Analysis of Impacts of Blackwood Creek Reach 6 Stream Channel and Floodplain Restoration on Sediment Loading to Lake Tahoe during the 2009 and 2010 Water Years

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Lake Tahoe Basin Management Unit
Ecosystem Conservation Department

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Special recognition goes to the members of the Blackwood Creek Geomorphic Assessment Team:

Dr. Andrew Simon, Cardno Entrix
Tim Abbe, Geomorphologist, Cardo Entrix
Mike Nolan, USGS (retired)
Dr. Andrew Stubblefield, Humboldt State University
Matte Kiesse, Geomorphologist, River Run Hydrology Consulting
Cindy Wolke, Geomorphologist, California State Parks

Finally, the technical guidance, document review and editing provided by Joey Keely (Supervisory Hydrologist, LTBMU) are, as always, much appreciated.

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I. Purpose of This Report

The purpose of this report is to address concerns presented by the LRWQCB during a field trip conducted in August of 2011, as part of Lahontan staff review of the LTBMUs permit application for the Blackwood Creek Reach 1 Stream Channel and Floodplain restoration project. During this field trip Lahontan staff stated that concerns had been raised by their science advisors regarding the LTIMP sediment data collected at Blackwood Canyon in water years 2009 and 2010, related to construction of the Reach 6 project. This project was constructed between September 1st of 2008 and October 9th of 2009. The specific concern expressed by Lahontan staff in a follow up email was as follows (*italicized information added*).

> "(*The executive director)* will not issue the SEZ Prohibition Exemption and Construction NPDES permit for the Blackwood (*Reach 1 project)* until he reviews the evaluation report *(to be produced by the LTBMU)* and agrees that the LTBMU SEZ project *(completed on Reach 6 in 2009)* cannot be linked to the increase in fine sediment particles *(in 2009 and 2010)* from Blackwood Creek into Lake Tahoe as determined by LTIMP data *(as displayed in graphs produced by UC Davis*)."

The LTBMU, with assistance from a geomorphic review team and USFS Regional Office staff, determined that the appropriate analysis to conduct to address the above stated concern, should focus on whether there have been changes in fine sediment concentrations, or change in the relationship of fine sediment concentrations vs. flow when comparing construction and immediately post-project data, to historic data acquired prior to construction. We also provide an analysis of the relative scale and nature of suspended sediment transport and deposition mechanisms within the watershed during and after construction.

A follow-up comprehensive evaluation of Reach 6 project effectiveness, related to the Blackwood Geomorphic TMDL Indicators as well as aquatic habit metrics, is scheduled to be completed in the winter of 2012/2013.

II. Previous Analysis and Reporting of Construction Impacts

Previous project construction reports documenting visual and water quality monitoring data during and immediately post construction of the Reach 6 project have been presented to Lahontan, as required by the project NPDES permit (USFS 2008, USFS 2009a, and USFS 2009b)**.** These reports indicate that there were some instances of exceedances of turbidity standards during construction, as well as immediately post construction during the October 13/14, 2009 storm event. However these exceedances were relatively small in frequency and duration (maximum turbidity levels measured was 137 NTUs, most around 5 NTUs).

These reports also indicate that there was little visual evidence of accelerated channel erosion in the constructed reach, beyond the type of adjustments which was expected in the low flow channel during high flow events. The one exception to this was a channel avulsion that occurred below the constructed reach in the spring of 2009, which is further described later in this report

The full post-construction reports are posted on the LTBMU website, and should be consulted for further information regarding these monitoring results.

III. Existing Post-Project Effectiveness Monitoring Analysis

The following presents results from a thesis in progress, prepared by a current USFS employee, Dave Immeker, for a Master's program at Utah State University. This paper presents a quantitative analysis of the effectiveness of the stream channel and floodplain restoration project, based on modeling and field measurements of the extent of increased flooding, reductions in sheer stress on channels banks, and volume of sediment deposition in the floodplain. The results presented in this draft thesis are summarized below.

Changes in Floodplain Plain Area Inundation

The restoration work in Blackwood Creek Reach 6 has increased the extent of overbank flooding in the reach, ranging from 25 to 100%, depending on streamflow. Using a combination of channel measurements and aerial photos to derive input parameters, the area of inundation that occurred at different flow volumes in the restored reach was modeled using HEC-RAS and HEC Geo-RAS software, for both pre and post-project. The results show that the 1.5-year flow (the smallest peak flow modeled for this project) had the greatest increase in area inundated by water with a nearly 100% increase between pre-restoration conditions and post-restoration conditions. At higher, less frequent flows, the difference in flooded area between pre-restoration conditions and post-restoration conditions was less (approximately 25%), but the post-restoration project still produced a larger area of flooding. Modeled results are displayed in Table A1. Overbank flooding creates flow conditions that result in deposition of fine sediments, which is discussed further below.

Changes in Channel Sheer Stress

Restoration has also decreased the relative sheer stress in Reach 6, decreasing the potential for channel bank erosion. The HEC-RAS model was also used to calculate the mean cross section shear stress for each modeled flow for both pre-project and post-project conditions. The results show mean cross section shear stress was 50 to 100% less for the post-restoration conditions for all flows modeled.

Volume of Sediment Deposition and Scour

Within the first six months following construction, the constructed reach experienced large flow events. During a fall storm in October of 2009, and during the spring snowmelt of 2010, Blackwood Creek Reach 6 saw peak flows of 750 cfs and 413 cfs respectively. After spring flows dropped in 2010, areas of scour and deposition were observed within the project area. In order to document the changes that occurred, the areal extent and average depth of areas of scour and deposition was mapped, to calculate the volume of material eroded and deposited in the restored reach.

This analysis estimates that 1,129 m^3 of deposition occurred within the project area, compared to 142 m^3 of scour. The table below illustrates the estimated mass of deposition and scour that occurred in the project reach, by grain size, and Figures A1 and A2 displays areas of deposition and scour graphically. Note that the amount of sediment deposited exceeds the amount scoured in each sediment category.

	Gravel+	**Sand**	**Silt**	**Clay**	**Total**
Total Weight in Deposit (tonnes)	623	776	114	28	1,541
Total Weight in Scour (tonnes)	188	83	7	3	281

Table 1. Weight in tonnes of the gravel and coarser, sand, silt and clay in the areas of deposit and scour.

This analysis estimates that after deducting the amount of scour from the amount of deposition there was a net aggradation of 132 tonnes of silt and clay sized particles (<0.063 mm) captured in the restored reach after the spring runoff of 2010. In an analysis produced by Waterways and River Run Consulting (Waterways and River Run, 2011), it is estimated that approximately 61 tonnes of fine sediment (<0.063 mm) was scoured annually from this reach prior to restoration. Although it is impossible to know what level of erosion (scour) might have occurred if the project had not been constructed, the restored reach has fundamentally changed from one dominated by channel erosion processes, to one that is now dominated by floodplain deposition processes. Maps and Tables of the sediment mapping analysis presented above are provided in Appendix A.

IV. Post-Project Rapid Geomorphic Assessment

To assist in the evaluation of current sediment transport processes in the Blackwood Watershed, including the evaluation of the relative contribution of the restored Reach 6 erosion processes relative to overall watershed response, the LTBMU convened a team of independent experts in the field of geomorphology and sediment transport processes to conduct a qualitative “rapid” geomorphic assessment in October of 2011. Several members of this team have conducted independent research in the Blackwood watershed, and therefore have a high degree of familiarity with the history of past erosion processes within this watershed. The assessment consisted of one day in the field to visit various locations in the Blackwood watershed, and a half day in the office discussing methods for analyzing existing water quality and other data to provide a quantitative estimate of project construction impacts.

The Team was unanimous in its conclusion based on the visual tour of the restored Reach 6 project, that sediment deposition is the current dominant fluvial process observed within the restored reach. The team observed numerous areas where substantial amounts of both course (cobbles and gravels) and fine sediment (silts and clays) deposition is occurring within the active floodplain of the restored reach. This is the area of floodplain that was constructed to receive overbank flows outside of the bankfull channel within a two to five year recurrence level. The team also commented that the coarse sediment deposition is building up the active floodplain in the restored reach, and that fine sediment deposition should increase as the active floodplains adjacent to the channel continue to build and floodplain vegetation develops.

The team also observed the degree of erosion along the high terrace cutbanks has been reduced. The term high terrace refers to the relic floodplain, which has become hydrologically disconnected as the channel has incised over time. Only two relatively short lengths (totaling about 150ft) of unstable fine sediment terrace cut banks were observed, where active erosion of terrace cutbanks is still occurring. The team also observed that channel roughness has been dramatically increased by restoration efforts, particularly where high flows would reach the outside meanders of the stream channel. This increased channel roughness reduces stream channel velocities, attenuates peak flows, and increases overbank flows and deposition.

The above observations are in stark contrast to the condition of this reach pre project, which was dominated by a much straighter channel, bordered by large sections of unstable fine sediment terrace cut banks, with no visible processes of flood plain development.

For a full discussion of the results of this exercise, please refer to Appendix B of this report.

V. Post-Project Construction Impact Data Analysis

The data analysis to evaluate the impacts of the construction of the Reach 6 project consists of two separate analyses, as suggested by the Geomorphic Assessment Team described in the previous section as well as recommendations from Regional USFS staff. The methods and results of these analyses are presented in this section.

A. Calculation of Suspended Sediment (SS) Loss Related to Construction of the Reach 6 Project

This analysis presents a calculation of estimated suspended sediment (SS) loss based on measured areas of disturbance within the project reach during water years 2009 and 2010, in comparison to total annual SS loads. These calculations are presented in Appendix C, and the following discussion summarizes the results of these calculations.

The total annual SS load for Blackwood as displayed in the UC Davis graphs provided by Lahontan to the USFS, was approximately 4,000 tonnes in 2009 and 3,000 tonnes in 2010. Suspended sediment is defined as sediment particles < 2mm in size.

To develop an estimate of the SS loss related to construction of the Reach 6 project, we first calculated the volume of SS that may have been detached and flushed from constructed project alluvial surfaces as surfaces were inundated by storm flows and spring peak flows. This redistribution of the smaller particles located in-between the larger gravel and cobble alluvial material is a phenomena described in the scientific literature as “winnowing”. We estimated that the total volume of SS material that may have been transported from this reach through this process was 0.9% of total annual load in 2009 and 4.8% of total annual load in 2010.

Next we estimated the volume of SS that was eroded from the Reach 6 project as a result of a channel avulsion that occurred in the spring of 2009, within the alluvial substrate below the constructed reach. During this event, the streamflow was diverted out of the main channel, cutting a new channel through the adjacent coarse-grained alluvial deposits in the lower floodplain. This avulsion occurred as a result of the project, because the grade control constructed at the bottom one third of the restored reach constructed in 2008, failed during the 2009 spring peak flows (USFS, 2009a). We estimate that during spring peak flows in 2009, the SS lost from the reach through this avulsion may have been 10% of the total annual SS load in 2009.

We then estimated the volume of SS that was eroded from a high terrace cutbank during that same spring runoff period, located approximately 300 meters downstream of the restored reach. This high terrace cutbank erosion, consisting of primarily fine grained sediments, was unrelated to restoration project activities, and typified the type of erosion exhibited in this reach prior to restoration. We estimate that during spring peak flows in 2009, the SS lost from this section of high terrace cutbank erosion may have been 8% of the total annual SS load in 2009.

Figure 1: Looking downstream at avulsed channel reach (left photo) and high terrace cutbank (right photo), eroded during spring of 2009.

The estimated volume of SS captured by the project was calculated by subtracting the volume of mapped SS deposition, from the amount of measured SS channel bank erosion, using the data presented in Section III, table 1. From these data, we estimate the amount of SS captured, was 825 tonnes. When compared to the 3,000 tonnes UC Davis estimated for Blackwood creek total annual SS load in 2010, this means SS loading to the Lake could have been 27% greater in 2010, if the project had not captured this sediment.

As can be seen by Appendix C there are many assumptions that went into these calculations. Nevertheless we believe they represent a conservative estimate of the potential contributions to SS loading to the Lake, originating from Reach 6 during and the first season post-construction.

B. Fine and Suspended Sediment Statistical Data Analysis

It was difficult to determine what type of statistical analysis would be most useful in determining whether there were significant changes that occurred in Blackwood Creek as a result of the restoration project as it relates to the transport of both fine (particles <.063 microns) and suspended (particles < 2mm) sediments. We asked for outside assistance with this analysis, and the results are presented in Appendix D and E. In all the analysis described below, the period of record for the pre-project dataset extended up until September of 2008. The period of record for the post-project dataset extended from September 2009 through October of 2010. Suspended sediment data were obtained from the publicly available USGS website, and fine sediment data were obtained from UC Davis. Because UC Davis is still working on graduate theses in progress utilizing this data, they have requested that the raw data not be presented in this report.

Barry Hill, the USFS Regional Hydrologist, provided assistance by conducting statistical analysis to determine if;

1) fine sediment particle numbers or instantaneous fine sediment loads from the Blackwood watershed increased significantly in Blackwood Creek during and the first season after implementation of the Reach 6 restoration project, when compared to the pre-project data,
2) there were differences between the pre and post data sets in Blackwood when compared to the same time periods in Ward Creek. Ward Creek is the most similar watershed to Blackwood Creek in the Tahoe Basin in terms of watershed characteristics, and
3) there were differences in the pre and post suspended sediment transport curves for both watersheds.

The statistical results of this analysis are contained in Appendix D. No statistically significant increase in either fine sediment particle numbers or instantaneous fine sediment loading were detected when comparing the pre-project, to the during/after project data sets. His analysis also determined there was no significant change in suspended sediment vs. flow relationships, in Blackwood Creek as a result of the Reach 6 restoration project. Statistical significance was determined at the 90% confidence limit. Mr. Hill’s analysis therefore rejects the hypothesis that the restoration increased releases of fines sediment from Blackwood Creek.

In addition we asked assistance from Larry Green, Statistics Instructor and Co-Chair of the Mathematics Department from Lake Tahoe Community College. Mr. Green was asked to determine an appropriate procedure, and assist with a statistical comparison of fine sediment vs. flow regressions. Mr.Green used the Quade’s procedure to compare the regression lines between the before project data set, and the during/after project data set. This analysis is presented in Appendix E. No statistically significant difference was detected between the fine sediment regression lines of the before data set when compared to the during/after project implementation data set, at the 90% confidence limit. Mr. Green’s analysis therefore also rejects the hypothesis that the restoration increased releases of fines sediment from Blackwood Creek.

Also presented in Appendix E are the scatter plots and calculated regression equations for fine sediment particle vs. discharge, after log conversions (produced by the LTBMU using Sigmastat software). It should be noted that the regression lines were weak for both data sets, with an R squared value of 0.306 for the before data set and R squared value of 0.506 for the during/after implementation data set.   Mr. Green also performed a Technical Review of all the analysis presented in this report, and found that the conclusions are statistically justified.

VI. Summary and Conclusions

Visual interpretations of the fine sediment loading graphs produced by UC Davis led to a concern from Lahontan staff that fine sediment particle loading may have increased from Blackwood Creek as a result of the Reach 6 restoration project. These were not substantiated by the analysis provided in this report.

In fact, the visual observations and measured data provided in this report indicate that substantial retention of sediment particles on restored floodplain surfaces has already been realized as a result of the project and that the restored reach has fundamentally changed from one dominated by channel erosion processes, to one that is now dominated by floodplain deposition processes.

Fine sediments were likely mobilized as a result of project construction through winnowing of fine and suspended sediments on constructed surfaces, as well as through undesired channel adjustments resulting from the project. However the magnitude of these short-term inputs was demonstrably minor in comparison to natural erosion processes and overall watershed response. Based on estimates of pre-project erosion rates and post-project deposition provided in this report, it is reasonable to conclude that fine and suspended sediment loading from Blackwood Creek in 2010 and 2011 would have been greater, if the project had not been constructed.

Statistical analysis found no significant measurable difference between pre-project and during/post project data at the watershed scale, in terms of fine sediment particle numbers, fine sediment loading, fine sediment vs. flow regressions relationships, or suspended sediment vs. flow regressions relationships. These findings were determined at the 90% confidence limit.

It is expected that continued monitoring of Blackwood Creek will show over time a statistically significant reduction in fine sediment observed at the watershed scale, as a result of restoration efforts throughout the watershed. A reduction in fine sediment loading in Blackwood Creek will contribute to reaching the specific Lake Tahoe TMDL reduction milestone for stream channel sources.

VII. References

Immeker. D. 2011. DRAFT: The Blackwood Creek Reach 6 Restoration Project's Influence on Reach Scale Sediment Scour and Storage Characteristics. Utah State University, Department of Watershed Sciences.

Water Ways and River Run. 2011. Technical Memo: Restoration in Blackwood Creek Reach 6; Initial Monitoring Results and Analysis. Water Ways and River Run Consulting. Santa Cruz, CA.

Rabidoux, A. 2005. Spatial and Temporal Distribution of Fine particles and Elemental Concentrations in Suspended Sediments in Lake Tahoe Streams, California-Nevada. University of California Davis, Office of Graduate Studies, Civil Engineering.

USFS. 2008. Letter to Lahontan, Blackwood Phase 3A, 2008 Implementation Monitoring Report. Lake Tahoe Basin Management Unit.

USFS. 2009.(a) Blackwood Phase 3A, 2009 Peak Flow and Geomorphic Monitoring Field Notes. Lake Tahoe Basin Management Unit.

USFS. 2009.(b) Blackwood Phase 3A, 2009 Implementation Monitoring Report. Lake Tahoe Basin Management Unit.

Appendix A

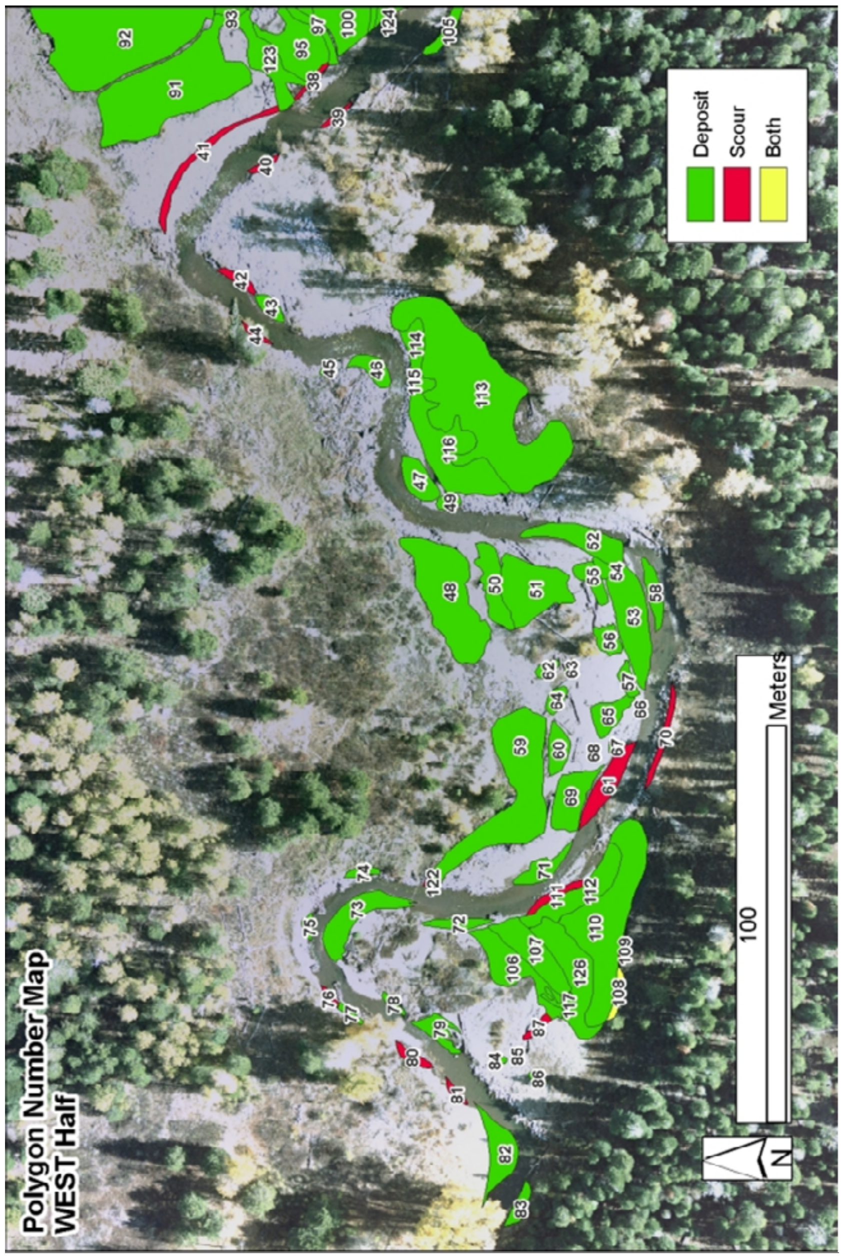
Selected Figures and Tables from Dave Immeker's Thesis, in Progress

. Event	Flow (m^3/s)	Pre-Restoration Flooded Area (m^2)	Post-Restoration Flooded Area (m^2)	Increase or Decrease in Flooded Area after Restoration	Change in Flooded Area (m^2) from Pre-Restoration to Post-Restoration	% Change
1.5-year peak	7.5	14,836	29,394	Increase	14,558	98%
2-year peak	10.5	16,540	31,640	Increase	15,100	91%
2.3-year peak (spring 2010 peak)	11.7	17,150	32,276	Increase	15,126	88%
3-year peak	16.0	19,951	34,188	Increase	14,237	71%
4-year peak	19.5	22,952	35,566	Increase	12,614	55%
5-year peak	29.2	29,731	41,374	Increase	11,643	39%
10-year peak	53.1	39,237	50,235	Increase	10,997	28%
15-year peak	58.3	41,377	52,004	Increase	10,626	26%
20-year peak	63.1	43,664	54,379	Increase	10,715	25%

Table A1. Comparison of the modeled flooded area between the 2007 pre-restoration conditions and the 2010 post-restoration conditions for a given flow.

		Mean Cross Section Shear Stress			
Event	Flow m^3/s	Pre-Restoration (N/m^2)	Post-Restoration (N/m^2)	Increase or Decrease in Shear Stress after Restoration	Percent change
1.5-year peak	7.4	43.0	29.0	Decrease	-48%
2-year peak	10.4	49.2	30.8	Decrease	-60%
2.3-year peak (peak flow of spring 2010)	11.7	51.8	31.7	Decrease	-63%
3-year peak	16.0	58.1	34.0	Decrease	-71%
4-year peak	19.5	61.5	37.5	Decrease	-64%
5-year peak	29.2	70.4	40.5	Decrease	-74%
10-year peak	53.1	93.1	48.0	Decrease	-94%
15-year peak	58.3	97.5	48.6	Decrease	-100%
20-year peak	63.1	100.7	50.2	Decrease	-100%

Table A2. Comparison of mean cross section shear stress modeled in HEC-RAS for pre-restoration conditions and post-restoration conditions for a range of flows.



Polygon Number Map
WEST Half
Deposit
Scour
Both
100
Meters
N

Figure A1: Areas of Sediment Deposition and Scour in Upper half of Blackwood Creek Reach 6
(#'s identify polygons, refer to Table A1).

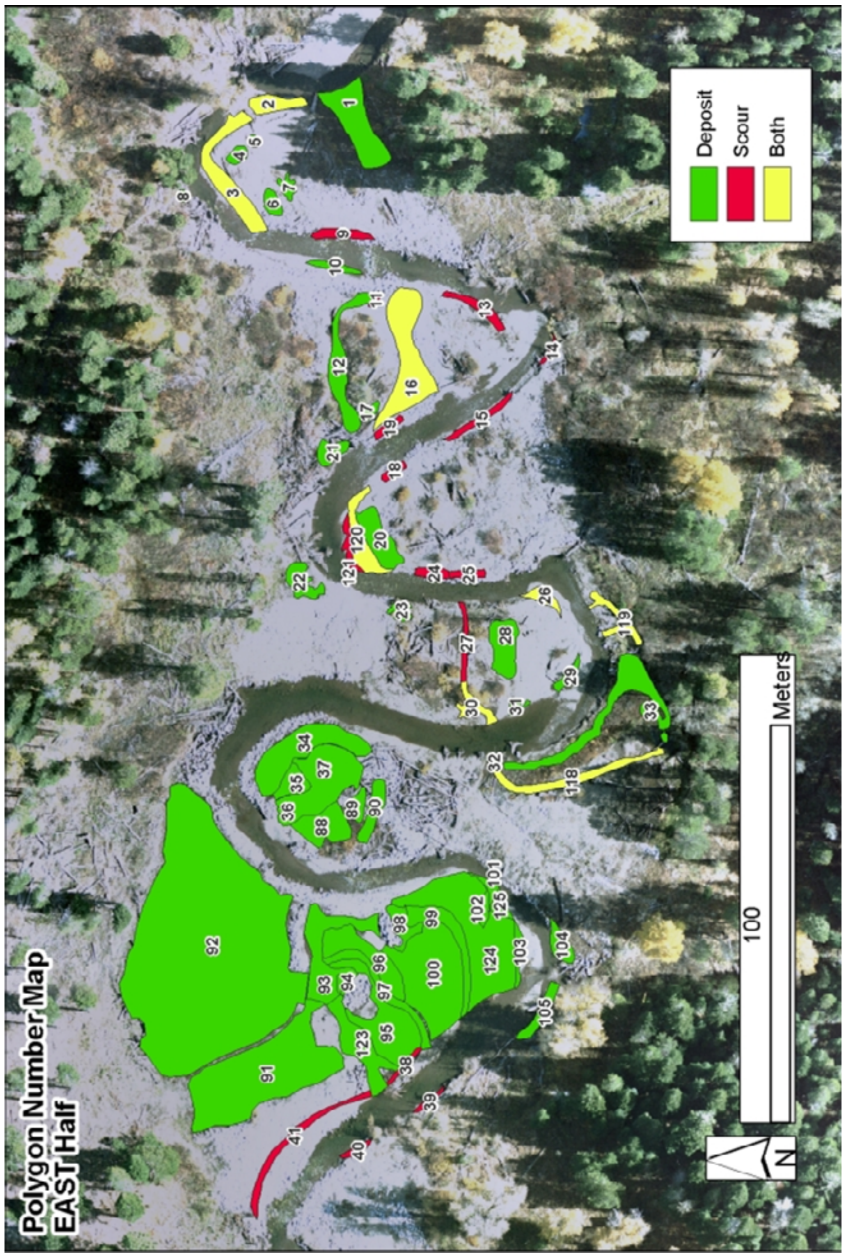


Figure A2: Areas of Sediment Deposition and Scour in Lower half of Blackwood Creek Reach 6

(#'s identify polygons, refer to Table A1).

Appendix B

Blackwood Canyon Rapid Geomorphic Assessment Notes

Prepared by Susan Norman, USFS

October 25 and 26th, 2011

Geomorphic Assessment Team:

Dr. Andrew Simon, Cardno Entrix
Tim Abbe, Geomorphologist, Cardo Entrix
Mike Nolan, USGS (retired)
Dr. Andrew Stubblefield, Humboldt State University
Matte Kiesse, Geomorphologist, River Run Hydrology Consulting
Cindy Wolke, Geomorphologist, California State Parks

USFS Observers: Sue Norman and Craig Oehrli, Hydrologist, US Forest Service. Notes

Purpose

The purpose of this assessment was to review historic information and visit various locations in the Blackwood Creek watershed to assess the current major sediment transportation and deposition processes currently in evidence throughout the watershed. The team visited the "badlands" area in the upper watershed, and Reach 6 upper, Reach 4 lower, and Reach 1 of the main stem of Blackwood Creek. From these observations a general qualitative assessment was documented through team observations regarding the location and relative magnitude of sediment transport and deposition areas as evidenced by indicators of geomorphic and upland erosion and deposition processes. This assessment considered how these processes relate to sediment loading data collected through the LTIMP tributary monitoring program, at the mouth of the Blackwood Canyon watershed. Because several team members have an extensive history of conducting there own independent research in this watershed, they had the capability to bring a long-term perspective.

Observations

The team found no qualitative evidence that sediment transport processes within the "badlands" areas of the upper watershed of Blackwood Canyon has changed from that described in previous published analysis of the watershed (Nolan, 1991). This area continues to be largely un-vegetated. The dominant erosion process is slow weathering of bed rock materials (sheet wash and small rills), although there is evidence of "debris slides" on some of the steeper slopes. The contribution to watershed sediment loads is probably consistent, including rates of erosion in response to extreme events, with the 3.8% of total sediment watershed loads (particles less than <2mm) published in the Nolan study. The steep unvegetated slopes in these areas likely contribute to the relatively unique flashy peak flows exhibited in this watershed, as compared to other Basin watersheds.

In the future, the LTBMU will look at CDMG map and aerial photos of areal extent of vegetation over time to further validate this observation.

Flashy peak flows continue to create high energy flow events in Blackwood stream channels, and it is likely that the main stem channel bank erosion is still the highest contributor of sediment from the watershed. (*The Nolan report estimated 65.9% of total sediment load from Blackwood was generated from Blackwood stream channel banks and 30.6% from stream beds. Of total stream channel erosion, 2/3 originated from the main stem of Blackwood Creek, with the remaining 1/3 originating from tributaries. A recent study conducted by Andrew Simon estimated that about 25% of the fine sediment delivered to the lake from watershed outlets emanates from stream bank erosion when compared to the total fine-loadings calculated in the report (5,206 T⁄ year). This study estimates that 20% of all fine sediment delivered to Lake Tahoe comes from the banks of the Upper Truckee River and Blackwood Creek. (Simon, 2008)*)

Based on observations of team members familiar with how the main stem Blackwood Channels looked when they were conducting field work associated with their past studies (1980s through mid 2000), channel characteristics in terms of incision and bank erosion appears to look no worse than in the past, and in many areas appears better. There was an area of channel visited in lower Reach 4, where relatively large scale active bank erosion is still in evidence.

The Team was unanimous in its conclusion based on the visual tour of the restored Reach 6 project, that sediment deposition is the current dominant fluvial process observed within the restored reach. The team observed numerous areas where substantial amounts of both course (cobbles and gravels) and fine sediment (silts and clays) deposition is occurring within the active floodplain of the restored reach. This is the area of floodplain that was constructed to receive overbank flows outside of the bankfull channel within a two to five year recurrence level. The team also commented that the coarse sediment deposition is building up the active floodplain in the restored reach, and that fine sediment deposition should increase as the active floodplains adjacent to the channel continue to build and floodplain vegetation develops.

The team also observed the degree of erosion along the high terrace cutbanks has been reduced. The term high terrace refers to the relic floodplain, which has become hydrologically disconnected as the channel has incised over time. Only two relatively short lengths (totaling about 150ft) of unstable fine sediment terrace cut banks were observed, where active erosion of terrace cutbanks is still occurring. The team also observed that channel roughness has been dramatically increased by restoration efforts, particularly where high flows would reach the outside meanders of the stream channel. This increased channel roughness reduces stream channel velocities, attenuates peak flows, and increases overbank flows and deposition.

The above observations are in stark contrast to the condition of this reach pre project, which was dominated by a much straighter channel, bordered by large sections of unstable fine sediment terrace cut banks, with no visible processes of flood plain development.

The Team had no means to assess, based on observations during this field trip, the relative contribution of sediment to total watershed loads that may have occurred immediately following Reach 6 construction. Construction related erosion in the 2009 water year would primarily have occurred as a result of turbid flow releases during construction, the winnowing of sand size and smaller sediment particles from constructed stream channel and floodplain surfaces (1/3 of reach restored) during the first flush events, and the channel avulsion that occurred below this reach during spring runoff of 2009. Construction related erosion in the 2010 water year would have occurred as a result of the winnowing of sand size and smaller sediment particles from constructed stream channel and floodplain surfaces (remaining 2/3 of reach restored) during the first flush events that occurred after complete project construction (October 2009 storm event, and 2010 spring runoff). There is no reason to expect that construction related erosion and loading would continue beyond the 2010 water year.

Analyzing Short-Term Construction Effects

The team suggested that the following analysis of sediment, flow, and cross section data could be conducted to determine whether restoration actions during and immediately post construction, had an overall measurable adverse effect on watershed sediment loads during the 2009 and 2010 water years.

Sediment Concentration Curves

Determine if sediment concentration curves changed during the 2009 and 2010 water years when compared to pre-construction periods. Post construction curves should be compared to the pre-construction periods. The 1997, 40-50 year frequency flow event and the 20-25 yr frequency flow event in 2006 may have influenced overall watershed channel erosion rates. This analysis would determine whether there were higher concentrations of sediment at given flow rates during the period of project construction, as opposed to that measured before the project. This analysis should also be conducted and compared to the Ward Creek watershed. Ward Creek is most appropriate watershed in the Tahoe Basin for base line comparisons to Blackwood, because of their similarity in watershed characteristics. Comparing double mass sediment load curves between Ward and Blackwood would provide a comparison of the relationship of total suspended sediment loads between the two watersheds over time.

Calculation of Suspended Sediment Loss Volume

Calculate volume of suspended sediment loss that likely occurred during first flush of restored reach, for both the upper one third of the reach restored in water year 2008, and the bottom two thirds of the reach restored in water year 2009. Calculate area of restored surfaces, and estimate depth and % of suspended sediment of restored surfaces. Compare volume of load to total suspended sediment watershed load during WY 2009 and WY 2010.

Comparison of Project WQ Data

Compare the turbidity measurements at the restored reach during the October 13/14, 2009 storm, to total suspended sediment measured at the mouth during the same time period. Convert turbidity measured above and below the reach during the October storm to estimate suspended sediment concentration using a calculated conversion factor based on historic Blackwood data

(Stubblefield, 2006). This October storm was 25 yr precipitation event, resulting in 8.5 inches of rain over a 24 hour period.

<u>Other Team observations and suggestions</u>

- Should add following monitoring component to long term effectiveness monitoring program to determine to what degree has overall main stem and tributary channel degradation (channel widening and incision) continued to occur, between 2007 and 2012. Where did channel degradation occur, and what was the relative contribution of the degrading reaches to overall watershed sediment loads? Compare cross section data measured in 2006 by Andrew Simon, to cross section data collected at those same locations in 2012 by the LTBMU. LTBMU will need to acquire Andrew Simon's data, and GPS locations. Separate bed from bank scour in cross section analysis. These cross sections should be measured every 5 to 10 years by either the LTBMU or its partners to maintain this data set that was originated in 1984, with the Nolan Study.

- When conducting analysis of Blackwood data, and comparing results to other Tahoe watersheds, it is important to consider the unique characteristics of the Blackwood watershed compared to other watersheds in Lake Tahoe. Blackwood has responded to human disturbance differently, because of a combination of steep slopes, volcanic geology, and the nature of human disturbance patterns. Ward can be a control in that geology is similar, however watershed response is different because Blackwood is still responding and recovering from the effects of a large scale in-channel gravel mining operation in the 60's. General creek has different geology (granitic, resulting in predominantly eroding sand in channel bed rather than cobbles and gravels), and although was affected by logging and grazing, also never experienced the scale of human disturbance experienced in Blackwood due to the gravel mining.

  This means that the erosion and sediment loading response within this watershed from rainfall and snowmelt events will be unique and will likely not follow the patterns observed in other watersheds. This needs to be considered when attempting to compare the water quality response in Blackwood to that observed in other watersheds. There are numerous instances where this is obvious in the data record. This should be pointed out in your analysis.

- Suggest that low-tech solutions (i.e. coffee bags filled with coarse alluvium) could be used to stabilize the toe of the two sections of unstable banks in the restored reach. Use BSTEM model to calculate height /design.

Appendix C

Estimate of Construction Impacts to Suspended Sediment Loading

Estimate of Possible Impacts to Suspended Sediment Loading From Blackwood Creek Reach 6 Restoration			
	2009	**2010**	Units
Assumptions			
Flow volume for calculated area of water contact	400	400	cfs
Reconstructed bankfull channel area of water contact	3025	10579	m2
Reconstructed Floodplain Area of water contact	1495	7805	m2
Depth of available suspended sediment, from "winnowing" is 1 inch (0.0254 m)	0.0254	0.0254	m2
Bulk density of 1.03 tonnes/m3 from Hill and Nolan*	1.03	1.03	tonnes/m3
Percent < 2 mm in alluvium, based on Tetratech Analysis, 1999	30%	30%	
Percent < 2 mm in high terrace cutbanks, based on Hill and Nolan, 1991.	80%		
Suspended sediment (SS) is defined as particles <2mm			
SS material is completely eroded from site and delivered to mouth			
Measured floodplain deposition minus measured scour, equals amount of sediment captured by project (from Immeker, 2011)			
Results -Winnowing of fines from constructed surfaces			
Volume eroded	114.8	467.0	m3
Mass eroded	118.3	481.0	tonnes
Mass of sed < 2 mm (30% of total mass)	35.5	144.3	tonnes
Blackwood Annual SS Load 2009 and 2010	4000	3000	tonnes
% of Total annual SS load winnowed from constructed surfaces	**0.9%**	**4.8%**	
Results- Avulsed Channel eroded below restoration in WY2009			
Volume eroded	1313.0		m3
Mass eroded	1352.4		tonnes
Mass of sed < 2 mm (30% of total mass)	405.7		tonnes
% of Total annual SS load eroded from avulsed channel reach	**10%**		
Results- Eroded terrace cutbank, .5 mile below active project in 2009			
Volume eroded (from USFS 2009 Report)	393.0		m3
Mass eroded	404.8		tonnes
Mass of sed < 2 mm (80% of total mass)	323.8		tonnes
% of Total annual SS load eroded from Reach 6 terrace cutbank, unrelated to project	**8%**		
Results- Suspended Sediment captured by project after construction			
Mass of sed < 2 mm captured (from Immeker, 2011)		825.0	tonnes
% increase in total SS load, if not captured by project		**27.50%**	
*Measurements taken of bulk density for bank material from cross sections taken in this area			
Sediment Source Data, Four Basins, Lake Tahoe California and Nevada			
** Area of eroded high terrace cutbank 91m long, by 1.2 to 2.4 m wide (ave 1.8 m), by 2.4 m deep.			
** Area of avulsed channel, calculated in AutoCAD. Approximate dimensions, 92 m length, 9.5m wide, and 1.5 m deep.			

Appendix D

Fine sediment load analysis for Blackwood Creek Riparian Restoration Project, Lake Tahoe Basin Management Unit, 2002 thru 2010
(Excerpted)

Barry Hill, Regional Hydrologist

January 4, 2012

A. Wilcoxin Rank Sum Test and Rank Transform Test

This analysis presents a non-parametric comparison of the before and after data sets to determine whether there were significant differences. This was done for both the Blackwood watershed as well as the Ward Creek watershed. The confidence level used to establish significance is 90%, i.e. $P \leq 0.10$.

Blackwood Creek

- The median fine sediment particle concentration (numbers of particles per mL, or #/mL) was 53,208 before restoration and 70,184 during and after restoration , and were not significantly different (Wilcoxon rank sum test, p=0.22).
- Median streamflows were not significantly different (Wilcoxon rank sum test, p=0.17).
- Instantaneous fine sediment loads were not significantly different (rank transform test, p=0.67).
- Fine sediment particle loads during or after restoration were not significantly different from particle loads corresponding to the same range of streamflow (1.3 to 455 cfs) before restoration (rank transform test, p=0.97).

Ward Creek

- The median fine sediment particle concentration (#/mL) was 48,097 before restoration began in Blackwood Creek and 56,962 during and after restoration, and were not significantly different (rank transform test, p=0.38).
- Median streamsflows were not significantly different (rank transform test, p=0.13).
- Instantaneous fine sediment particle load (#/s) were not significantly different (rank transform test, p=0.94).

B. 2-way ANOVA

This analysis compares the before and after fine sediment loads at Blackwood with the before and after fine sediment loads at Ward.

- Results of the 2-way ANOVA indicate that neither time period (p=0.57) or watershed (p=0.12) produced significant differences in fine-sediment loads.

C. Confidence intervals for slopes of STCs

This analysis compares the *suspended sediment* transport curves (STCs) of the before and after data sets at both low flows and high flows. Both streamflow and sediment data were log-transformed prior to developing the STCs. Inspection of the STCs developed using all data for each period showed that more reasonable representations would result from dividing the data into low flow (streamflow less than or equal to 10 cfs) and high flow (>10 cfs) groups. Data for a large flood in the 2006 water year were considered unrepresentative outliers and were removed from the sample pool prior to analysis. To reduce the likelihood of serial correlation, randomly selected subsamples (100 samples for the before restoration period, and 40 samples for the shorter during and after restoration period) were used in the analyses.

- The confidence intervals for the low-flow STCs for both Blackwood (Table 8) and Ward Creeks (Table 9) before and during/after restoration all ranged from below to above zero, indicating that none of these low-flow STCs represent significant relations ships between streamflow and suspended-sediment concentrations. In other words, streamflow and suspended-sediment concentrations at low flows are not significantly related for either stream in either time period. In addition, the confidence intervals for the slopes all overlap, indicating no significant differences in these relations based on time period (before or during/after restoration) or watershed.

- At high flows, relationships between streamflow and suspended-sediment concentrations were significant for both streams and both time periods (Tables 8 and 9). However, the confidence intervals for the slopes all overlap, indicating no significant differences in these relations based on time period (before or during/after restoration) or watershed.

Table 8: 90% confidence intervals for slopes of sediment transport curves for Blackwood Creek before and during/after restoration

Streamflow range	Before restoration	During/after restoration
Low (< or = 10 cfs)	-1.10 to 2.52	-1.05 to 2.58
High (>10 cfs)	0.88 to 1.74	0.29 to 1.80

Table 9: 90% confidence intervals for slopes of sediment transport curves for Ward Creek before and during/after restoration

Streamflow range	Before restoration	During/after restoration
Low (< or = 10 cfs)	-0.59 to 1.26	-0.71 to 1.44
High (>10 cfs)	0.83 to 1.76	0.38 to 1.89

Appendix E
Comparison of Fine Sediment Particle # vs. Q Regression Lines
Prepared by Larry Green, LTCC
And
Fine Sediment Scatter Plots and Regression Equations
Prepared by Sue Norman, LTBMU

Quades test procedure is done as follows:

1. Rank the composite data by cfs (or log cfs, the ranks will be the same) and save these ranks as X.
2. Rank the composite data by fine sediment particle #s (or log fine particles, the ranks will be the same) and save these ranks as Y.
3. Regress on X vs Y.
4. Calculate the residuals.
5. Perform an ANOVA (or equivalently a t-test since there are only two data sets) on the before vs. after residuals.

Before data includes up to 9/25/2008, after (during) restoration includes data after that date, through 11/3/2010.

Analysis of Variance results:

Residuals	n	Mean	Std. Error
Before Restoration	169	-3.5831	4.550412
After Restoration	69	8.77051	8.44047

ANOVA table

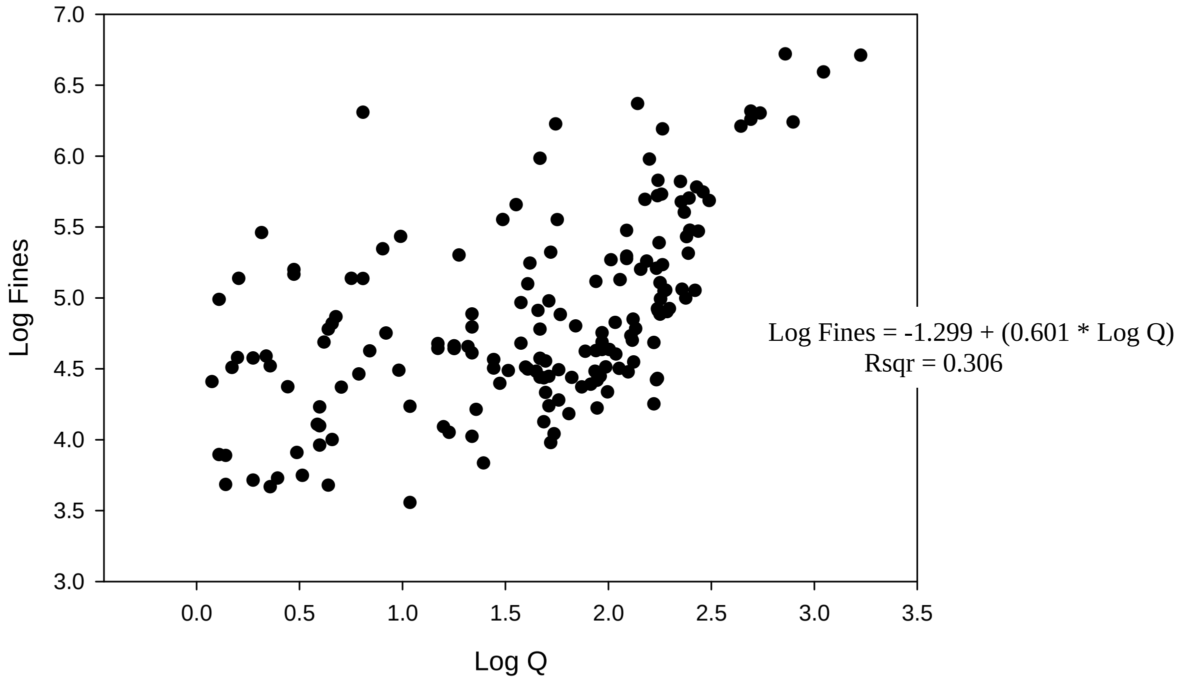
Source	df	SS	MS	F-Stat	P-value
Treatments	1	7477.28	7477.2817	1.914	0.168
Error	236	922157	3907.4456		
Total	237	929634			

Tukey 95% Simultaneous Confidence Intervals

Before Restoration Residuals subtracted from After Restoration Residuals

Difference	Lower	Upper	P-value
12.35357	-5.2398	29.946898	0.168

Blackwood Before (all data)



Blackwood After (all data)