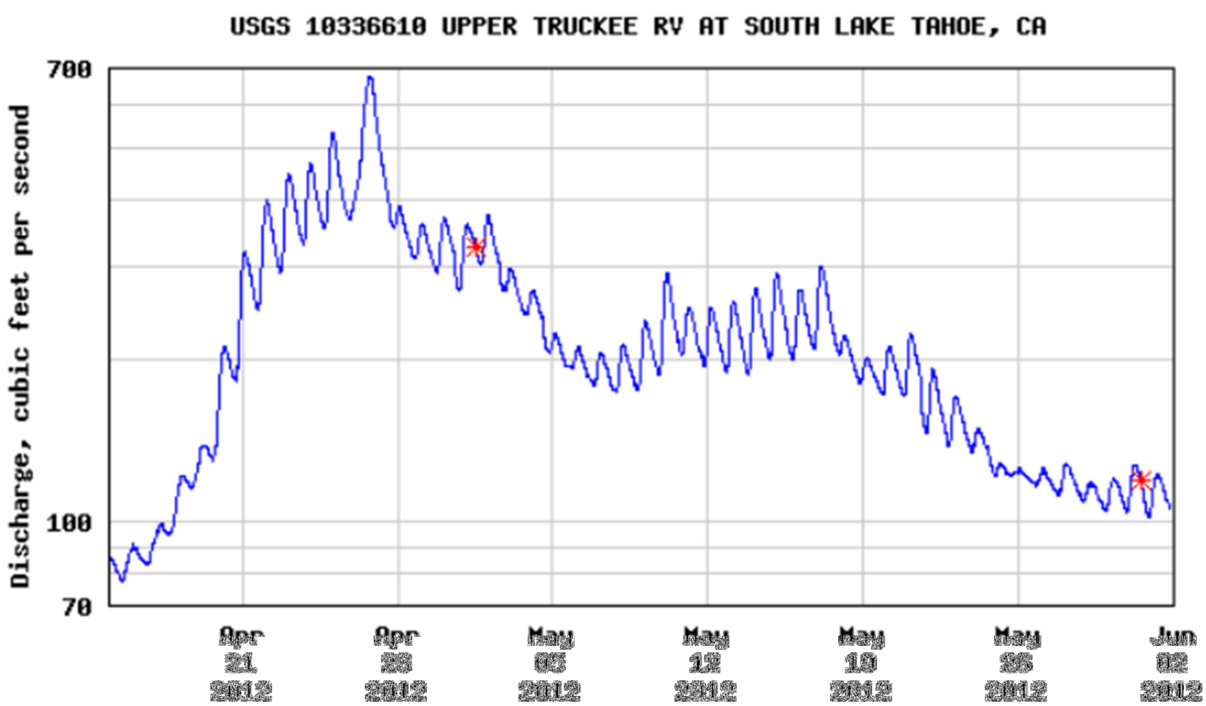
Equation (1) FSP (mg/l) = Turbidity (ntu)*(0.77) (2^{ND} Nature, 2011)

The FSP loads at each sample location and for each reach were then calculated between April 22 and May 2. FSP loads were not calculated for April 20 and 21 because the first turbidity sample at sample location D was not collected until April 22, and the discharge during April 20 and 21 were relatively low compared to higher discharge rates during the remainder of the sampling effort. In addition, the FSP loads were normalized for each reach using only Meyers discharge for all sample locations, and the per mile load of the restored reach was compared to the per mile load of the three unrestored reaches.

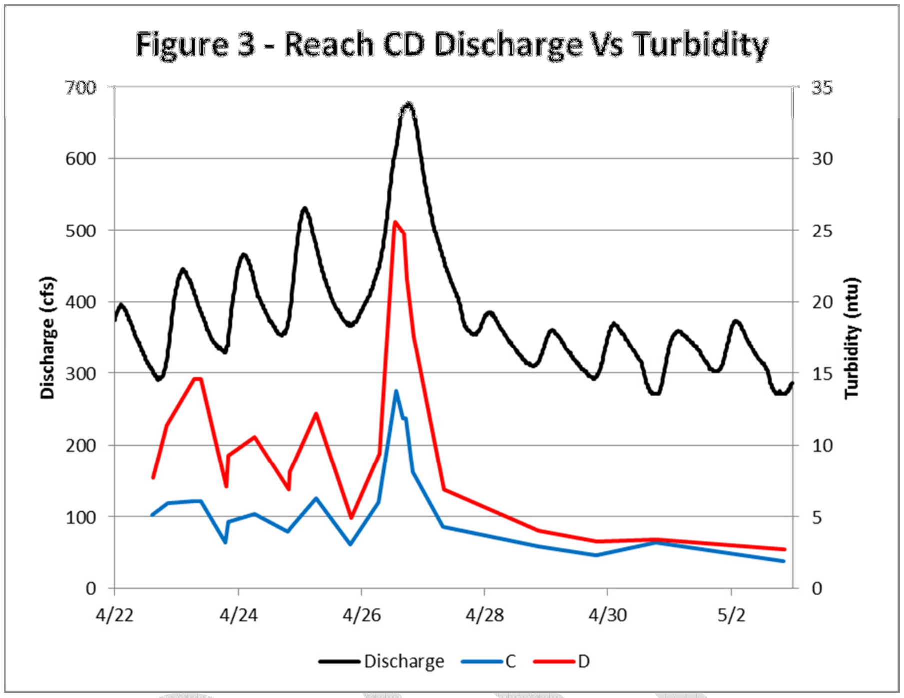
Results

The approximate river mile length of reach AB is 3.20 miles, BC is 2.46 miles, CD is 0.68 miles, and DE is 1.60 miles. The distance from sample location E to Lake Tahoe is approximately 1.75 river miles. Throughout the sampling, the turbidity of the UTR increased from the upper sampling locations to lower sampling locations in nearly all instances. The spring snowmelt discharge at Highway 50 is presented in Figure 2.

Figure 2



The change in turbidity of restored reach CD is shown on Figure 3. The turbidity at sample locations C and D diminished throughout the snowmelt flood and the increase in turbidity was greatest during the peak discharge condition.



The longitudinal turbidity during and after peak discharge is shown in Figure 4. During the peak discharge, the rate and magnitude of turbidity increase for reach CD were greater than any of the reference reaches.

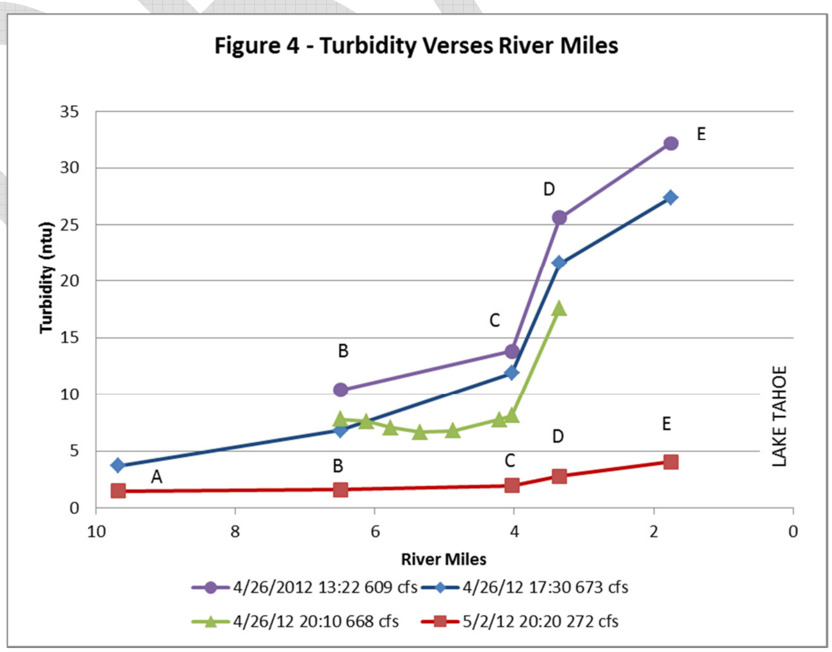


Figure 5 shows the rate of turbidity increase for each of the four reaches near peak discharge of 673 cfs, which is in excess of the design channel forming flow of 450 cfs. On April 26 at 17:30 near peak discharge of 673 cfs, the restored reach CD increased the turbidity of the UTR per river mile at a rate 14.6 times greater than reach AB, 6.9 times greater than reach BC, and 3.9 times greater than reach DE.

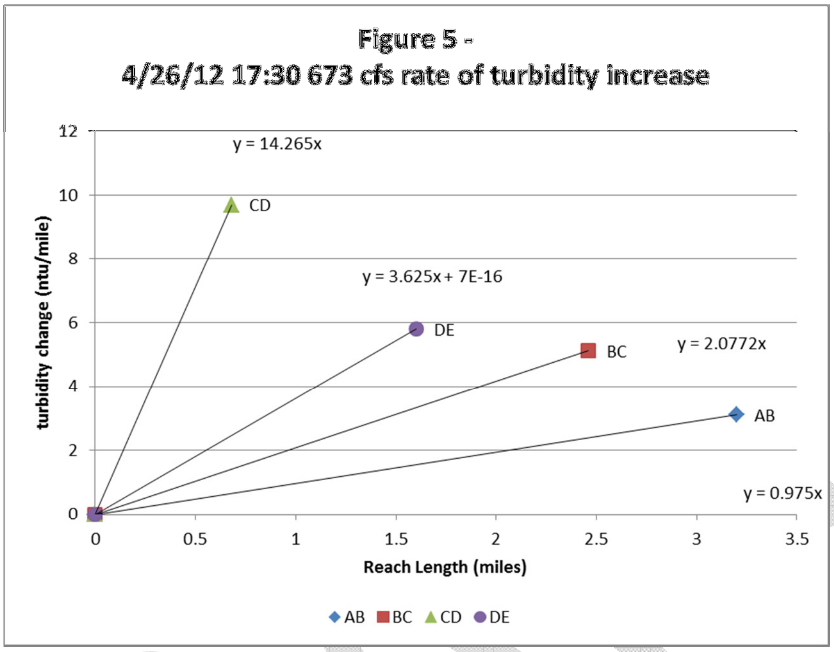


Figure 5 - 4/26/12 17:30 673 cfs rate of turbidity increase

Figures 6 through 10 present the measured relationship between discharge and turbidity, the linear equation to fit the data, and the R^2 of this relationship between the linear trend line and the measured turbidity. The linear models were used at each sample location to predict the turbidity based on discharge between April 22 and May 2 and the model results are also shown in Figure 6 through 10.

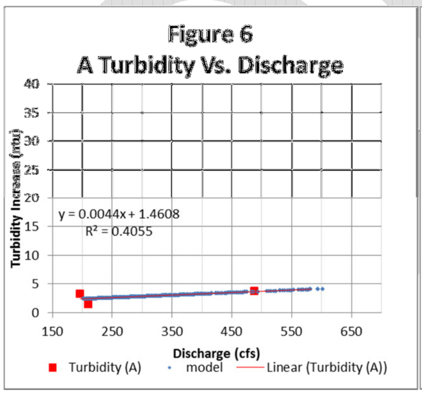


Figure 6 A Turbidity Vs. Discharge

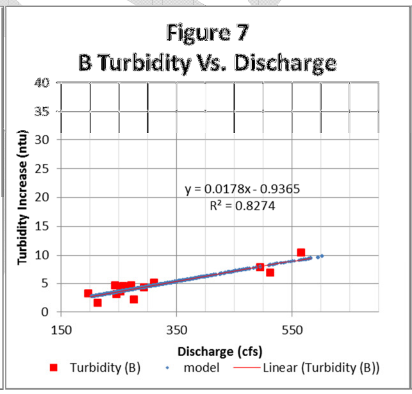


Figure 7 B Turbidity Vs. Discharge

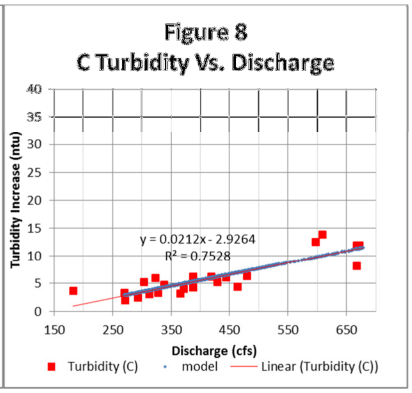
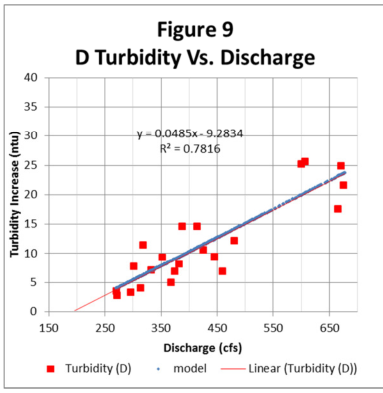


Figure 8 C Turbidity Vs. Discharge



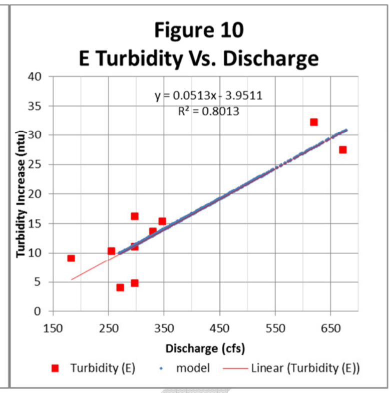


Figure 10 presents the calculated daily FSP load for each of the four reaches and also presents the instantaneous discharge for the Meyers and Highway 50 USGS gauges.

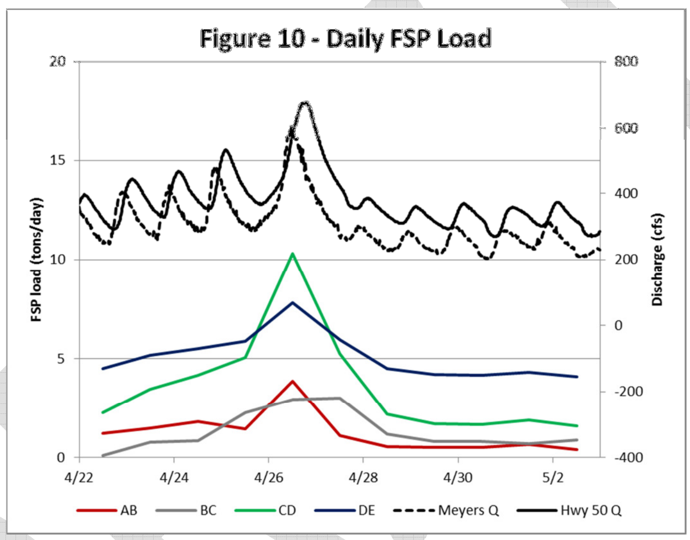


Table 1 presents the calculated FSP load for each sample location and for each reach between April 22 and May 2 using the Meyers and South Lake Tahoe USGS gauge record. Reach DE generated 1.4 times the total FSP load than restored reach CD, however, reach DE is 2.4 times as long as reach CD. The FSP load rates for reaches AB and BC were relatively minor compared to reaches CD and DE.

Table 1 - FSP Load per River Mile

Sample location	FSP Load (tons)	Reach	FSP Load (tons)	Reach Length (river miles)	FSP Load (tons/mile)
A	20	AB	14	3.20	4
B	34	BC	14	2.46	6
C	48	CD	40	0.68	58
D	88	DE	56	1.60	35
E	144				

Between April 22 and May 2 the total volume of runoff at Highway 50 in South Lake Tahoe was 25% greater than Meyers, or 3.6×10^8 cubic feet and 2.9×10^8 cubic feet respectively. So in order to compare the relative FSP load rates per river mile for each of the four reaches, the loads for sample locations C, D, and E were normalized by recalculating their load at these sample locations using discharge from the Highway 50 bridge in Meyers. The results are presented in Table 2.

Table 2 - FSP Load per River Mile Normalized to Meyers Discharge

Sample location	FSP Load (tons)	Reach	FSP Load (tons)	Reach Length (river miles)	FSP Load (tons/mile)
A	20				
		AB	14	3.20	4
B	34				
		BC	5	2.46	2
C	38				
		CD	31	0.68	46
D	70				
		DE	45	1.60	28
E	115				

Restored reach CD generated a greater FSP load rate per mile than any of the three reference unrestored reaches. The FSP load per mile for restored reach CD is 1.6 times greater than reach DE, 11 times greater than reach AB, and 25 times greater than reach BC.

Discussion

Using turbidity data collected as a surrogate for fine sediment during flows below and in excess of the design channel forming flow rate for Reach CD during the 2012 peak snowmelt condition, load reduction in the volume of sediments downstream of the restored reach CD were not observed. Measurements suggest that rather than improving water quality for the fine sediment component, the restoration of reach CD increased the concentration and loading rate of fine sediment significantly during peak flows in 2012 relative to all three unrestored reaches of the UTR that were measured. While the water quality changes due to restoration may have been expected to be small, data presented here suggest the fine sediment pollutant loads of the UTR during flow in excess of channel forming rates were significantly greater from the restored reach during 2012.

Effectiveness monitoring is used to evaluate the impacts of resource management actions and whether or not management goals for the project were met and is a critical element of adaptive management to allow adjustment in management in response to new information, knowledge or technologies (UTRWAG, 2008). However riparian ecosystem restoration in the Lake Tahoe basin seldom incorporate adaptive management and effectiveness evaluation reports typically contain no components of an adaptive management plan (2NDNATURE, 2010). For the water quality objective for UTR restoration, adaptive management can be facilitated best using effective water quality monitoring. Based on the higher rate of sediment loading from the restored reach during snow melt flooding in 2012, it is recommended that water quality measurements of fine sediment begin along the restored reach in order to determine the water quality benefits or impacts of this river restoration project.

References

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