Monitoring Road Decommissioning in the Mann Creek Watershed: Post-storm Report

Payette National Forest

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Executive Summary

The USFS, Rocky Mountain Research Station (RMRS) and Intermountain (INT) Region, Pacific Northwest Region (PNW), Pacific Southwest Region (PSW) and the Northern Region (NR) are monitoring a sample of the road decommissioning and maintenance projects to assess their effectiveness in reducing impacts and risks to key watershed processes. Risk profiles are being developed and compared, before and after road treatments, with the Geomorphic Road Analysis and Inventory Package (http://www.fs.fed.us/GRAIP). This suite of robust inventory and analysis tools evaluates the following road impacts and risks: road-stream hydrologic connectivity, fine sediment production and delivery, shallow landslide risk, gully initiation risk, stream crossing failure risk, and drain point condition.

Since FY 2009, inventories have been conducted at eight sites in the Intermountain Region. A site consists of a group of road segments totaling four miles treated with either decommissioning or Storm Damage Risk Reduction (i.e., stormproofing). Post-storm inventories have been collected at four of these sites during FY2010. This report focuses on how decommissioning work implemented by the Payette National Forest in the Mann Creek watershed compared to untreated control roads following a significant storm event. At the Mann Creek sites, treatments included removal of culverts and fills at stream crossings and recontouring of the road prism.

Following a significant storm event, hydrologic flowpaths on treated roads remained diffuse, and storm-related damage consisted of rills and small gullies within the recontoured road prism. Storm damage on untreated roads involved gullied wheel tracks and ditches, formation of non-engineered drains and erosion of fill materials, gully formation, and general degradation of the road surface.

Predictions of sediment production and delivery confirm the reductions predicted following treatment on the treated roads; however, along control roads, modeled sediment delivery increased from 16.6 Mg/yr to 54.5 Mg/yr following the storm due to a 23% increase in stream connectivity. Storm-related changes in the control road's drainage structures, namely the formation of non-engineered drains and by-passes of existing drainage, resulted in local decreases in modeled slope stability.

Summary of GRAIP road risk predictions for the Mann Creek watershed decommissioning project.

Impact/Risk Type	Effect of Treatment: Initial GRAIP Prediction	Effect of Treatment: Post-storm validation
Road-Stream Hydrologic Connectivity	-97%, -2,923 m of connected road	-98%, -2937 m of connected road
Fine Sediment Delivery	-98%, -40.7 Mg/yr	-99%, -41.4 Mg/yr
Landslide Risk	Restored to near natural condition	Restored to near natural condition
Gully Risk	Reduced from low to negligible	Reduced from low to negligible
Stream Crossing Risk		
- plug potential	-100% (eliminated at 13 sites)	-100% (eliminated at 13 sites)
- fill at risk	-100% (807 m^3 removed)	-100% (807 m3 removed)
- diversion potential	-100% (eliminated at 8 sites)	-100% (eliminated at 8 sites)
Drain Point Problems	-100% (0% vs. 35% of drain points)	+ 12% (0% to 12%)

Impact/Risk Type	Control Roads Effects of Storm	Treatment Roads Effects of Storm
Road-Stream Hydrologic Connectivity	+ 1136 m (+ 12 connected drains)	- 14 m (- 3 connected drains)
Fine Sediment Delivery	+ 38.0 Mg/yr	- 0.5 Mg/yr
Landslides	+ 1 (1,700 Mg)	+ 2 (285 Mg)
Gullies	+ 9 (4.9 Mg)	+ 1 (0.8 Mg)
Drain Point Problems	+ 25% (23% to 48%)	+ 12% (0% to 12%)

Acknowledgements

We would like to thank the field crews (Laura Hutchinson, Jim Peterson, Matt Steiger, and Jim Bitzenberg) for collecting the data. We would also like to thank Dave Kennell and Tom Crawford of the Payette National Forest for help in selecting these sites and logistical support during a very busy field season. Thanks also to Rick Hopson and the Region 4 staff for supporting this monitoring effort. Post-storm inventories on treated roads were completed by Katelin Aldritt, Michael Barr, Ian Bell, and Scott Bergandorf from the RMRS; the post-storm inventory of the control roads was completed by Paul Micheletty and Matt Taylor from the Boise National Forest.

1.0 Background

The National Forest Transportation System is vast and represents an enormous investment of human and financial capital. This road and trail network provides numerous benefits to forest managers and the public, but can have adverse effects on water quality, aquatic ecosystems, and other resources. There is currently a large backlog of unfunded maintenance, improvement, and decommissioning work on national forest roads, and many critical components of the network (e.g., culverts) are nearing or have exceeded their life-expectancy. This significantly elevates risks to aquatic resources. Many Intermountain Region forests have been actively addressing known road issues in critical resource areas. Various road treatment techniques and restoration activities are being applied throughout the region to address the resource risks posed by forest roads.

The USFS, Rocky Mountain Research Station (RMRS), Intermountain (INT) Region, Pacific Northwest Region, Pacific Southwest Region, and the Northern Region are implementing a roads monitoring project to evaluate the effectiveness and to learn from the successes of road restoration treatments being implemented on national forests throughout the regions. As of October 2010, post-storm event data has been collected at six sites, post-treatment data has been collected on 33 sites with partial datasets collected at 13 additional sites.

This report briefly describes the overall objectives of the regional-scale study and the methods being used. Specific results presented herein, however, are focused only on road decommissioning work completed by the Payette National Forest (PNF) in the Mann Creek watershed in FY2009. As other data become available, similar reports will be developed for additional sites. In addition, syntheses of results at multiple sites will be produced throughout and at the end of this monitoring project.

2.0 Study Objectives

The monitoring project is designed to assess the effectiveness of decommissioning and maintenance projects in reducing road impacts and risks to several key watershed processes. Specifically, the project is intended to address the following questions.

How effective are USFS road restoration projects in:

1) reducing or eliminating:
    a. the risk of increased peak flows resulting from road-stream connectivity?
    b. fine sediment production and delivery to stream channels?
    c. shallow landslide risk?
    d. gully initiation risk?
    e. the risk and consequences of stream crossing failures?
2) improving the performance of the road drainage system

3.0 Methods

The Geomorphic Road Analysis and Inventory Package (GRAIP, Prasad et al. 2007, http://www.fs.fed.us/GRAIP) is being used to inventory and model the risk profile of each of the road segments included in the study. The GRAIP system consists of a detailed, field-based road inventory protocol combined with a suite of geographic information system (GIS) models. The inventory is used to systematically describe the hydrology and condition of a road system using Geographic Positioning System (GPS) technology and automated data forms (Black et al., 2009; Cissel et al., 2009). The GIS models use these data to analyze road-stream hydrologic connectivity, fine sediment production and delivery, shallow landslide potential with and without road drainage, gully initiation risk, and the potential for and consequences of stream crossing failures. Detailed information about the performance and condition of the road drainage infrastructure is also supplied.

Risk profiles are being developed and compared at untreated control segments and treated segments before and after road projects. At a given site, monitored road segments typically comprise 4 miles of both treated and control sites. Control sites were selected based on their similarity to treated sites with respect to road construction methods, maintenance levels, geology, and hydrologic regimes. Each site also includes a final validation evaluation at both treatment and control sites following a substantial storm event (minimum 5 – 10 year recurrance interval). This will allow testing of the initial GRAIP risk predictions and provide an unbiased comparison between the treated and the untreated roads.

4.0 Monitoring Locations

Regional Monitoring Sites

In FY2009, pre-treatment evaluations were completed at five sites[1] on four national forests in the Intermountain Region. Decommissioning was implemented at four of these sites and one other site was treated with "storm damage risk reduction[2]" (Figure 1, Table 1). Four post-treatment inventories were also completed in FY2009. In FY2010, post-storm surveys were completed at three sites (Mann Creek, Calf Creek, and Squaw Creek), and four new sites were completed.

[1] Each site will include the following evaluations: pre-treatment, post-treatment, and post-storm validation on treated road segments; and pre-treatment and post-storm validation on control segments.

[2] "Storm Damage Risk Reduction (SDRR) is used to refer to relatively low-cost treatments applied across extensive portions of the road network with the objective of protecting aquatic resources and infrastructure. These treatments are intended to reduce the chronic effects of roads (e.g., fine sediment delivery) and significantly reduce the likelihood and consequences of catastrophic failures (e.g., diversion of stream flow onto roads) associated with large storm events. A variety of tools may be used to achieve these objectives, depending on site-specific conditions. These include diversion potential dips at road-stream crossings, water bars, and broad-based drain dips. These simple, extensive treatments are intended to compliment the use of more intensive treatments (e.g., decommissioning, road realignments) that are typically implemented on relatively small segments of the network.

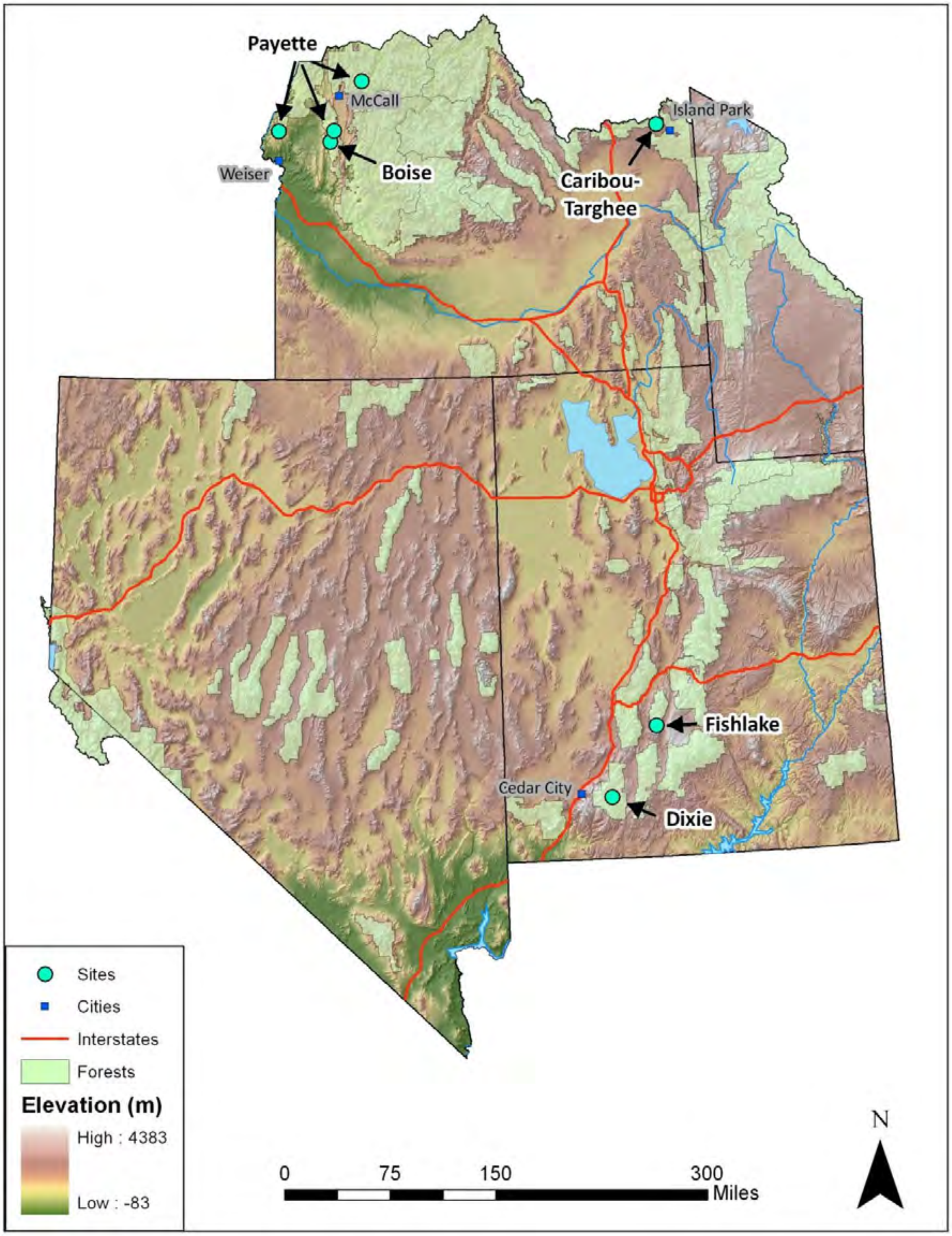

Figure 1: Locations of monitored sites in Region 4.

Table 1: The locations and types of road treatments monitored.

National Forest	Start Year	Treatment	Watershed
Payette	2009	Decommissioning	Mann Creek
Payette	2009	Decommissioning	Calf Creek
Boise	2009	Decommissioning	Squaw Creek
Caribou-Targee	2009	Other Treatments	Island Park
	2009	Storm Damage Risk Reduction	Island Park
Payette	2010	Long-Term Closure	Little Weiser
Boise	2010	Storm Damage Risk Reduction	Rice Creek
Dixie	2010	Decommissioning	Mammoth Creek
Fish Lake	2010	Decommissioning	Monroe Mountain

Mann Creek Sites

During the summer and fall of 2009, field crews inventoried decommissioning sites in the Intermountain Region, including the Mann Creek watershed (Table 1, Figure 1). This watershed is principally underlain by basalts, with Columbia River Group basalts dominating the mid-elevation band. The higher elevations are underlain by sedimentary rocks of the Olds Ferry and Izee terranes as well as mafic plutons of the Blue Mountains island arc terrane. The average annual precipitation for the basin ranges from 10 - 30 inches per year. The watershed is managed for multiple uses including timber harvest, grazing, and recreation. The inventoried sites are located between 4,800 and 6,000 feet above sea level just east of the Snake River.

The Mann Creek watershed is located in Washington county between U.S. Highway 95 and the Snake River. Mann Creek Reservoir, located near the mouth of the watershed, is about halfway between Weiser and Cambridge.

Data were collected on roads in the spring of 2009 before the decomissioning treatments began, and once again in summer of 2009 once the treatments were completed (Figure 2). Pre-treatment roads were native or gravel surface roads that were generally in good shape. With the exception of road 501641000, the roads were classed as maintenance level 2 or 3 (Table 2). The maintenance class of road 501641000 is unknown, as the forest did not classify it, though it appears to be similar to maintenance level 2 based on photographs and comparisons to descriptions of road maintenance classes. Flow on the roads was generally contained in wheel tracks or a ditch. Both treatment and control sites included roads on a range of hillslope positions, though dominantly valley-bottom, and included frequent live stream crossings. The watershed has moderately steep topography, so stream crossing fills are not typically large.

Decommissioning treatments were performed by USFS equipment and staff, and involved removing stream crossing culverts and fills and partially to fully recontouring the road prism.

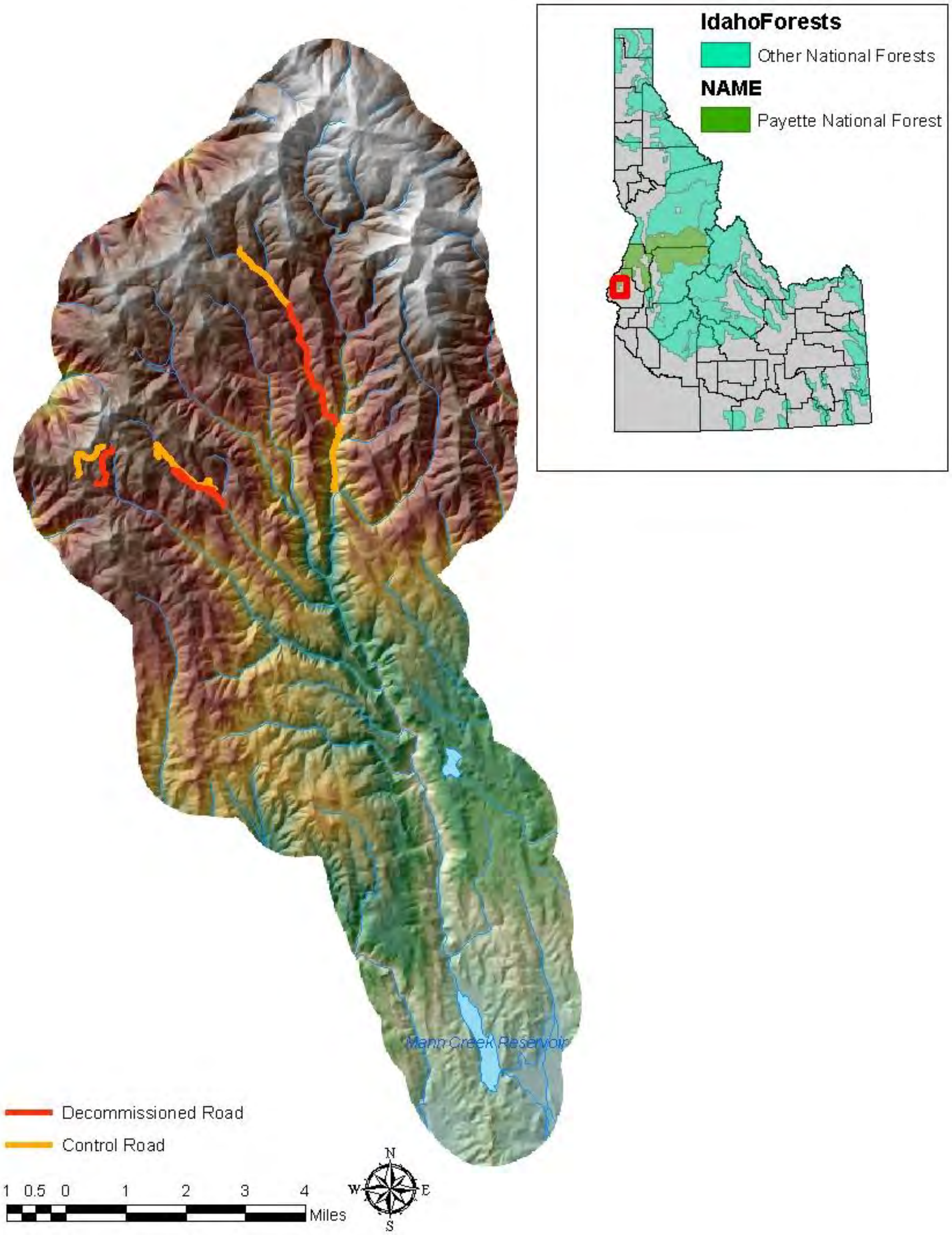

Figure 2: Map of road locations within the Mann Creek watershed.

Table 2: Decommissioning treatments applied by road number.

Decommissioned Road			Control Road		
Road #	**Maintenance Level**	**Treatment**	**Road #**	**Maintenance Level**	**Treatment**
50007	2	Stream crossing extraction, recontouring, and culvert removal	50029 50473 50007?	2	None
50029	2	Stream crossing extraction, recontouring, and culvert removal	50029 50473 50007?	2	None
50470	1	Stream crossing extraction, recontouring, and culvert removal	50029 50473 50007?	2	None
50019 Old 51189	3	Stream crossing extraction, recontouring, and culvert removal	50019 Old 51189	3	None
50164100 0	Unclassified	Stream crossing extraction, recontouring, and culvert removal	500100500	Unclassified	None

5.0 Storm Event

In April of 2010 a series of small rain-on-snow events occurred within the Mann Creek drainage. While these events generally had recurrence intervals of 2 – 3 years, the resulting flooding, especially along Mann Creek, caused extensive damage to stream-side roads, especially where diversions occurred (Figure 3). These rain-on-snow events affected a fairly narrow elevation band below the treated roads as the snow line retreated. Another similar event in May might have affected some portions of the study site.

On June 2, 2010, a strong series of thunderstorms passed through the area. These storms brought heavy rains over a ripe snow pack, and even though the precipitation intensities have less than 5 year recurrence intervals, the resulting floods, measured at the USGS gage in Cambridge, Idaho, have a recurrence interval of ~8 years (Figure 4). The river crested at 7,440 cfs on June 5.

Figure 3: Damage from the April storms. The author is standing in a gullied wheeltrack where flood water was diverted down the road from the stream crossing behind the author's head.

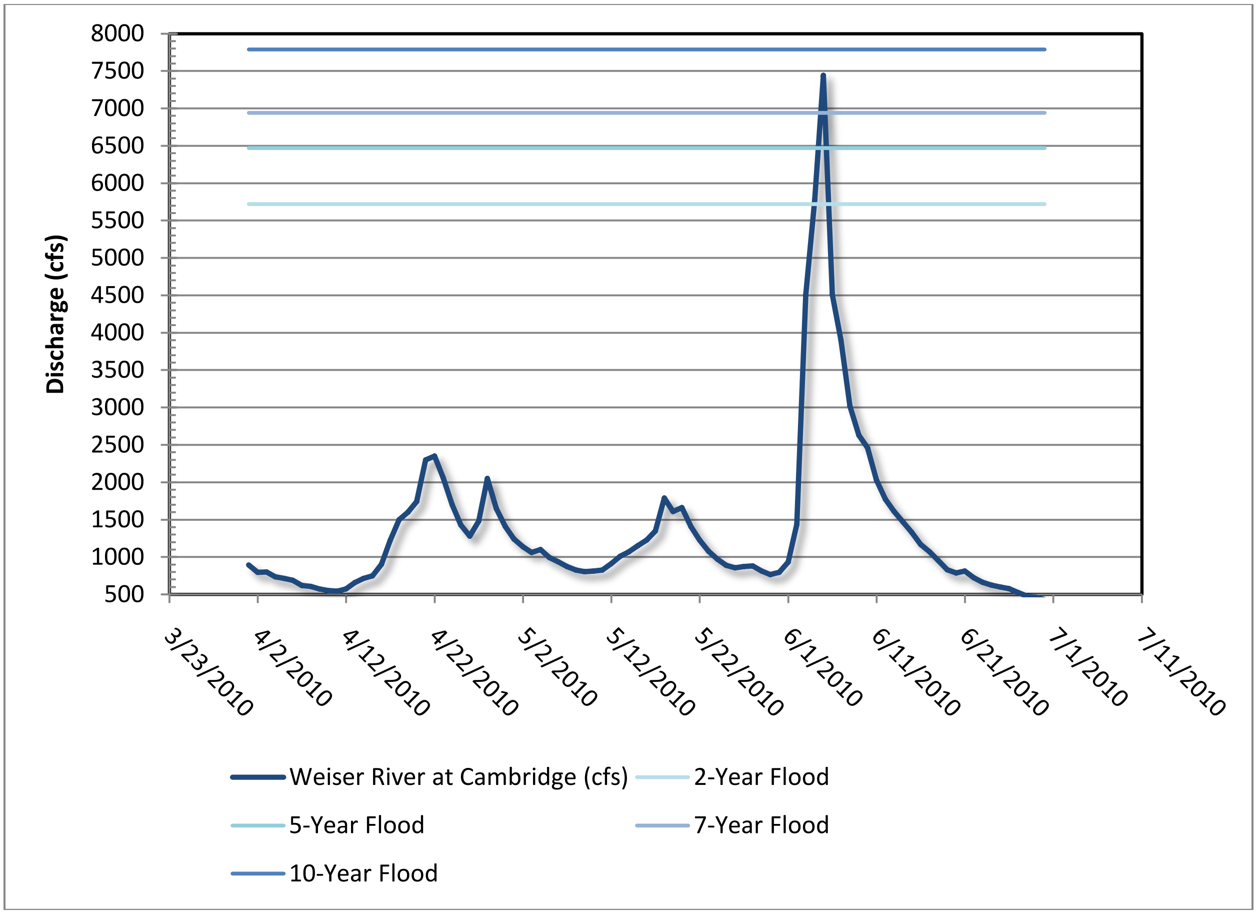

Figure 4: Wieser River hydrograph.

6.0 Storm Damage Characteristics

Treatment Roads

Crews surveyed the decommissioned roads in late June and early July to determine what changes were caused by the storms. Most storm-related damage consisted of rills and small gullies in the recontoured surface (Figure 5); these rills were, with few exceptions, limited to the fill material and did not extend onto the hillslope below the recontoured road. Where these met size criteria for gullies, eroded sediment volumes were estimated and recorded. Most of these rills and gullies were concentrated between 4,500 and 5,000 ft elevation. The estimated volume of these rills and gullies is 600 ft^3 (~28.6 metric tons). This type of erosion was expected given that the recontoured roads consisted of unconsolidated fill with less vegetation than surrounding hillslopes.

Crews found one gully that extended beyond the recontoured surface where the road crossed a swale (Figure 6). They also found two small landslides where recontoured fill had slumped

(Figure 7). The combined estimated volume of the gully and both landslides is ~6,000 ft^3 (~286 metric tons).


Figure 5: Rills and small gullies on the recontoured road surface.

Figure 6: Gully crossing recontoured road.


Figure 7: Slump in recontoured fill. View is from top of scarp.

Control Roads

A crew surveyed the control roads on June 10 and 11. Repair work had already been completed on the lowest portion of the 50009 road; hence this portion was not surveyed after the storm. Damage generally consisted of longitudinal rills or gullies along the road surface or ditch (Figure 8), new non-engineered drains (Figure 9) and fill erosion (528 ft^3 or ~25.2 metric tons), and gully formation (Figure 10). In 2009, 13.4% of the road surface was recorded as being in other than “good” condition (13.1% rutted, 0.3% rocky); after the storm, 53.8% of the road surface was in less than “good” condition (52.3% rilled or eroded, 1.5% rocky).

Nine gullies were found totaling 100 ft^3, or ~4.9 metric tons, along with one large cutslope failure (~35,600 ft^3 or ~1,700 metric tons; Figure 11).

Figure 8: Gullied flowpath on control road 500100500.


Figure 9: Non-engineered drain formed along control road.

Figure 10: Gully and rills along control road. These extend from the road surface across the fill and onto the hillslope below.

Figure 11: Cutslope failure along control road 50029/50473/50007?.

7.0 Inventory and Model Results

Sediment Production and Delivery

Comparison of the treatment and control roads prior to treatment indicates that the two sets of roads were likely to produce similar amounts of sediment (Table 3). While the control roads were expected to produce somewhat more sediment and have virtually the same portion of the road connected to the stream, sediment delivery from the control roads was predicted to be about 40% of that from the treatment roads. This was due to differences in vegetation densities in the road flowpaths; control roads were more likely to have greater than 25% vegetation cover in at least one flowpath than were the treatment roads.

Treatments were expected to reduce annual sediment production by 56% and annual sediment delivery by 98% (Table 3). Post-storm surveys indicate these reductions may be closer to 73% for sediment production and 99% for delivery. Recontouring the road surface eliminated the longitudinal, concentrated flowpath and replaced it with a transverse, diffuse flowpath, drastically reducing sediment production. Sediment delivery is further reduced because the diffuse flowpath is less likely to allow stream connections.

The post-storm survey of the control roads was shorter by 1 km than the pre-storm survey because repairs had already been completed on the kilometer of road omitted, which is why sediment production appears to be reduced following the storm. When averaged over the length of the surveyed road, sediment production increased slightly (17.0 kg/m/yr – 18.1 kg/m/yr). The increase in sediment delivery is significant (2.0 kg/m/yr – 7.3 kg/m/yr) and is due, in large part, to an increase in connected road length (38% - 61%). In addition, some local areas have seen large increases in sediment production (up to 17.5x prior levels). Areas that saw the greatest decreases (to 80% of prior levels) in sediment production, weren't stream connected, while areas that saw the biggest increases were stream connected.

Table 3: Modeled sediment production and delivery characteristics.

	Sediment Production (Mg/yr)	Sediment Delivery (Mg/yr)	Delivering Road Length (m)	% Sediment Delivery	% Delivering Road Length
Pre-treatment	136.6	41.7	3,000	31%	37%
Post-treatment	60.5	1.0	77	2%	1%
Post-storm Treatment	37.5	0.3	63	1%	1%
Pre-storm Control	144.5	16.6	3,262	11%	38%
Post-storm Control	135.4	54.5	4,598	40%	61%

Mass Wasting Risks

Landslide risks within the Mann Creek watershed appear to be minimal; prior to the storm, no landslides were located on either the control or treatment roads. On treatment roads, landslide risks were predicted to have returned to near the natural state following recontouring and conversion to diffuse drainage. This appears to have held true, as the two small landslides located along the treated roads after the storm event consisted entirely of loose, unconsolidated, recontoured fill material. These two failures were limited to recontoured fill material which was likely past its saturated angle of repose. The one landslide located along the control roads was much larger, but resulted from, and was confined to, a cutslope failure.

Flowpaths along the decommissioned roads did not change and were still diffuse; hence landslide risk along treatment roads did not increase after the storm. While landslide risks may be low, damage resulting from the storm appears to have increased those risks along the control roads, as discussed below.

The risk of shallow landslide initiation is predicted using SINMAP 2.0 (Pack et al., 2008, http://hydrology.neng.usu.edu/sinmap2/), modified to account for contributions of road runoff. SINMAP has its basis in the infinite plane slope stability model and produces raster grids that illustrate slope stability based on hillslope and specific catchment area at each DEM grid cell. While it is possible to calibrate SINMAP to account for local geology, the data necessary was not available; therefore this analysis uses SINMAP's default values and may over-predict unstable areas. Pre- and post-storm landslide risk grids are subjected to a series of mathematical operations that result in grids that show the important changes to landslide risk due to the storm. These change grids are compared to the natural landslide risk grid (Figure 12) to show how the storm affected slope stability in the context of the background risks (i.e. the risks without the influence of the road drainage). Important grid cell changes are those pre- to post-storm differences that show a risk change from stable to unstable, unstable to stable, or that become more or less stable while remaining unstable following the storm.

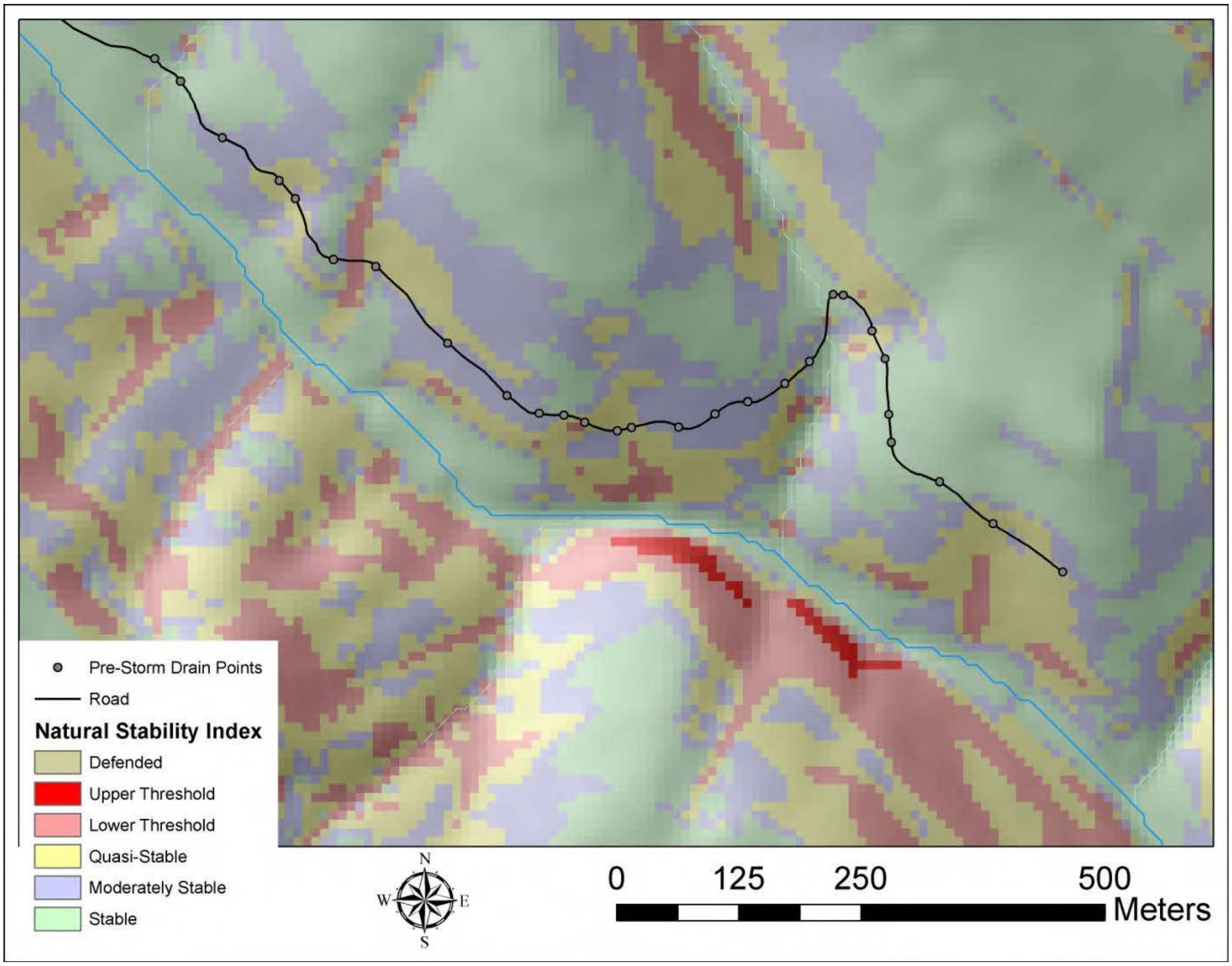

Figure 12: Natural slope stability index in the area of the control section of the 50029/50473/50007 road. The yellow, blue, and green cells are generally classified as stable, while the pink, red, and tan cells are generally classified as unstable.

A second stability index (SI) run was performed to address the effects of road water contribution to drain points on the control road prior to the storm. A third model run was performed to illustrate the risk of shallow landsliding after the storm damage occurred. In Figure 13, the areas along the 50029 road where the storm changed the risk from the unstable category (defended, upper threshold, and lower threshold from Figure, above) to the stable category (quasi-stable, moderately stable, and stable) are shown in green, and areas where the storm changed the risk from the stable category to the unstable category are shown in red. These are the areas where risk has been sufficiently reduced (green), or where risk has been increased significantly (red). The storm-related damage along the road changes the hydrologic structure of the road; this results in changes in the locations and quantities of water drained from the road. If a gullied flowpath bypasses existing drainage, the area below the bypassed drain may experience a relative increase in stability (green); however, because of the additional water delivered to some other drainpoint, whether new or existing, the hillslope below that drain will become less stable (red).

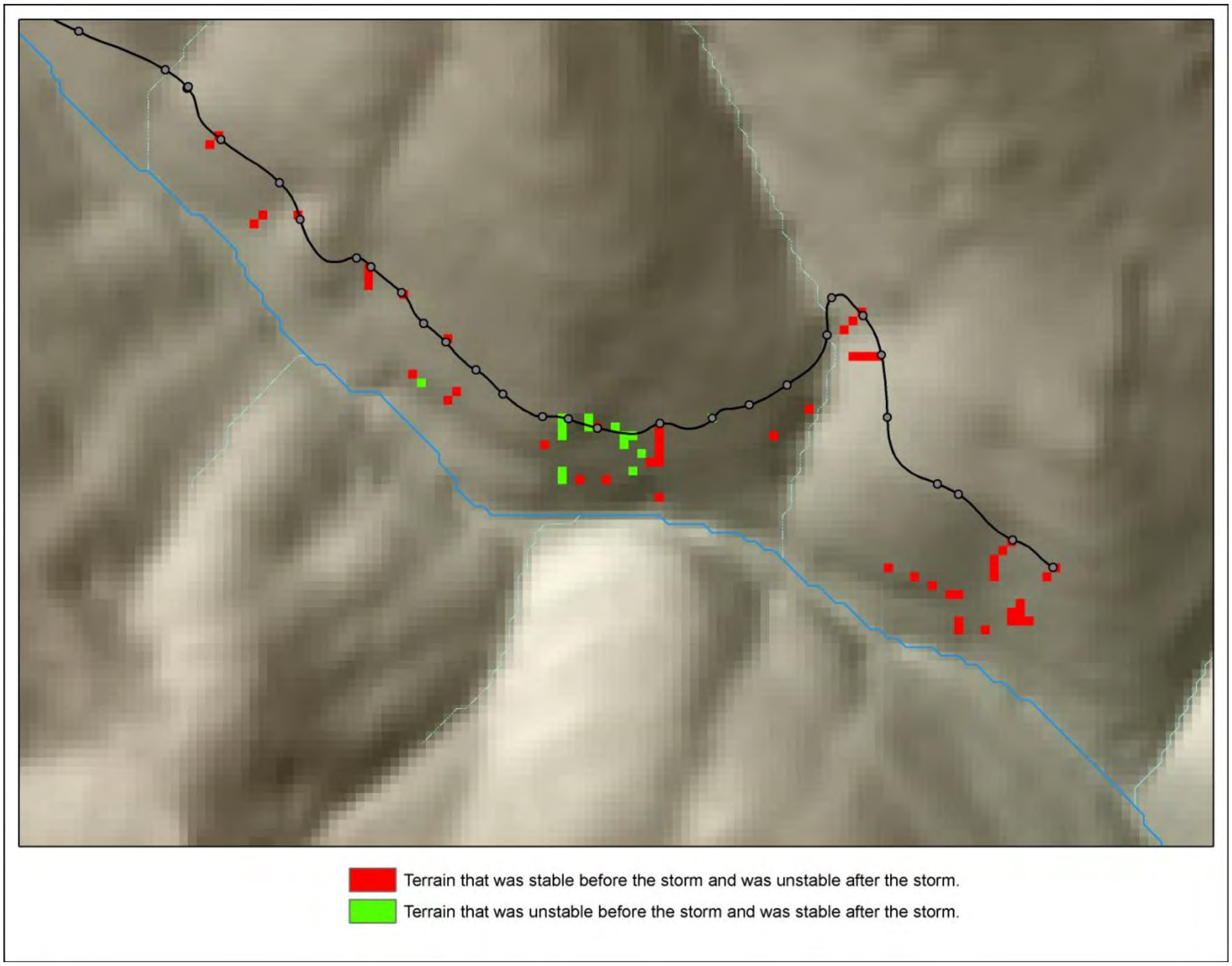

Figure 13: The most significant slope stability changes along the control section of road 50029. The risk of the areas in green was sufficiently reduced, while the risk in the red areas was significantly increased.

Figure 14 shows the areas where the risk of shallow landsliding was high (unstable grid cells) both before and after the storm. The light blue cells are areas where the risk decreased (became more stable), but the terrain was still unstable after treatment. This was generally due to a decrease in the length of road that drained to each point, but was not enough of a reduction to move the risk category to stable. The orange cells are areas where the risk increased (became less stable) after the storm, and the terrain was unstable before the storm. This is generally due to the addition of drainage over slopes that were unstable without considering the effects of road drainage.

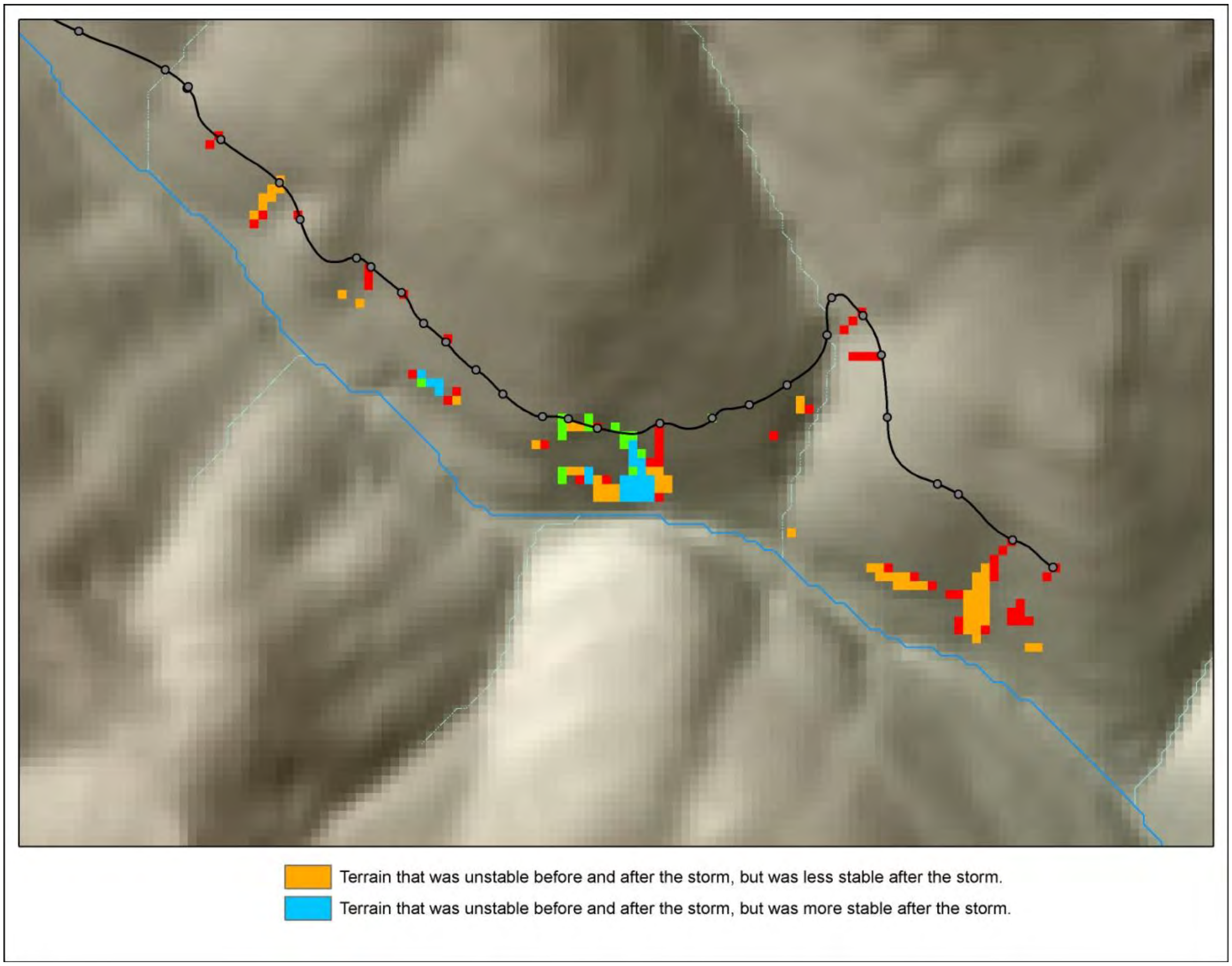

Figure 14: Changes in slope stability risk along the control section of road 50029 where the terrain was unstable before and after the storm. The blue areas are locations where the risk was lowered, and the orange areas are where the risk increased.

In some locations, a drain point that was located above a slope that was unstable without road drainage consideration received less flow after the storm, and so became more stable. In these locations, there was no way to reduce the overall shallow landslide risk to be stable. These locations are shown in Figure 15, where the cross-hatch areas were unstable without consideration of road drainage and cross-hatch over blue shows the areas that also experienced reduced risk. In some of these locations, the storm may have reduced the stability category to nearly background (natural) levels. Reduction to fully background levels would require the removal of the drain points over those unstable slopes. Areas where the underlying risk (without a road) was unstable and the stability risk increased after the storm (cross-hatch over orange) show that drainage was added over a slope that was unstable without consideration of road drainage.

Figure 15: Background slope stability and the changes in slope stability. The cross-hatch pattern is all of the area in the map that was unstable without consideration of road drainage.

8.0 Gullies

During pre- and post-treatment visits, only one gully was located (along one of the control roads); this "gully" is likely a deeply incised stream and was not recorded as a gully during post-storm visits. The post-storm inventory describes this as a natural ford across a small stream.

Following the storm event, only one gully was located along the treated roads and nine gullies were recorded along the control roads. All of these were new gullies. The gully found along the treatment roads (along the decommissioned 50019) is located where a wet swale crosses the road and likely delivered concentrated flow during the storm event. This gully begins just above the recontoured road and extends onto the hillslope just below recontoured road. It has a volume of ~17 ft^3.

Nine gullies were located along the control roads. All of these gullies extend across the road fill slope onto the hillslope below the road and initiate at drain points (two ditch relief culverts and seven non-engineered drains) along the road. The total volume of these gullies is ~103 ft^3.

9.0 Stream Crossing Analysis

Adjustments and channel formation were also recorded at excavated stream crossings (Figure 16). Crews measured channel incision within the excavated crossings as well as bed particle size distributions within the crossing and in an adjacent upstream reach. Nine of the twelve excavated crossings had not experienced flow prior to the post-treatment site. An estimated 2,600 ft^3 (~125.7 metric tons) of material has been removed by the stream during adjustment at these nine crossings. This is separate from the fill removed by equipment during the excavation. These crossings are mostly 1^{st}-order streams.

Crossings 1, 4, and 12 had all received some flow prior to the post-treatment inventory; since the crews did not record incision measurements during the post-treatment inventory, the amount of post-storm incision could not be calculated at these locations. Photographs indicate that much of the ~6,000 ft^3 of material from these three crossings was removed prior to the post-treatment inventory. Without accurate measurements immediately following the treatment, prior to any adjustment, it is impossible to determine how much of this ~6,000 ft^3 of material was removed by equipment at the time of treatment or removed by the stream during adjustment following the treatment. Crossings 1 and 4 are 4^{th}-order streams; crossing 12 is a 3^{rd}-order stream.

Side slopes on the excavated crossings appear to be stable, no failures were noted on any of the side slopes within the study area. The three perennial stream crossings (1, 4, and 12) did not show evidence of lateral adjustments following the storm event.

The bed particle size distributions can be used to help determine if adjustments at the crossing are complete; if the distributions in the crossing and upstream are similar after the storm, it is less likely that further adjustments to the channel morphology within the crossing will occur.

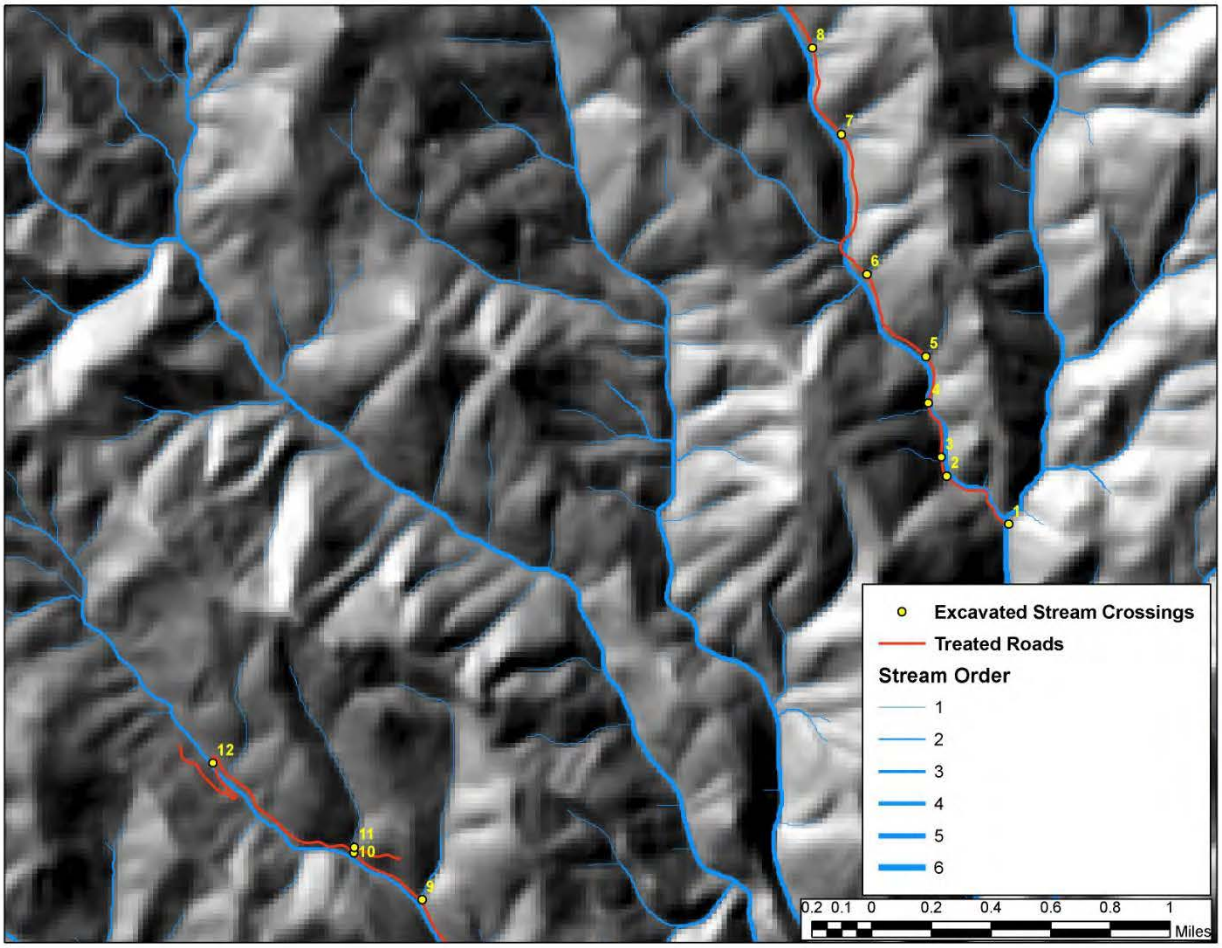

Figure 16: Map showing excavated stream crossings with numeric labels.

Excavated stream crossings are at various states of adjustment following the storm event and spring runoff. Most of the examined crossings follow the expected response where excess fines in the crossing following excavation are being, or have been, removed. This indicates that the bedload more closely resembles that of the natural channel upstream of the crossing. The pattern is more advanced and more clearly defined in higher-order channels than in lower-order channels because of greater stream power and longer flow durations. Increased stream power does not predict greater erosion, only quicker sorting and removal of excess fines from the stream bed within the excavated crossing. Three of the 1st-order channels show an opposite pattern where the bedload has become significantly finer than post-treatment, but also remain significantly finer than upstream reaches. Some likely reasons include a lack of significant adjustment (crossing 5), scour through the disturbed sediment into undisturbed colluviums (crossing 6), or entrapment of fines by large anchor clasts (crossing 8).

Crossing 1, along the main stem of Mann Creek, shows an example of a well-adjusted stream crossing (Figure 17). This crossing has rapidly adjusted by removing fines left behind following excavation of the fill and culverts. This is one of two 4th-order stream crossings in the study.

Figure 18 shows the bedload grain-size distributions for four different 1st-order stream crossings, including the three described above, that are not adjusting as expected.

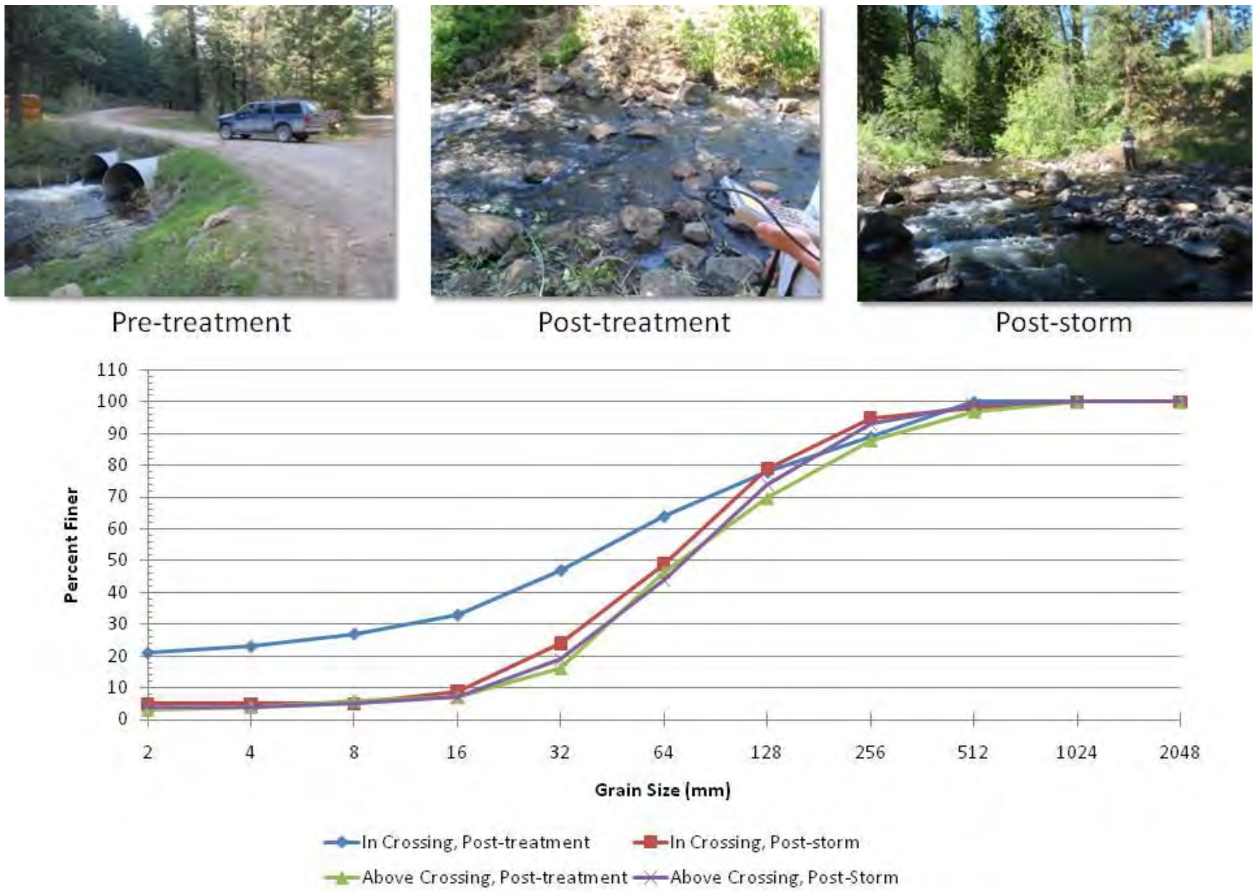

Figure 17: Grain size distributions for and pictures of crossing 1. Note the shift in the "in crossing" size distributions indicating removal of fine sediment and restoration of natural bed characteristics observed upstream.

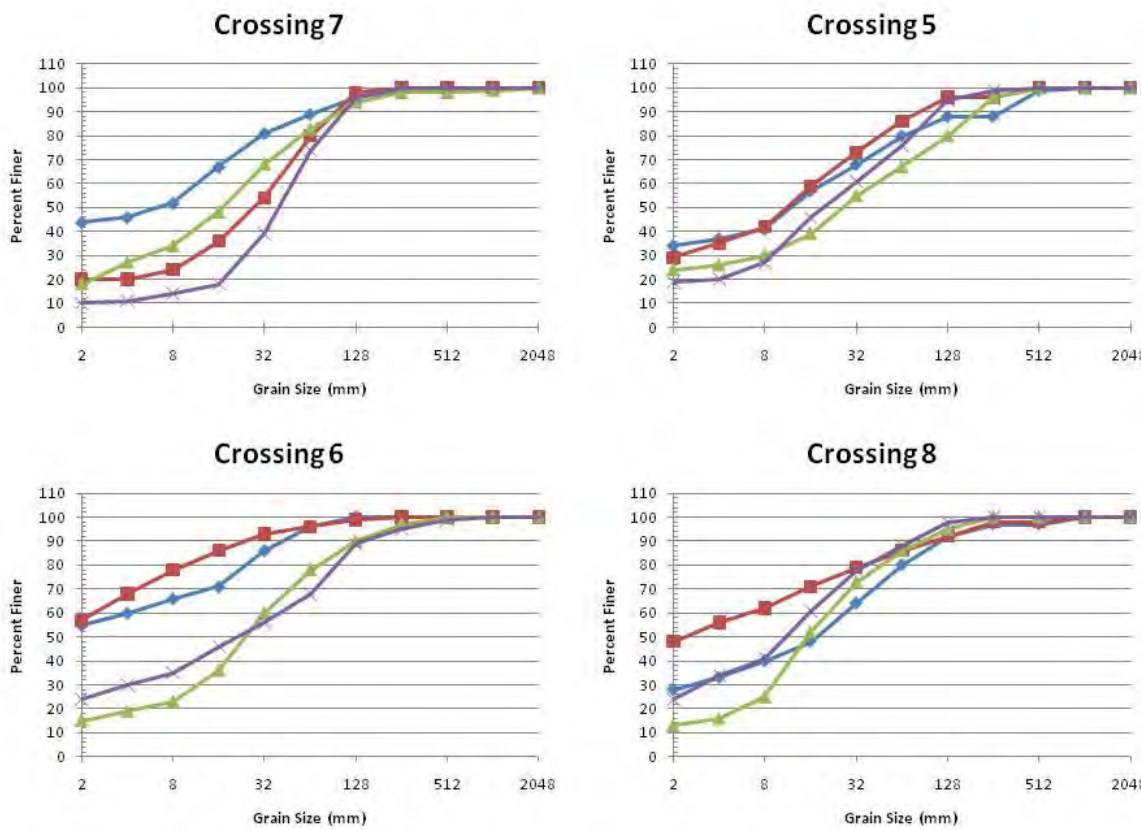

Figure 18: Sediment size distributions from four other crossings. Crossing 7 shows incomplete adjustment along the expected trend and textural coarsening of the upstream reach following high flows. Crossing 5 shows a lack of any significant adjustment to bed sediment. Textural fining observed at crossing 6 was due to incision into underlying colluviums; at crossing 8 textural fining was due to entrapment of fines by large keystone clasts.

10.0 Conclusions

Recontouring of treatment roads was expected to convert longitudinal concentrated flowpaths to lateral diffuse flowpaths and cause the former road to behave similarly to the surrounding hillslopes. Observations following a significant storm event support these expectations (Table 4). Observations further indicate that the recontoured treatment roads sustained less storm-related damage than untreated control roads. Storm-related damage on treatment roads consisted of rills and small gullies similar to those that form on unconsolidated, unvegetated slopes; these rills and gullies were limited to the recontoured fill surface. Storm related damage on the control roads consisted of longitudinal gullies formed on existing flowpaths (wheel tracks or ditches), formation of non-engineered drains with fill erosion, and formation of gullies below drains; there was also a marked (40.4% of total road length) increase in the amount of road classified as having problems associated with scour occurring along the road flowpath.

Model runs using the post-storm inventories confirmed post-treatment model predictions for the treated roads or indicated that reductions may be greater than predicted by the post-treatment model runs. Control roads, however, are predicted to have greatly increased sediment delivery because storm-related damage resulted in greater stream connection, especially in areas where sediment production was locally increased. Changes in the control roads hydrologic structure also caused local decreases in slope stability.
Observations at the excavated stream crossings show that most of the crossings are adjusting as expected. Higher-order crossings have nearly completed adjustment and bedload characteristics are now similar to upstream reaches. Some 1st-order crossings did not follow the expected pattern of increased sorting and removal of finer sediment.

Table 4: Summary of GRAIP model risk predictions for the Mann Creek road decommissioning project.

Impact/Risk Type	Effect of Treatment:	Effect of Treatment:
	Initial GRAIP Prediction	**Post-storm validation**
Road-Stream Hydrologic Connectivity	-97%, -2,923 m of connected road	-98%, -2937 m of connected road
Fine Sediment Delivery	-98%, -40.7 Mg/yr	-99%, -41.4 Mg/yr
Landslide Risk	Restored to near natural condition	Restored to near natural condition
Gully Risk	Reduced from low to negligible	Reduced from low to negligible
Stream Crossing Risk		
- plug potential	-100% (eliminated at 13 sites)	-100% (eliminated at 13 sites)
- fill at risk	-100% (807 m^3 removed)	-100% (807 m^3 removed)
- diversion potential	-100% (eliminated at 8 sites)	-100% (eliminated at 8 sites)
Drain Point Problems	-100% (0% vs. 35% of drain points)	+ 12% (0% to 12%)
Impact/Risk Type	**Control Roads**	**Treatment Roads**
	Effects of Storm	**Effects of Storm**
Road-Stream Hydrologic Connectivity	+ 1136 m (+ 12 connected drains)	- 14 m (- 3 connected drains)
Fine Sediment Delivery	+ 38.0 Mg/yr	- 0.5 Mg/yr
Landslides	+ 1 (1,700 Mg)	+ 2 (285 Mg)
Gullies	+ 9 (4.9 Mg)	+ 1 (0.8 Mg)
Drain Point Problems	+ 25% (23% to 48%)	+ 12% (0% to 12%)

References

Best, D. W., Kelsey, H. M., Hagans, D.K. and M. Alpert. 1995. Role of fluvial hillslope erosion and road construction in the sediment budget of Garret Creek, Humboldt County, California. In Geomorphic Process and Aquatic Habitat in the Redwood Creek Basin, Northwestern California. Nolan, K. M., Kelsey, H. M., and Marron, D. C. editors. USGS professional paper #1454. pp m1-m9.

Black, T. A., Cissel, R, and Luce, C. H. 2009. The Geomorphic Road Analysis and Inventory Package (GRAIP) Data Collection Method. USDA Forest Service Rocky Mountain Research Station, Boise Aquatic Science Lab.

Cissel, R., Black, T. A., Luce, C. H,,Tarboton, D. G., Schreuders, K. A., and Prasad, A 2009. The Geomorphic Road Analysis and Inventory Package (GRAIP) Office Procedure Manual. USDA Forest Service Rocky Mountain Research Station, Boise Aquatic Science Lab.

Flanagan, S. A., Furniss, M. J., Theisen, S., Love, M., Moore, K., and J. Ory. 1998. Methods for Inventory and Environmental Risk Assessment of Road Drainage Crossings. USDA Forest Service Technology and Development Program 9877-1809-SDTDC 45pp.

Furniss, M. J., Love, M., and S. A. Flanagan. 1997 Diversion Potential at Road Stream Crossings. USDA Forest Service Technology and Development Program 9777-1814-SDTDC 12pp.

Istanbulluoglu, E., Tarboton, D.G., Pack, R.T., Luce, C.H. 2003. A sediment transport model for incision of gullies on steep topography. Water Resources Research. 39(4): 1103-1117.
Jones, J. A., and G. E. Grant, 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon, Water Resour. Res., 32, 959-974.

Luce, C.H., and T. Black. 1999. Sediment production from forest roads in western Oregon. Water Resources Research. 35(8): 2561-2570.

Madej, Mary A. 2001. Erosion and Sediment Delivery Following Removal of Forest Roads, Earth Surface Landforms and Processes, 26(2) pp.175-190.

Pack, R. T., Tarboton, D.G., Goodwin, C.N. and A. Prasad, 2005. SINMAP 2. A Stability Index Approach to Terrain Stability Hazard Mapping, technical description and users guide for version 2.0, Utah State University.

Prasad, A. 2007. A tool to analyze environmental impacts of road on forest watersheds. MS Thesis. Utah State University, USA.

Prasad, A,, Tarboton, D. G., Schreuders, K. A., Luce, C.H., and T.A. Black. 2007. GRAIP1.0 Geomorphic Road Analysis and Inventory Package: A tool to analyze the environmental impact of roads on forested watersheds. Tutorial and Reference Manual. http://WWW.engineering.usu.edu/dtarb/graip.

Wemple, B. C., Jones, J. A., and Grant, G. E. 1996. Channel network extension by logging roads in two basins, western Cascades, Oregon, Water Resources Bulletin, 32, 1195-1207.