Legacy Roads and Trails Monitoring Project

Road Decommissioning in the Granite Creek Watershed
Umatilla National Forest

April 2012

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Executive Summary

In Fiscal Year 2008, Congress authorized the Legacy Roads and Trails Program and allocated the US Forest Service (USFS) $40 million to begin its implementation. Based on continued success, the program was allocated an additional ~$180 million from FY2010 – FY2012. This program is intended to reduce road and trail impacts to watersheds and aquatic ecosystems by decommissioning unneeded roads, removing fish passage barriers, and addressing critical repair and maintenance needs.

The USFS, Rocky Mountain Research Station and Pacific Northwest Region are monitoring some of the road decommissioning and maintenance projects in Oregon and Washington 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.

To date, pre-treatment inventories have been conducted at twenty-one locales where decommissioning or heavy maintenance (i.e., storm damage risk reduction; SDRR) treatments have since or will be implemented. At each of these locations, four miles of road were assessed. Inventories were also completed on four miles of control sites for each locale. Eighteen post-treatment inventories were executed, as well as two post-storm validation evaluations. This status report focuses only on decommissioning work implemented by the Umatilla National Forest (UNF) in the Granite Creek watershed. At the UNF sites, treatments included removal of culverts and fills at stream crossings, recontouring, ripping, or tilling of road surfaces, and construction of waterbars on ripped and tilled roads.

Before-after comparisons using GRAIP indicate that decommissioning treatments resulted in a variable reduction of many impact-risk metrics, and a moderate increase in others. Comparing pre-treatment and post-storm inventories, road-stream connectivity increased by 427 m (7%), from 499 m of connected road to 926 m. Delivery of fine sediment was reduced by 0.8 Mg/yr (-34%), from 2.2 Mg/year to 1.5 Mg/year. In comparison, control roads saw an increase of 130 m (2%) connected road length, from 475 m to 605 m. This was accompanied by an increase in delivered fine sediment of 11.8 Mg/yr (255%), from 4.6 Mg/yr to 16.4 Mg/yr.

The slope stability risk below drain point locations on the treatment road was reduced in a few locations as water was redistributed across the hillslope to new drainage points and remained constant at other locations. On the control roads, storm-related damage resulted in local decreases and increases in slope stability risks, though no road-related landslides were present in the study area. Some areas of locally increased risk may affect the stability of nearby, downslope recontoured road fills on decommissioned roads.

The risk of gully initiation, as determined by comparisons of a gully initiation index (ESI) to an empirically-derived threshold (ESI_{crit}), was decreased across the length of treated road. Decommissioning treatments converted most of the road to diffuse drainage and lowered the average ESI from 1.96 to 0.93; the ESI_{crit} was found to be 12, and a lower threshold was found at an ESI value of 1.25. The net effect was that treatments decreased the number of drainage points with elevated gully risk by one (-100%). Average ESI values on the control roads increased from 8.82 to 9.12, and the number of drainpoints with an ESI greater than ESI_{crit} increased from 11 to 16. Gullies are uncommon (only 10 observed in this study [15 gully observations, including gullies observed in multiple inventories, out of 429 drainpoint observations]) and are not likely to be a problem in this environment.

The stream blocking index was reduced from an average of 1.2 before treatment to zero after treatment (n=7), indicating the risk of stream crossings becoming plugged was completely eliminated by excavation and removal of culverts and associated fills. While former crossings sites may contribute fine sediment to streams in the short term, the restoration treatments removed over 200 m^3 of earthen material from areas with a high potential for failure and delivery to stream channels. Diversion potential was eliminated at all 7 crossing sites. While low, stream blocking and failure risks on control roads remained the same between pre-treatment and post-storm inventories.

Taken collectively, results indicate the decommissioning treatments have been effective in reducing most of the measured hydrogeomorphic impacts and risks to aquatic ecosystems. The increase in stream connectivity is likely the result of the close proximity of roads to streams. Risks associated with the control roads, however, increased in most cases, or remained the same.

Impact/Risk Type	Effect of Treatment:[*]	Effect of Treatment:[*]
	Initial GRAIP Prediction	Post-storm validation
Road-Stream Hydrologic Connectivity	+466 m (+8% of total road length)	+427 m (+7% of total road length)
Fine Sediment Delivery	+3,476 kg/yr (+158%)	-751 kg/yr (-34%)
Landslide Risk	Some increases in stability, very low risk	Some increases in stability, very low risk
Gully Risk	-1 drain above ESI_{crit}, none above	-1 drain above ESI_{crit}, none above
Stream Crossing Risk		
- plug potential	-100%, all crossings excavated	-100%, all crossings excavated
- fill at risk	-222 m^3, all fills removed	-222 m^3, all fills removed, one side-slope failure
- diversion potential	-100%, eliminated at all crossings	-100%, eliminated at all crossings
Drain Point Problems	-100%, all problems eliminated	-10 (-91%)

[*] *Post-storm validation measured as change from pre-treatment conditions.*

Impact/Risk Type	Control Roads	Treatment Roads
	Effects of Storm[*]	Effects of Storm[*]
Road-Stream Hydrologic Connectivity	+130 m (+2% of total road length)	-39 m (-1% of total road length)
Fine Sediment Delivery	+11,799 kg/yr (+255%)	-4,227 kg/yr (-74%)
Landslides	Storm-related damage may impact stability of recontoured fills on lower roads, but risks are low	No significant change
Gullies	+5 drains above ESI_{crit}, 16 above	No significant change
Drain Point Problems	+6 (11%)	+1 (2%)

[*] *Effects of storm, for control and treatment roads, are measured from the most recent inventory prior to the storm; the post-treatment inventory is used for the treated roads. Nearly two years passed between pre- and post-storm inventories. Note that not all inventories covered the same length of road: Pre-treatment, 5,778 m; Post-treatment, 5,831 m; Post-storm Treatment, 5,740 m; Pre-storm Control, 6,048 m; Post-storm Control, 6,042 m.*

Acknowledgements

We would like to thank the field crew members (Sarah Weeks, Kenyon Soleki, Katelin Aldritt, and Michael Barr) for collecting the inventory data. Caty Clifton and Kim Clarkin assisted with the site selection for this study. Ed Farren, Kate Day, and Caty Clifton provided review and comment on the draft manuscript.

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. Consequently, in Fiscal Year (FY) 2008, Congress authorized the Legacy Roads and Trails Program and in 2010 allocated the US Forest Service (USFS) $90 million to begin its implementation. This program is intended to reduce road and trail impacts and risks to watersheds and aquatic ecosystems by decommissioning unneeded roads, removing fish passage barriers, and addressing critical repair and maintenance needs.

Recognizing the importance of this program, the USFS, Rocky Mountain Research Station (RMRS) and Pacific Northwest (PNW) Region are implementing the Legacy Roads and Trails Monitoring Project (LRTMP) to evaluate the effectiveness of road restoration treatments being implemented on national forests in Oregon and Washington. 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 Umatilla National Forest (UNF) in the Granite Creek watershed in FY2008. 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 LRTMP is designed to assess the effectiveness of decommissioning, maintenance, and repair 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. 2007a, and Prasad et al. 2007b, 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., 2010). 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 (Cissel, et al., 2011). 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, slope position, and hydrologic regimes. Each site investigation also includes a final validation evaluation at both treatment and control sites following a substantial storm event (5-10 year recurrence 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

4.1 Regional Monitoring Sites

Through 2010, pre-treatment evaluations were completed at twenty-one sites[1] on national forests throughout the Pacific Northwest Region. Decommissioning has been implemented at eleven of these sites, three sites have received storage treatments, and seven sites have been treated with storm damage risk reduction methods (SDRR)[2] (Figure 1, Table 1). Eighteen post-treatment inventories and two post-storm validation evaluations were also completed since FY2008. Post-treatment and, to the degree possible, post-storm evaluations will be completed at the remaining sites in FY2011. In 2009, a similar study was begun in Regions 1, 4, and 5.

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[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] SDRR (also referred to as stormproofing) 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, waterbars, 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: Location of monitored sites, FY2008, PNW Region.

Table 1: List of sites and treatments in Region 6.

National Forest	Treatment	Watershed
Okanogan	Decommissioning	Methow / Twisp River
	Storm Damage Risk Reduction	Methow / Twisp River
Olympic	Decommissioning	Skokomish River
	Storm Damage Risk Reduction	Skokomish River
Mt. Hood	Decommissioning	Bull Run River
Mt. Baker - Snoqualmie	Decommissioning	Suiattle River
	Decommissioning	Baker Lake
	Storm Damage Risk Reduction	Skykomish River
	Storm Damage Risk Reduction	Suiattle River
Umatilla	Decommissioning	Wall Creek
	Decommissioning	Granite Creek
	Storm Damage Risk Reduction	Granite Creek
Siuslaw	Decommissioning	Alsea River
	Storm Damage Risk Reduction	Nestucca River
Willamette	Storm Damage Risk Reduction	Hills Creek
	Storm Damage Risk Reduction	Hills Creek
Wallowa - Whitman	Decommissioning	Chesnimus Creek
Umpqua	Decommissioning	North and South Forks Umpqua River
Rogue River	Decommissioning	Applegate River
	SDRR	Applegate River
	Storage	Applegate River

4.2 Granite Creek Sites

The Granite Creek watershed covers an area of 146 square miles of Grant county in the Blue Mountains of eastern Oregon. The treatment roads are located in the northern part of the Granite Creek watershed, which is dominantly Tertiary andesites overlying Paleozoic to Triassic marine sediments of the Rattlesnake terrane. Elevations within the watershed range from 3,900 to 8,300 feet above sea level; the roads described in this study are between 4,400 and 5,500 feet above sea level. Annual precipitation is between 24” and 28”, largely as snow during the winter. Vegetation communities vary from forest-grassland mosaics to Ponderosa pine woodlands, to mixed conifer and sub-alpine forests in the higher portions of the watershed.

Decommissioning techniques applied to roads within the Granite Creek watershed included excavation and removal of stream crossing and ditch relief culverts, and recontouring, ripping, and tilling the road surface. All heavy equipment work was contracted. The sequence of decommissioning actions for all roads was as follows. During the Instream Work Window (July 15 to Aug 15, 2008): 1) An excavator walked from the access point to farthest end of road and cleared logs and boulders off the road surface. The excavator was followed by a pick-up which stockpiled bales of native seed straw at all stream crossings. After placing the straw and servicing the excavator, the pick-up returned to the beginning point. 2) A D-7 dozer started at the access point and ripped the road surface to farthest end and back to beginning. 3) The excavator recontoured road surface back to beginning point. Excavator replaced original logs and trees on road prisms and fills. The trees and logs were placed perpendicular to the contour to discourage OHV traffic. Where available, logs were placed parallel to contour at the lower edge of prism, to detain any overland flow. When the excavator finished work at each crossing, the operator and inspector placed the stockpiled straw to reduce short term erosion. This was the end of the construction phase. About 83 percent of the road surface was recontoured (road prism returned to near natural hillslope grade), 7.5 % was ripped (using ripping tines on the back of a bulldozer), and 8.8% was tilled (road surface turned using an excavator, often to bucket depth; grades into recontour when hillslopes approach horizontal). Water bars are generally not needed in the Granite Watershed after roads are ripped.

In October, 2008, seasonal employees spread native grass and forb seed on all disturbed surfaces to reduce erosion. In June, 2009, a contractor planted, tubed, and caged hardwood trees on streams adjacent to decommissioned roads. In October, 2010, North Fork John Day Watershed Council in cooperation with Eco-Trust, planted and tubed conifers on the decommissioned roads. This ended the revegetation phase.

Table 2: Road treatments by road number.

Road #	Treatment
1035-030	Stream crossing extraction, recontouring, culvert removal. Road ripped above junction with 1035-035.
1035-032	Stream crossing extraction, recontouring, and culvert removal.
1035-035	Stream crossing extraction, recontouring, ripping, and culvert removal.
1038-011	Stream crossing extraction, recontouring, and culvert removal.
1038-035	Stream crossing extraction, recontouring, culvert removal. Some lower portions tilled.
7350-080	Stream crossing extraction, recontouring, and culvert removal.
1038-031	Control - No Treatment
7355-020*	Control - No Treatment

*Road numbers verified using GIS roads layer produced by Umatilla National Forest, http://www.fs.fed.us/r6/data-library/gis/umatilla/data/Transportation_mal.zip

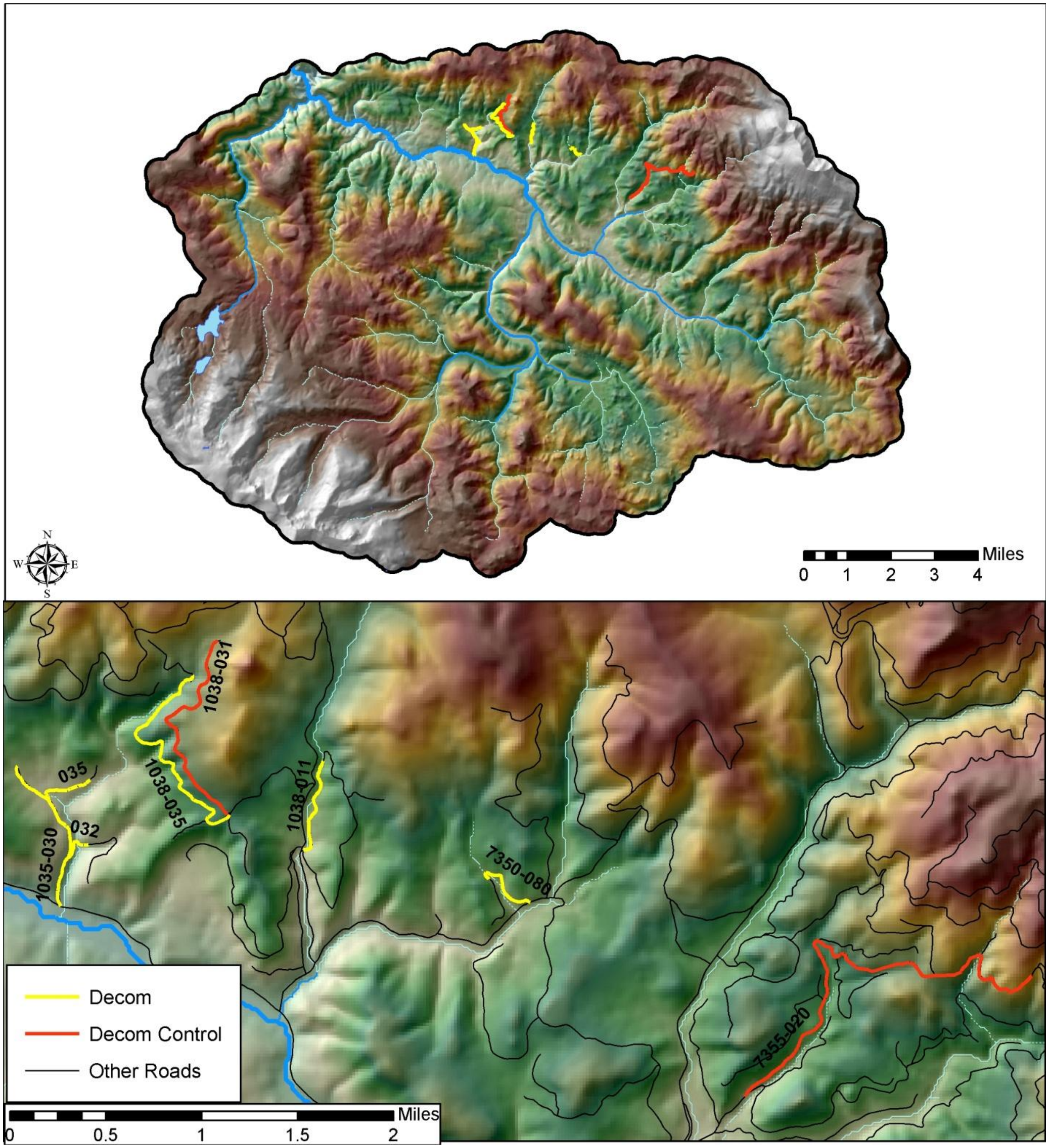

Figure 2: Locations of monitored roads in the Granite Creek watershed, Umatilla National Forest.

5.0 Storm Events

SNOTEL stations near the Granite Creek site (Gold Center, Eilertson Meadow, Tipton, and Bourne) recorded rainfall intensities during a series of storms on the first and second of June, 2010, in excess of the 5 year return intervals for 24 hour events. Floods resulting from these storms had return intervals of 2.5 years (13,300 cfs, ranked 33rd in 83 years of daily records) on the North Fork John Day River at Monument, Oregon, 4.5 years (2520 cfs, ranked 18th in 82 years) on the Middle Fork John Day River at Ritter, Oregon, and 13.7 years (2,500 cfs, ranked 3rd in 41 years), on the John Day River at John Day, Oregon. Granite Creek is an ungaged tributary of the North Fork John Day River. All of these stream gages are at lower elevation and have much greater drainage areas but indicate the flows in contributing tributaries during this period.

6.0 Results

The GRAIP inventory and modeling tools were used to characterize the following types of impacts and risks:

- Road-stream hydrologic connectivity
- Fine sediment delivery
- Landslide risk
- Gully initiation risk
- Stream crossing failure risk
- Drain point problems

The Granite decommissioning treatments were designed to achieve two objectives. The first objective was to reduce chronic low level soil erosion and stream sedimentation and lower the risk of gullying and mass wasting by stabilizing road prisms and surfaces, redistributing fills, removing culverts, and increasing infiltration. The second objective was to increase shade along streams by increasing riparian vegetation productivity and diversity.

6.1 Road-stream Hydrologic Connectivity

Roads can intercept shallow groundwater and convert it to surface runoff, resulting in local hydrologic impacts when that water is discharged directly to channels (Wemple et al., 1996). Additional runoff is also produced from the compacted road surface. Basin-scale studies in the Oregon Cascades suggest that a high degree of integration between the road drainage system and the channel network can increase some peak flows (Jones and Grant, 1996).

GRAIP calculates the hydrologically-connected portion of the road using the field assessment of drain point connection and a road segment flow routing system. The flow path below each drain point is followed until evidence of overland flow ceases or the flow path reaches a natural channel. In the Granite Creek watershed, treatments increased the amount of road that was hydrologically connected to the stream network, especially along road 1038-011. Prior to treatment, 9% (499 m out of 5,778 m) of the road was connected to the stream network (Figure 3); following treatment, 17% (965 m out of 5,831 m) of the road network was connected (Figure 4), and 16% (926 m out of 5,740 m) was connected following the storms and snowmelt of June 2010 (Figure 5). Close proximity to the stream increased the risk that disturbances related to road treatment would result in hydrologic connections. The disturbed area associated with recontouring the 1038-011 reduced the amount of buffer space between the road and the stream; this buffer space was already minimal prior to treatment and disturbances within the buffer space during treatment allowed diffuse drainage from the recontoured road to connect with the stream. Diffuse drainage consists of fine rivulets or inter-granular flow without evidence of concentration in the downslope direction. Due to the reduced flow volumes and velocities, infiltration may be greater and sediment delivery per length of road may be much lower than comparable sections of road drained by concentrated flow at a different drainpoint.

Eight percent of the length of untreated control roads were hydrologically connected(475 m out of 6,048 m) in 2008 prior to decommissioning work on the treatment roads. After the storm events in June 2010, connectivity on the control roads increased to 10% (605 m out of 6,042 m).

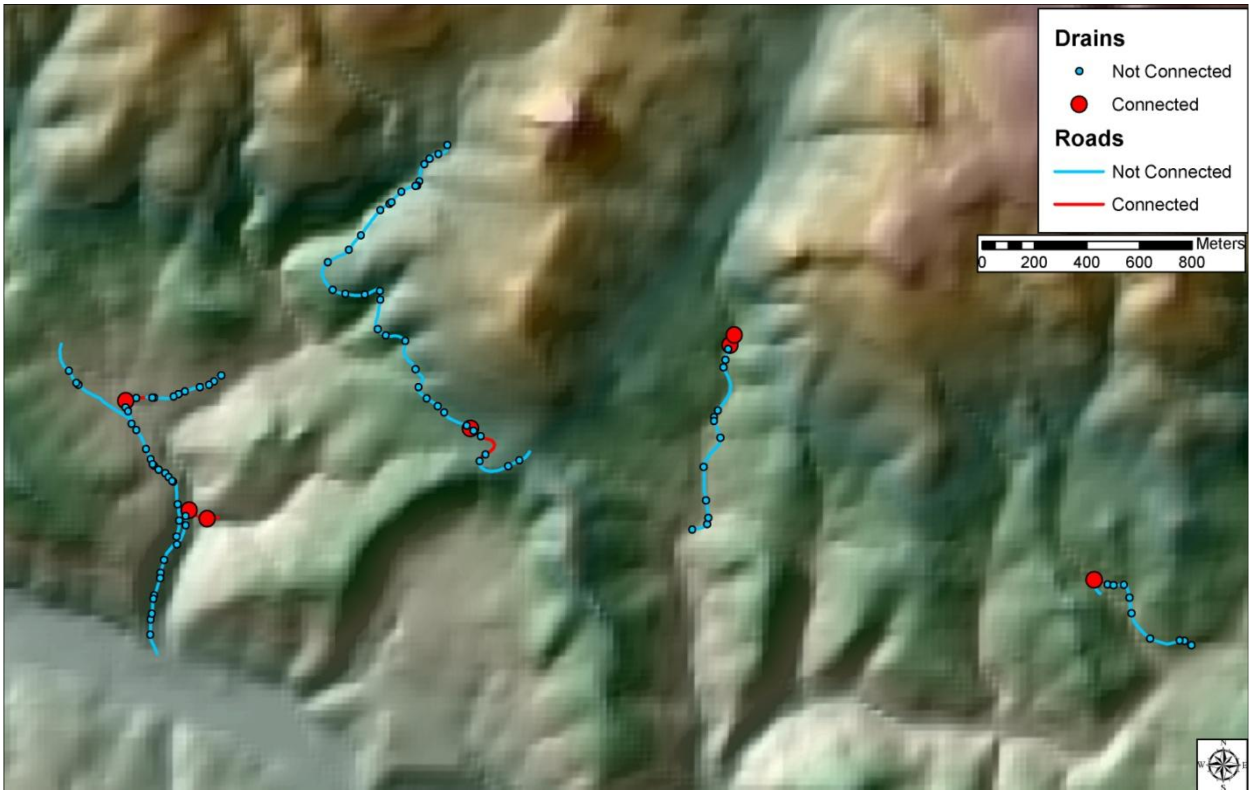

Figure 3: Stream connection, pre-treatment road.

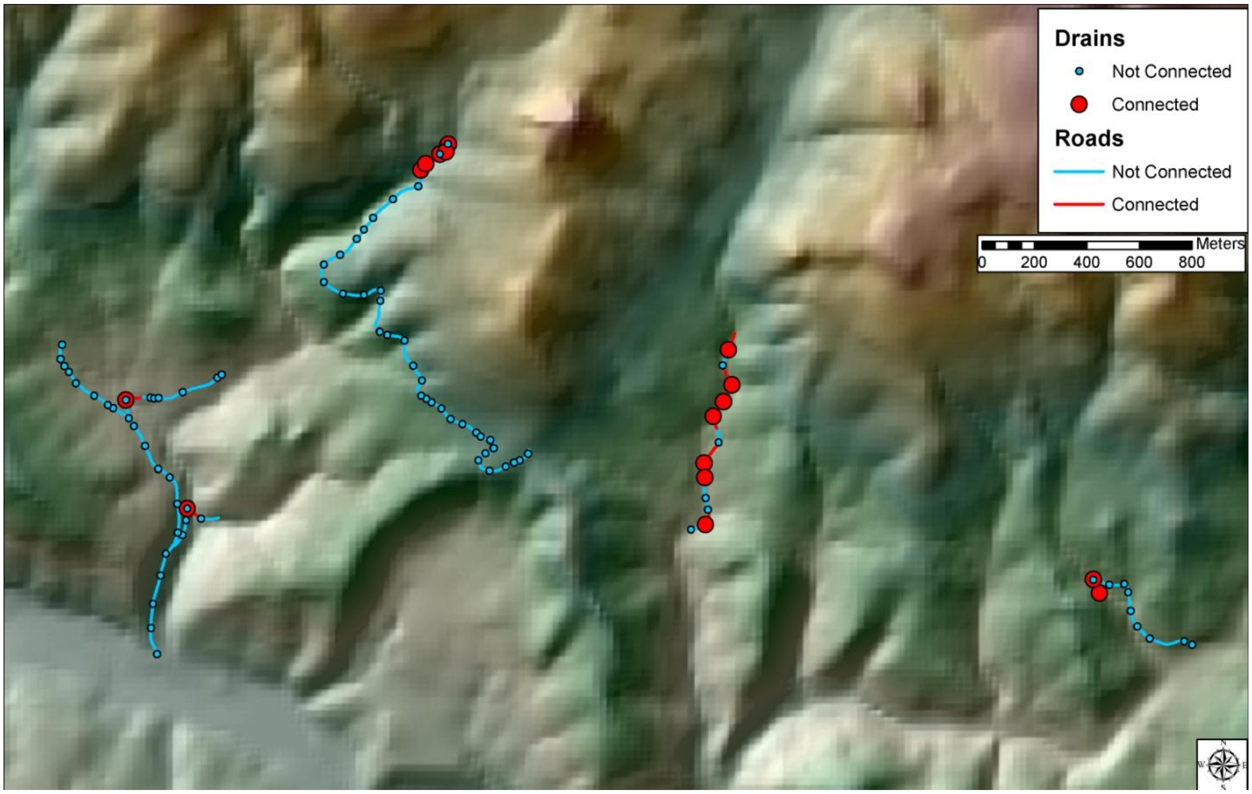

Figure 4: Stream connection, post-treatment road.

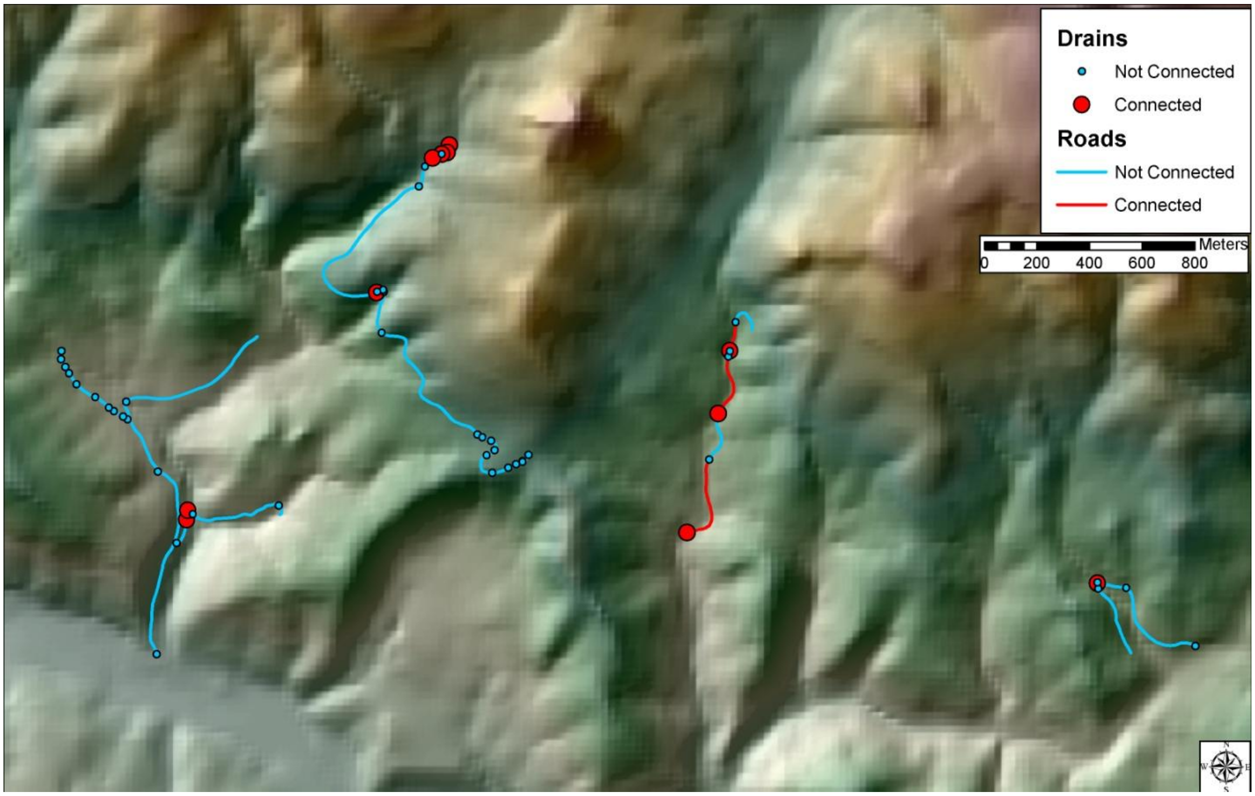

Figure 5: Stream connection, post-storm treatment road.

6.2 Fine Sediment Production & Delivery

Fine sediment production for a road segment (E) is estimated based on a base erosion rate and the properties of the road (Luce and Black 1999), as shown below.

$$E = B \times L \times S \times V \times R$$

B is the base erosion rate[3] (kg/m)
L is the road length (m) contributing to the drain point
S is the slope of the road segment discharging to the drain point (m/m)
V is the vegetation cover factor for the flow path
R is the road surfacing factor

Delivery of eroded sediment to the channel network is determined by observations of each place that water leaves the road. Each of these drain points is classified as delivering, not delivering, or uncertain. No estimate of fractional delivery is made because there is insignificant hillslope sediment storage in locations where there is a clear connection to the channel under most circumstances. For this analysis, uncertain observations were treated as delivering.

While GRAIP works well with typical roads, where water generally flows along the road for some distance before draining from the road, it was not designed to specifically handle the altered flow on a recontoured road. Erosion and flow on recountoured surfaces is similar to that on disturbed hillslopes. The result is that flow on a recontoured road is transverse, rather than longitudinal as on other roads, and this presents a geometry problem for GRAIP's sediment production calculations. Sediment production from recontoured road segments was manually re-calculated during the GRAIP model run using a slope-area method derived from cutslope sediment data obtained during the Low Pass sediment study (Luce and Black, 1999); the Low Pass sediment study was also used to develop the default baserate used by GRAIP. This allows better predictions of sediment production from the recontoured surfaces.

Treatment Roads

Pre-treatment

Delivery of fine sediment occurs through a mix of road drainage features including ditch relief culverts, waterbars, stream crossings and others. Appendix A provides a key to the drain point types described in the inventory.

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[3] For this analysis, a base erosion rate of 79 kg/m of road elevation was assumed, based on observations in the Oregon Coast Range (Luce and Black 1999). This base rate was chosen to allow comparisons to other Legacy Roads project reports and because there is no established base rate in this watershed.

Pre-treatment roads found to be in generally good condition (80%), with the remainder considered rocky (13%) or rutted (7%). Eleven percent of the road surface was considered to be native soil; 47% was crushed rock and the remaining 42% was covered in herbaceous vegetation. Figure 6 provides examples of typical road conditions.

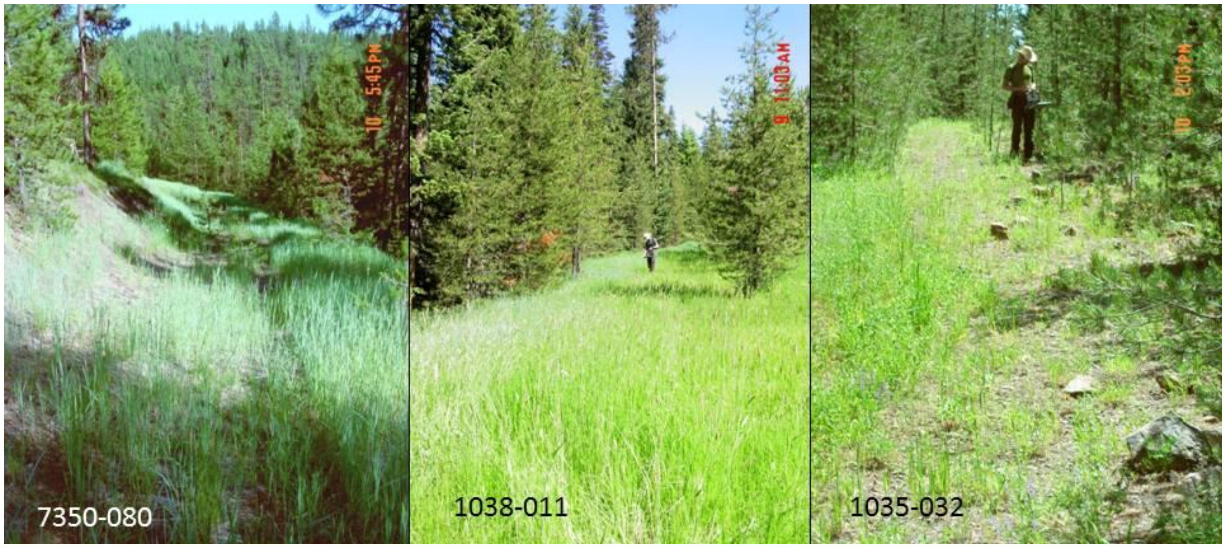

Figure 6: Typical pre-treatment road conditions.

In Table 3, sediment delivery is categorized by drain type to assess their effectiveness in preventing sediment from entering the channel. However, the sample shown here is too small for extensive statistical analysis by drain point. Figure 7 shows sediment production and delivery along the pre-treatment roads. One-hundred and two drain points were documented, 11% of which were hydrologically connected to stream channels. These points delivered 2.2 tonnes/year of sediment, or 6% of the sediment generated by the road surfaces and ditches.

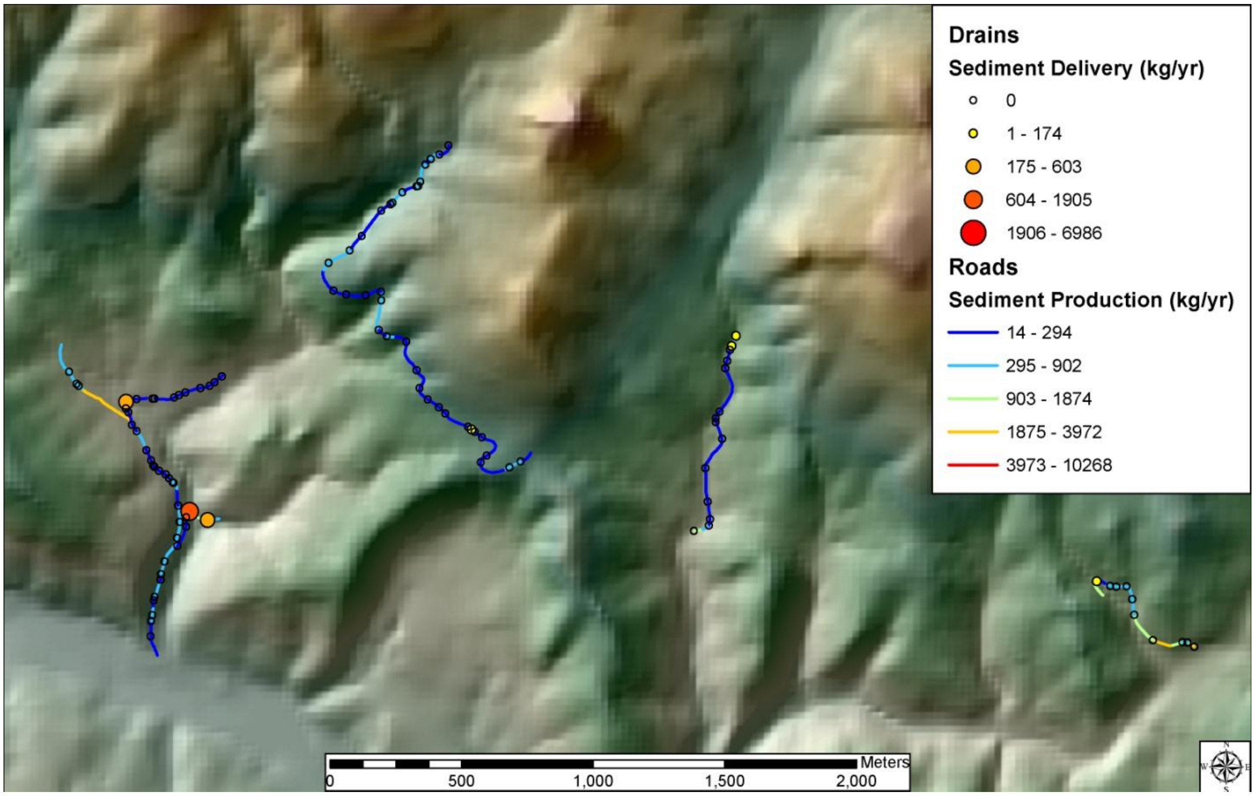

Figure 7: Sediment production and delivery, pre-treatment roads.

Table 3: Summary of sediment production and delivery by drainpoint type, pre-treatment road.

Drain Type	Count		Sediment Received (kg/yr)	Sediment Delivered (kg/yr)	% Sediment Delivery	% Effective Length Connected
	All	Connected				
Broad Based Dip	15	0	7,249	0	0%	0%
Diffuse Drain	55	0	10,902	0	0%	0%
Ditch Relief Culvert	4	1	330	143	43%	38%
Non-Engineered Drain	7	3	6,440	474	7%	15%
Stream Crossing	7	7 (4 orphan)	1,587	1,587	100%	100%
Sump	4	0	3,564	0	0%	0%
Water Bar	10	0	5,148	0	0%	0%
All Drains	**102**	**11**	**35,220**	**2,203**	**6%**	**6%**

Post-treatment

Several types of treatments were used to decommission roads in the Granite Creek watershed. About 83% of the treated roads was recontoured, 7.5% was ripped, and a further 8.8% was tilled. In addition, culverts were removed at stream crossings and ditch relief sites, and some water bars were constructed along ripped or tilled road sections. Typical treatments are shown in Figure 8.

Figure 8: Post-treatment road conditions. Ripped / tilled road on left; recontoured road on right.

Following treatment, sediment production increased from 35.2 Mg/yr to 58.8 Mg/yr and sediment delivery increased from 2.2 Mg/yr to 5.7 Mg/yr, with 97% delivered at diffuse drains (Table 4). These increases are likely due to changes in cover condition by temporary conversion of vegetated and/or crushed rock road surfaces (present in some areas) with bare native/mixed rock surfaces, resulting in increased short term sediment production and hydrologic connection between the road and the stream. Most of the new stream connections are at diffuse drains located along the 1038-011 road (Figure 9). The proximity of roads to streams likely increased the development of hydrologic connections. Over the next few years as treated surfaces revegetate, connectivity, and sediment delivery, may be reduced.

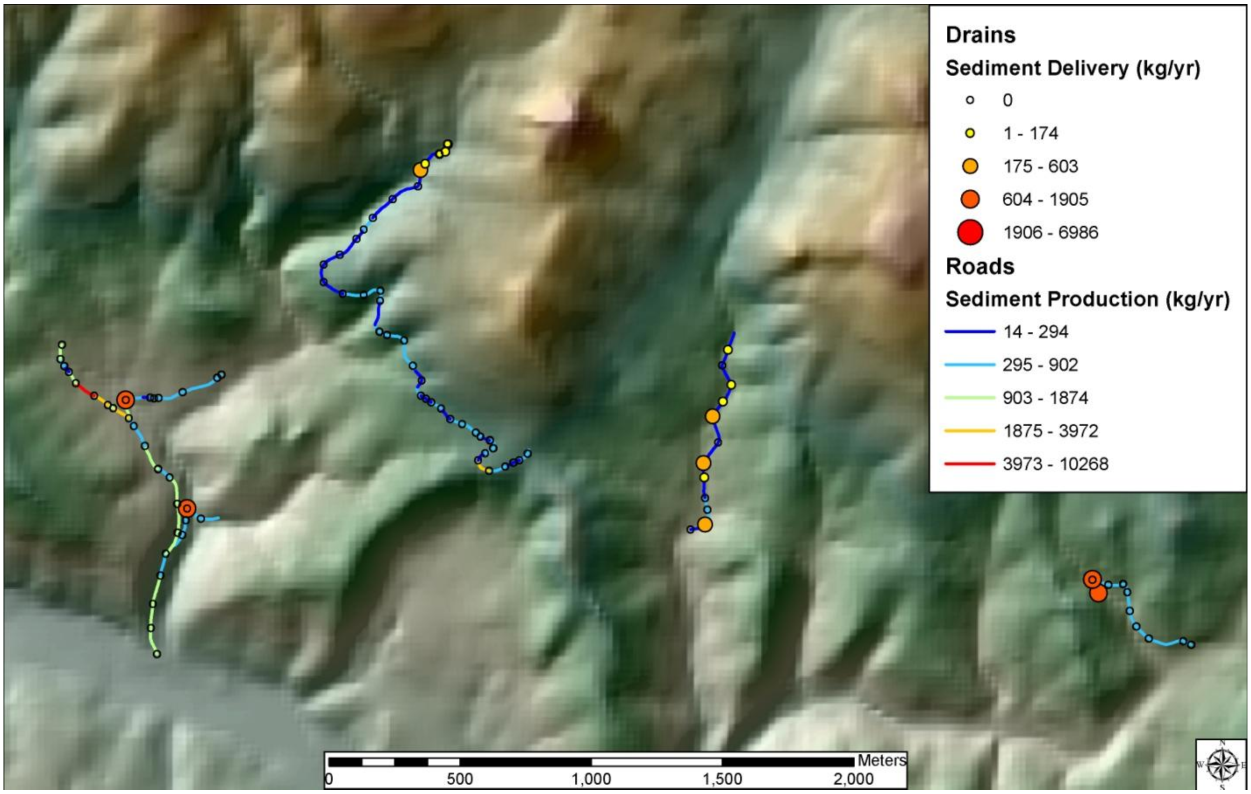

Figure 9: Sediment production and delivery, post-treatment roads.

Table 4: Summary of sediment production and delivery by drainpoint type, post-treatment road.

Drain Type	Count		Sediment Received (kg/yr)	Sediment Delivered (kg/yr)	% Sediment Delivery	% Effective Length Connected
	All	Connected				
Broad Based Dip	8	0	0	0	0%	0%
Diffuse Drain	89	14	58,678	5,525	9%	16%
Stream Crossing	7	7 (7 orphan)	0	0	0%	0%
Water Bar	12	2	154	154	100%	100%
All Drains	**116**	**23**	**58,832**	**5,680**	**10%**	**17%**

The applied treatments resulted in removal of existing vegetation along the roads. All told, sediment production increased by 23.6 Mg/yr and sediment delivery increased by 3.5 Mg/yr (Table 5). The largest changes were the results of new diffuse drainage and removal of broad based dips and non-engineered drains.

Table 5: Changes in sediment production and delivery by drainpoint type, post-treatment v. pre-treatment.

Drain Type	Δ Count		Δ Sediment Received (kg/yr)	Δ Sediment Delivered (kg/yr)	Δ % Sediment Delivery	Δ % Effective Length Connected
	All	Connected				
Broad Based Dip	-7	0	-7,249	0	0%	0%
Diffuse Drain	34	14	47,776	5,525	9%	16%
Ditch Relief Culvert	-4	-1	-330	-143	-43%	-38%
Non-Engineered Drain	-7	-3	-6,440	-474	-7%	-15%
Stream Crossing	0	0 (+3 orphan)	-1,587	-1,587	0%	0%
Sump	-4	0	-3,564	0	0%	0%
Water Bar	2	2	-4,994	154	100%	100%
All Drains	**14**	**12**	**23,612**	**3,476**	**3%**	**11%**

Post-storm

Following the storm event at the beginning of June, 2010, a crew re-inventoried the treatment and control roads. Increased vegetation cover likely contributed to reduced sediment production to 6.4 Mg/yr, though connectivity remained relatively high (16%). Typical conditions are shown in Figure 10.

Figure 10: Typical road conditions during the post-storm inventory. The section of the 1038-011 shown here (right) was connected to the stream during treatment.

Sediment delivery was at 1.5 Mg/yr, or 23% of production (Table 6). Eighty-seven percent of the delivered sediment was delivered by diffuse drains, mostly along the 1038-011 road (Figure 11).

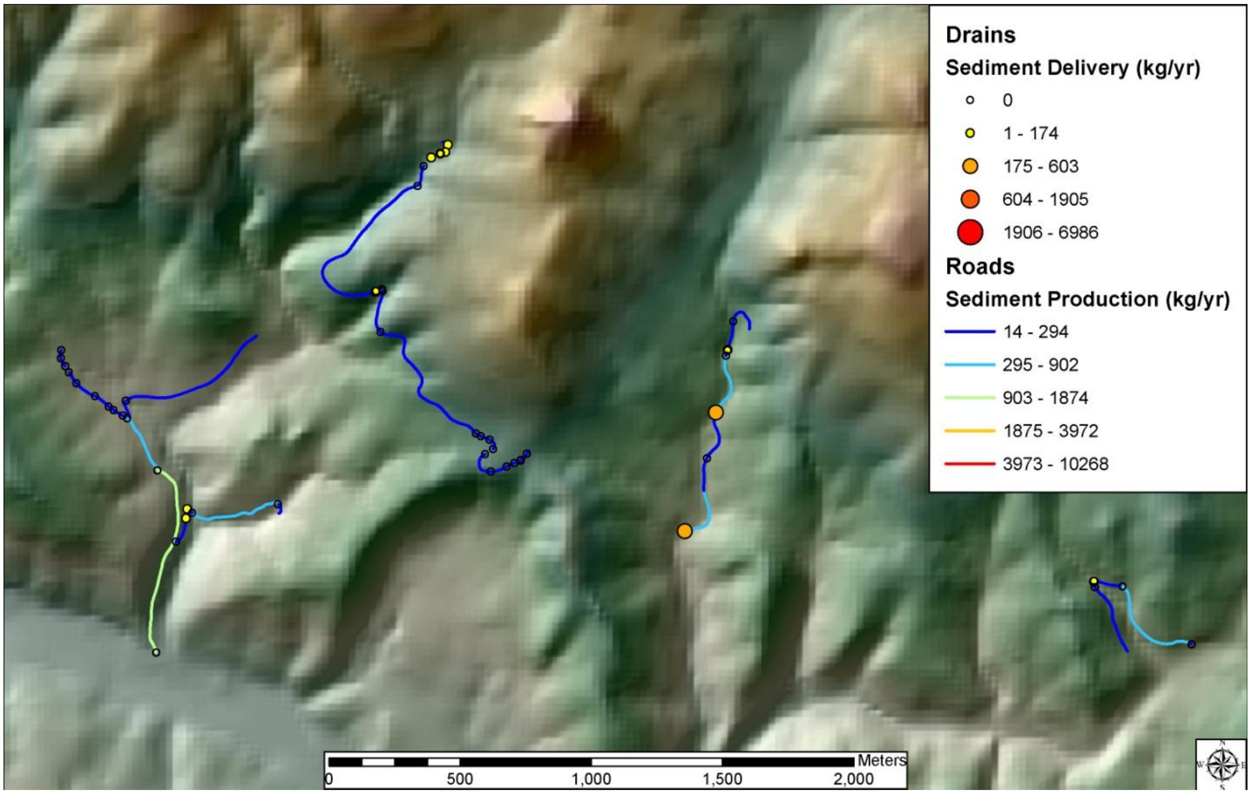

Figure 11: Sediment production and delivery, post-storm treatment roads.

Table 6: Summary of sediment production and delivery by drainpoint type, post-storm treatment road.

Drain Type	Count		Sediment Received (kg/yr)	Sediment Delivered (kg/yr)	% Sediment Delivery	% Effective Length Connected
	All	Connected				
Diffuse Drain	21	8	6,153	1,263	21%	15%
Water Bar	23	1	91	55	60%	12%
Excavated Stream Crossing	6	6 (4 orphan)	135	135	100%	100%
All Drains	**50**	**15**	**6,379**	**1,452**	**23%**	**16%**

The most significant change noted in the post-storm inventory is the large decrease in sediment production, and therefore delivery, on diffusely drained road segments (Tables 7 and 8).

Table 7: Changes in sediment production and delivery by drainpoint type, post-storm v. post-treatment.

Drain Type	Δ Count		Δ Sediment Received (kg/yr)	Δ Sediment Delivered (kg/yr)	Δ % Sediment Delivery	Δ % Effective Length Connected
	All	Connected				
Broad Based Dip	-8	0	0	0	0%	0%
Diffuse Drain	-68	-6	-51,521	-4,263	11%	-1%
Stream Crossing	-1	-1 (-3 orphan)	135	135	0%	0%
Water Bar	11	-1	-63	-99	-40%	-88%
All Drains	**-66**	**-8**	**-51,453**	**-4,227**	**13%**	**0%**

Table 8: Changes in sediment production and delivery by drainpoint type, post-storm v. pre-treatment.

Drain Type	Δ Count		Δ Sediment Received (kg/yr)	Δ Sediment Delivered (kg/yr)	Δ % Sediment Delivery	Δ % Effective Length Connected
	All	Connected				
Broad Based Dip	-15	0	-7,249	0	0%	0%
Diffuse Drain	-34	8	-4,749	1,263	21%	15%
Ditch Relief Culvert	-4	-1	-330	-143	-43%	-38%
Non-Engineered Drain	-7	-3	-6,440	-474	-7%	-15%
Stream Crossing	-1	-1 (0 orphan)	-1,452	-1,452	0%	0%
Sump	-4	0	-3,564	0	0%	0%
Water Bar	13	1	-5,057	55	60%	12%
All Drains	**-52**	**4**	**-28,841**	**-751**	**17%**	**10%**

Control Roads

Pre-storm

The control roads were selected and first inventoried at the same time the pre-treatment inventory was conducted for the treatment roads. The initial survey found that the majority (64%) of the road was in good condition; the rest was rutted (19%), rocky (12%), or rilled/eroded (5%). The majority (73%) of the road had a crushed rock surface; 26% of the road had native soil for surfacing and 1% was covered with herbaceous vegetation. Figure 12 shows typical conditions along the 7355-020 road; the 1038-031 had more vegetation.

Figure 12: Typical control road sections, pre-storm. Crushed rock surface on left; native surface with gullied wheel track on right. Both pictures from the 7355-020 road.

Sediment production on the control roads at the time of the pre-treatment inventory was 73.6 Mg/yr, with 4.6 Mg/yr (6%) delivered to the stream network (Table 9). This higher sediment production rate, compared to the treatment roads, is likely due to the lack of vegetation on the road surface and in the flowpaths. Eight percent of the control roads were hydrologically connected to the stream network. All of the sediment delivery occurred via drainpoints on the 7355-020 road (Figure 13).

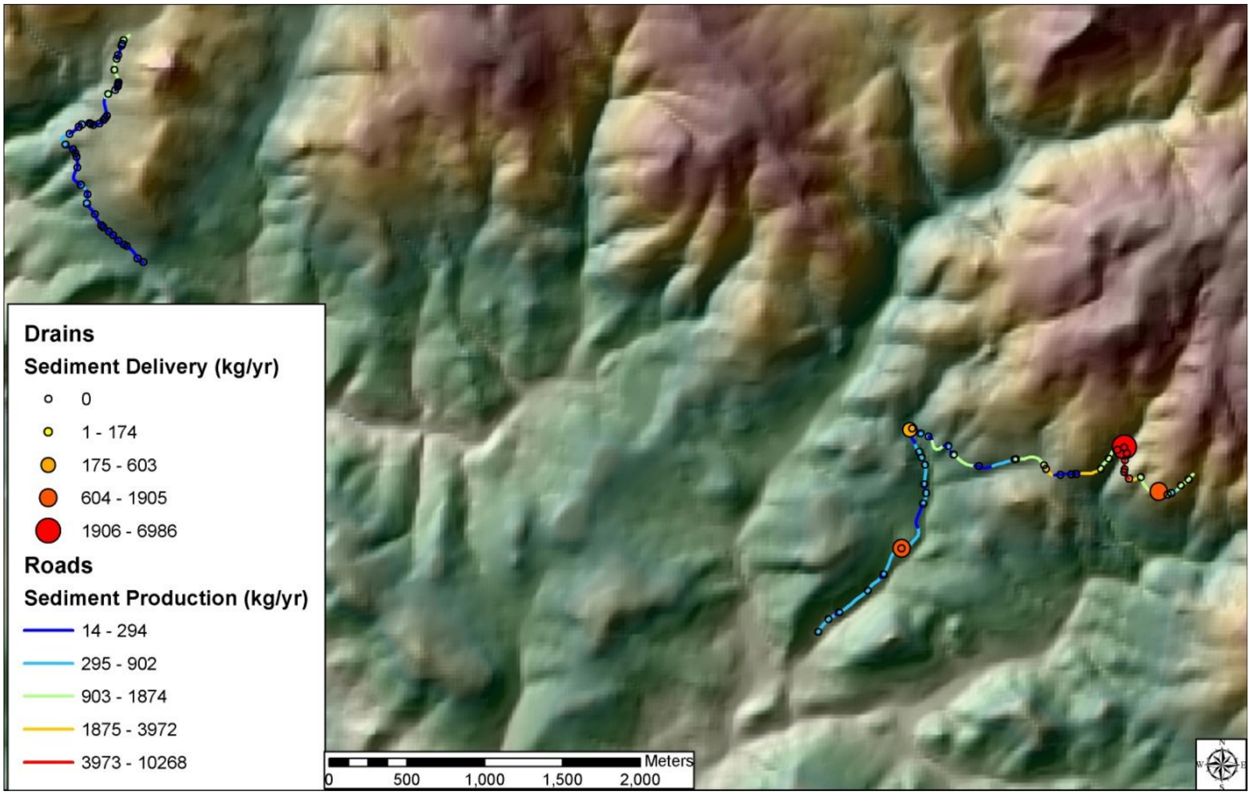

Figure 13: Sediment production and delivery, pre-storm control roads.

Table 9: Summary of sediment production and delivery by drainpoint type, pre-storm control road.

	Count					
Drain Type	**All**	**Connected**	**Sediment Received (kg/yr)**	**Sediment Delivered (kg/yr)**	**% Sediment Delivery**	**% Effective Length Connected**
Broad Based Dip	27	1	39,600	2,255	6%	3%
Diffuse Drain	19	0	8,395	0	0%	0%
Ditch Relief Culvert	5	0	398	0	0%	0%
Non-Engineered Drain	7	1	16,075	806	5%	38%
Stream Crossing	4	4 (2 orphan)	1,573	1,573	100%	100%
Sump	3	0	542	0	0%	0%
Water Bar	18	0	7,015	0	0%	0%
All Drains	**83**	**6**	**73,599**	**4,635**	**6%**	**8%**

Post-storm

The post-storm inventory took place in June, 2010. Sixty-five percent of the road surface was found to be crushed rock, with the remaining 35% surfaced with native soil. Eighty-seven percent of the road was reported to be in good condition, with 9% rilled/eroded and 4% rutted. Typical conditions are shown in Figure 14.

Figure 14: Typical control road conditions, post-storm.

Sediment production decreased slightly to 68.6 Mg/yr. Sediment delivery, however, increased 350% up to 16.4 Mg/yr (24% of the produced sediment; Table 10). All of the sediment delivery remained along the 7355-020 road (Figure 15).

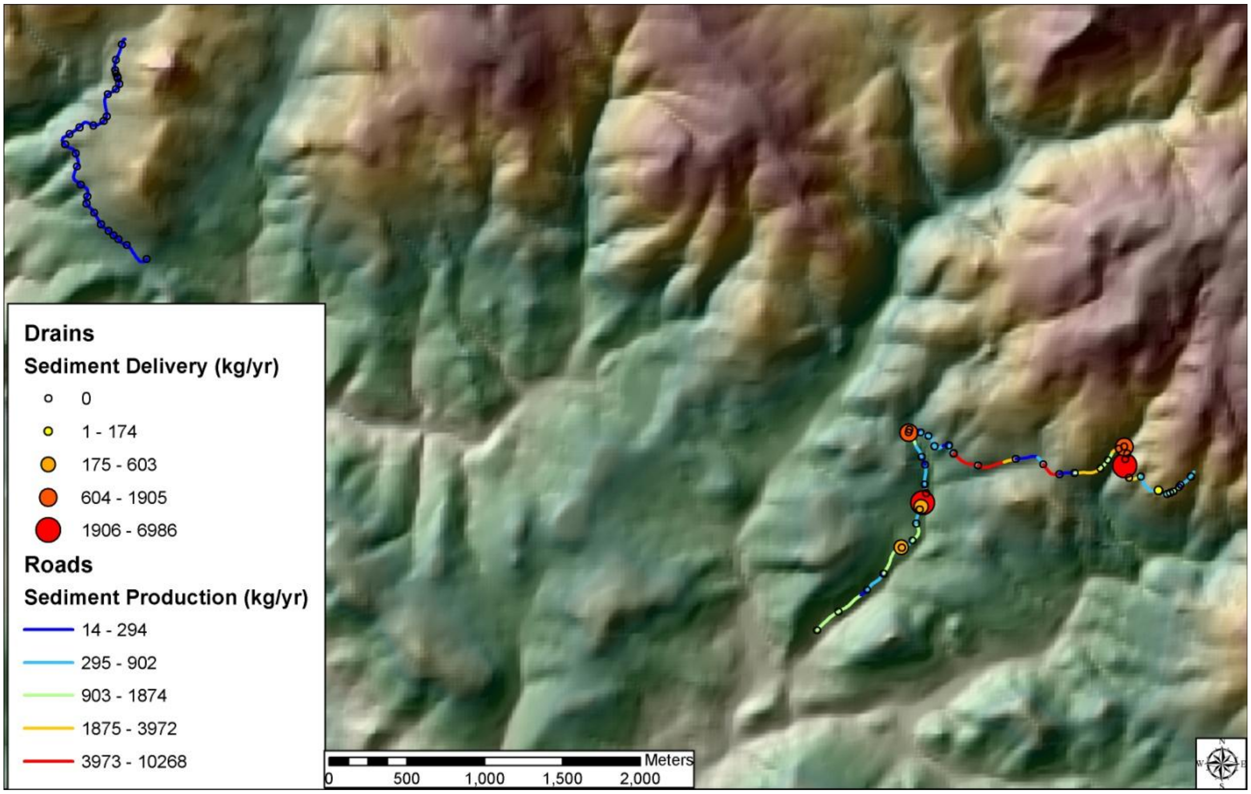

Figure 15: Sediment production and delivery, post-storm control roads.

Table 10: Summary of sediment production and delivery by drainpoint type, post-storm control road.

Drain Type	Count		Sediment Received (kg/yr)	Sediment Delivered (kg/yr)	% Sediment Delivery	% Effective Length Connected
	All	Connected				
Broad Based Dip	31	3	45,881	7,384	16%	9%
Diffuse Drain	3	0	340	0	0%	0%
Ditch Relief Culvert	6	0	245	0	0%	0%
Non-Engineered Drain	13	4	18,896	8,875	47%	41%
Stream Crossing	5	5 (4 orphan)	174	174	100%	100%
Sump	1	0	1,461	0	0%	0%
Water Bar	16	0	1,553	0	0%	0%
All Drains	**75**	**12**	**68,551**	**16,434**	**24%**	**10%**

During the intervening time between the initial control road inventory in 2008 and the post-storm inventory in June of 2010, the amount of vegetation present in the flowpaths on the roads increased. This increase in vegetation resulted in slightly lower sediment production. Differences in sediment production and delivery are reported in Table 11. While a few of these changes may be due to crew interpretation (one crew described the start of a road as a sump, the other later called it a waterbar), most of the changes are the result of actual changes. Most of the diffuse drainage along the 1038-031 was converted to concentrated flow with drainage at broad based dips or non-engineered drains. At least one of the new broad based dips was previously diffuse drainage; this drain is located in a swale (natural grade reversal) and may not have been recorded in 2008 if there was no evidence of concentrated flow. The additional stream crossing is an 18” pipe that was not previously recorded and likely missed during the 2008 inventory; it drains a small ephemeral channel that may have extended above the road during the storm.

Table 11: Changes in sediment production and delivery by drainpoint type, post-storm v. pre-storm control road.

Drain Type	Δ Count		Δ Sediment Received (kg/yr)	Δ Sediment Delivered (kg/yr)	Δ % Sediment Delivery	Δ % Effective Length Connected
	All	Connected				
Broad Based Dip	4	2	6,281	5,129	10%	6%
Diffuse Drain	-16	0	-8,055	0	0%	0%
Ditch Relief Culvert	1	0	-153	0	0%	0%
Non-Engineered Drain	6	3	2,821	8,068	42%	2%
Stream Crossing	1	1 (+2 orphan)	-1,399	-1,399	0%	0%
Sump	-2	0	919	0	0%	0%
Water Bar	-2	0	-5,462	0	0%	0%
All Drains	**-8**	**6**	**-5,048**	**11,799**	**18%**	**3%**

6.3 Landslide Risk

No landslides were recorded during any of the inventories associated with this study. Landslide risks in the project area of the Granite Creek watershed are likely to be relatively low.

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, and locally calibrated to known locations of landslides in the rock type underlying the treatment road (dominantly andesites). 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. Landslide risk grids depicting the risks associated with pre-treatment, post-treatment, or post-storm road conditions are subjected to a series of mathematical operations that result in grids that show the important changes to landslide risk due to the treatments. These change grids are compared to the natural landslide risk grid (Figure 16) to show how the treatment and storm events affects 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-treatment and 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 after the treatment and storm.

Figures 16 through 19[4] illustrate the risk and change in risk in the area. SINMAP was run initially to determine the intrinsic stability of the slopes over which the road traverses and to identify locations that are at high risk of failure without the road. Since no landslide calibration

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[4] Figure 17 is rendered at half scale compared to figures 18 and 19. The legend items for each figure are consistent from one figure to the next.

data was available, SINMAP's default values were used and this may result in over-estimation of landslide risks; relative changes due to treatment or storm damage can still be shown. The inherent landslide risk is predicted to be low to moderate in the area of the inventoried roads (Figure 16).

A second stability index (SI) run was performed to address the effects of road water contribution to drain points on the original, pre-treatment road network. A third model run was performed to illustrate the risk of shallow landsliding with the modified road drainage system resulting from the restoration treatments. A fourth model run was used to determine the effects of the storm event on the treated roads.

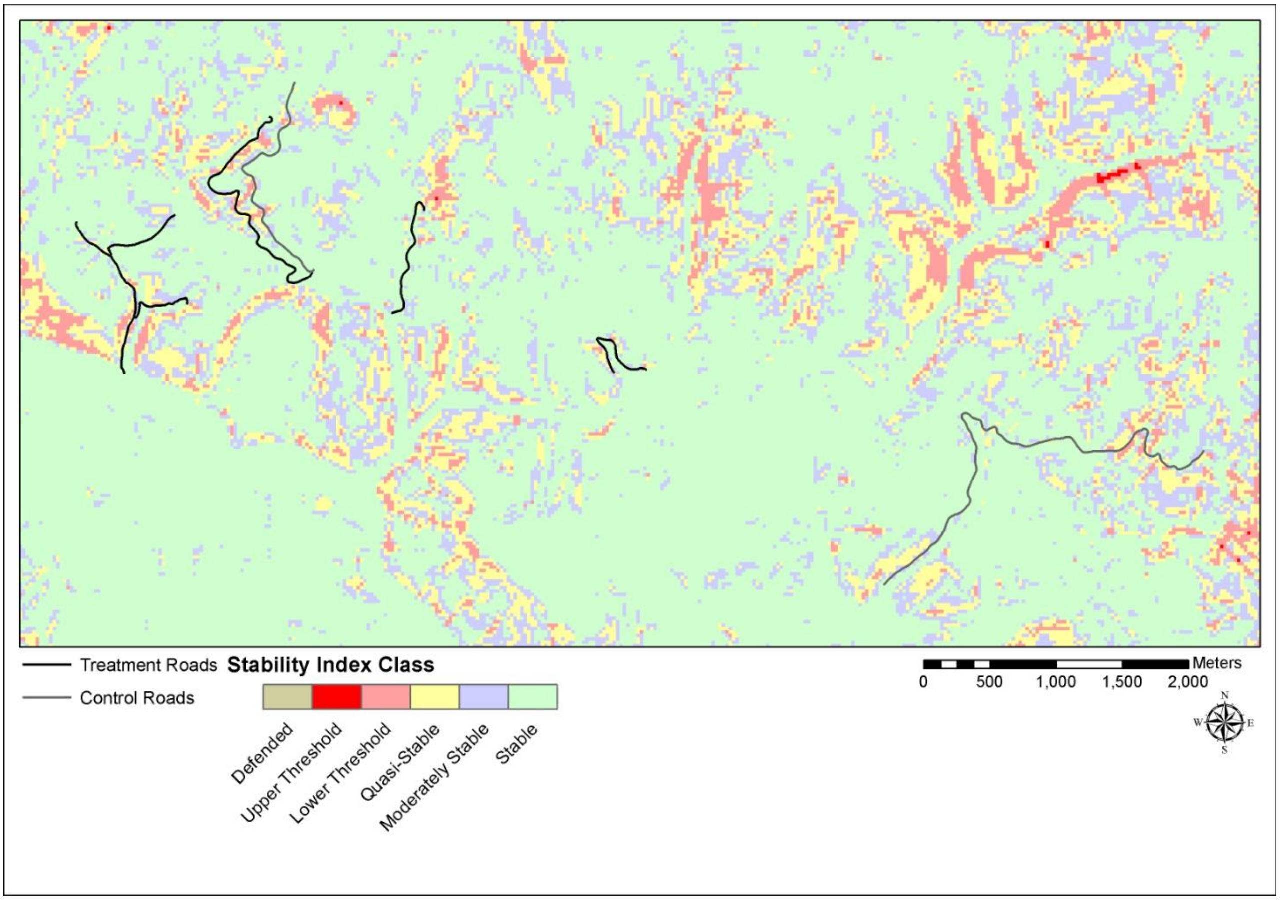

Figure 16: Natural slope stability in the area of the monitored Granite Creek basin roads. The yellow, blue, and green cells are generally qualified as stable, while the pink, red, and tan cells are generally qualified as unstable.

In Figure 17, the areas along the treated roads where the treatment changed the risk from the unstable category (defended, upper threshold, and lower threshold from Figure 16, above) to the stable category (quasi-stable, moderately stable, and stable) are shown in green, and areas where the treatment 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). Note that the treatments had very limited effects on slope stability, though no areas were destabilized by the treatments. Figure 17 also shows the areas where the risk of shallow landsliding was high (unstable grid cells) both before and after treatment. The light blue cells are areas where the risk decreased (became more stable), but the terrain was still unstable after treatment. For the most part, this was because the inherent natural (road drainage not considered) landslide risk is high at those locations. This may also be 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. Naturally unstable areas are shown with a cross-hatch pattern.

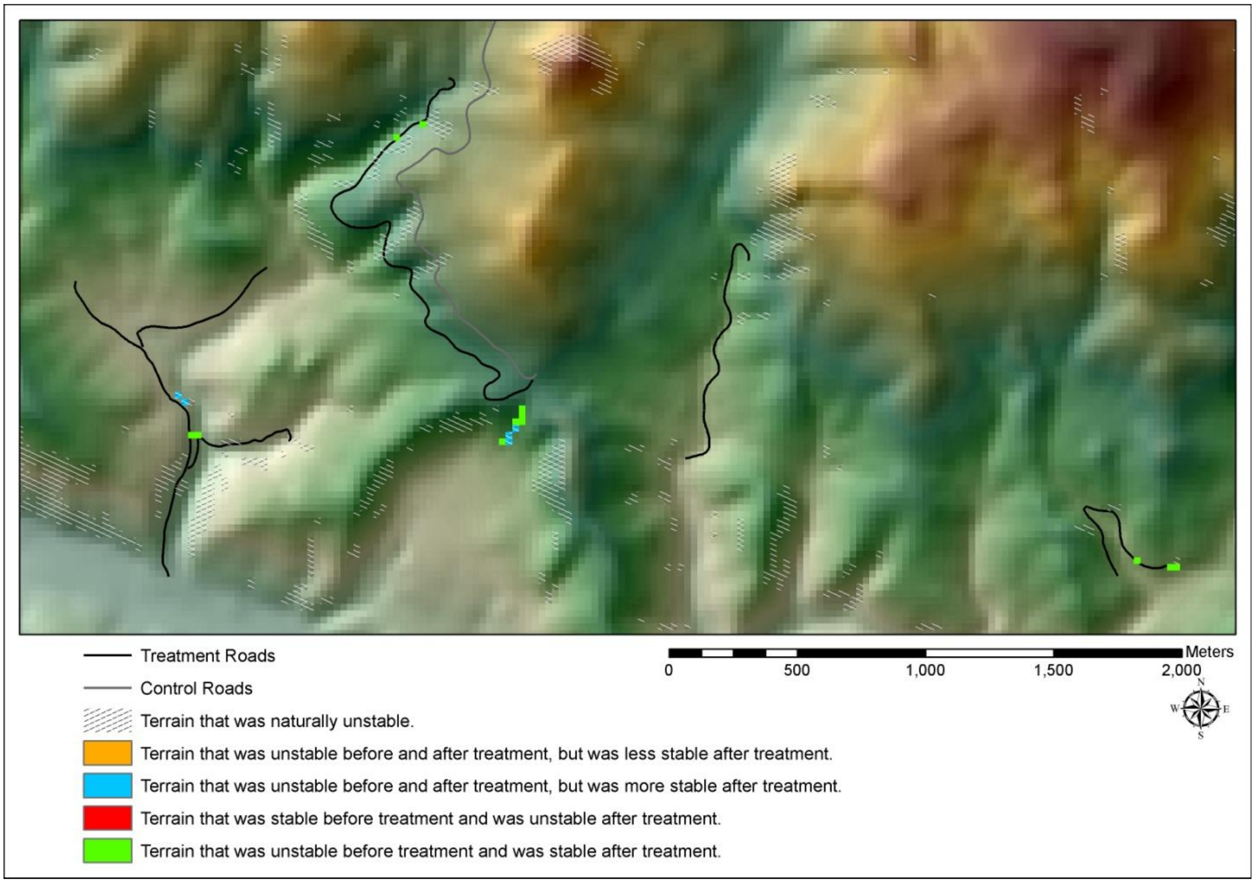

Figure 17: Modeled changes in slope stability along decommissioned roads. All changes indicate increased stability.

A similar analysis was performed using separate model runs to determine the effects of storm-related damage on the control roads. Most of the areas where changes occurred became less stable, though some areas did become significantly more stable (Figure 18). The orange cells are areas where the risk increased (became less stable) after treatment, and the terrain was already unstable before treatment. This is mostly due to the addition of drainage over slopes that were unstable without considering the effect of road drainage. In some locations, extra water was diverted to pre-existing drain point locations (though the drain point type may have changed due to treatment) that already drained to slopes in the unstable category due to road drainage.

The 1038-031 road is situated above the decommissioned 1038-035 road (Figure 19). Storm-related damage on this road may impact the stability of recontoured road fills on portions of the 035 road. While these areas did not fail during the storm and snowmelt event in June of 2010, drainage from the upper road may lead to instability in larger events.

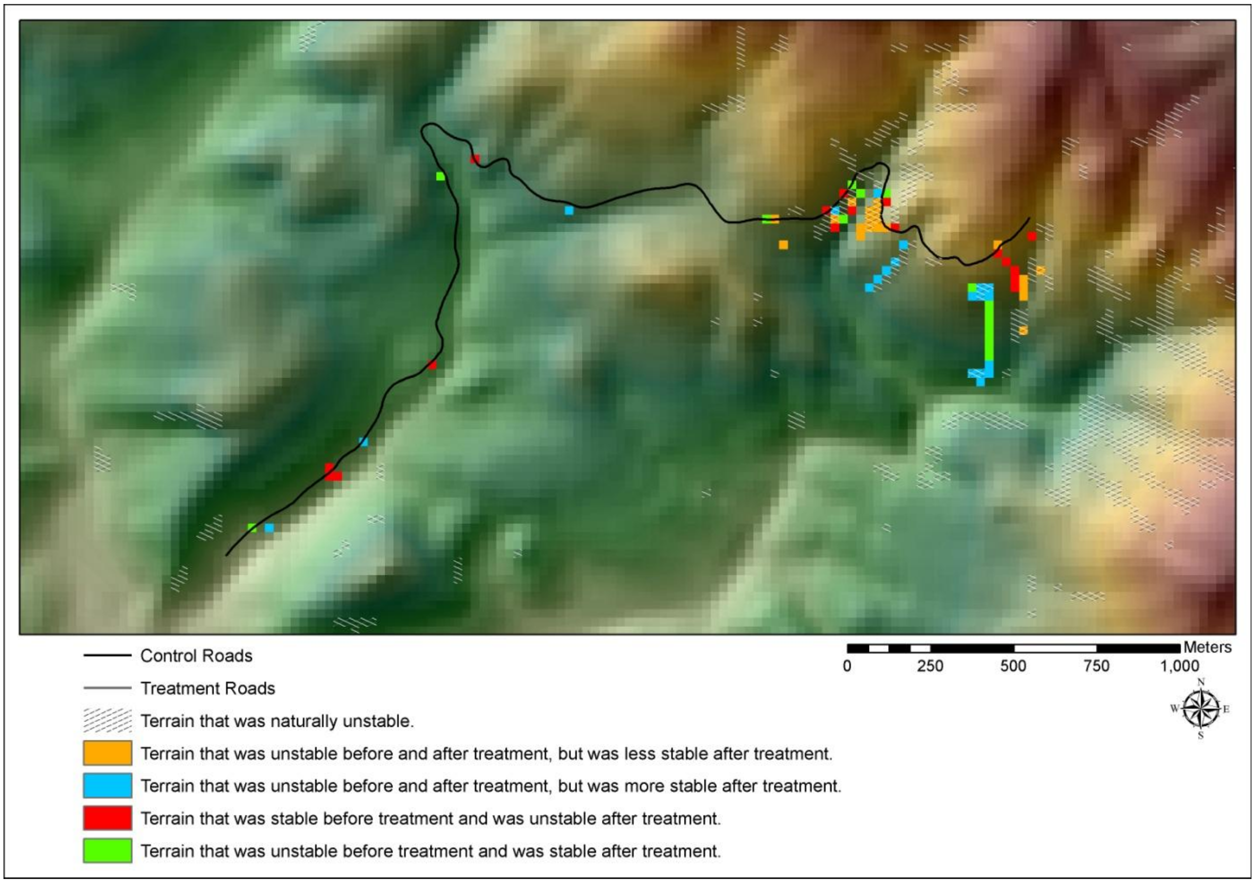

Figure 18: Modeled slope stability changes due to storm-related damage, road 7355-020.

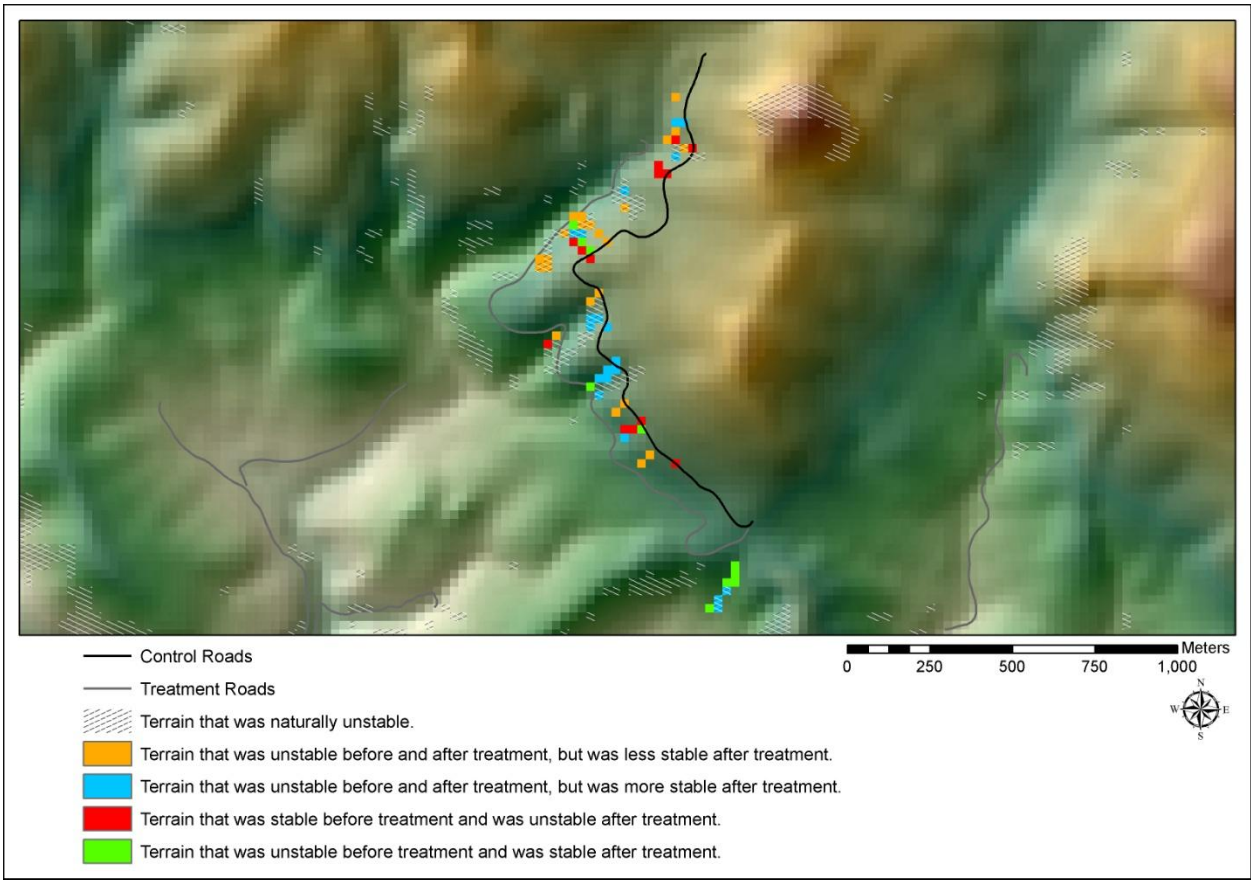

Figure 19: Modeled slope stability changes due to storm-related damage, road 1028-031. Note that some of these changes may impact the decommissioned road down-slope.

6.4 Gully Initiation Risk

Gullies are not common along the decommissioned roads; two gullies were located prior to treatment, and only the larger one was found during the post-storm visit. This gully is in a wet swale and is also fed by a spring. In both the pre-treatment and post-storm inventories, reported gully volumes are approximately 60 cubic feet.

Gullies were more common along the control roads. Six gullies were located during the initial control road inventory in 2008; these gullies had a combined volume of ~190 cubic feet. Three of these initial gully locations had gullies recorded during the post-storm inventory in 2010. At two of the locations, gully volume had decreased slightly; the other location had two distinct gullies totaling 140 cubic feet. The total gully volume recorded during the post-storm inventory was ~180 cubic feet.

Gullying at drain points below roads can be a substantial source of sediment to stream channels (Takken et al., 2008). Gully initiation occurs when the shear stress applied by runoff exceeds the strength of the soil surface on the hillslope (Reid et al., 2010).

GRAIP computes the Erosion Sensitivity Index (ESI) (Istanbulluoglu et al. 2003), as shown below, at each drain point.

$ESI = LS^{\alpha}$, where:
L is the road length contributing to the drain point (m)
S is the slope of the hillslope below the drain point (m/m)
α is an exponent determined to be ≈2

When calibration data for a site fits the expected pattern of longer contributing road length and hill slope at each drain point leading to a higher frequency of gullied drain points, ESI values for each drain point are calculated and compared to a critical ESI threshold (ESI_{crit}) to identify areas with a high risk of gully formation (i.e., where $ESI > ESI_{crit}$). ESI_{crit} is empirically-derived for each study area using inventoried gullies, and is the ESI value above which the risk of gullying increases significantly. Data from the decommissioning project and the SDRR project, located in the same area, were used to determine the ESI_{crit} value for this study area, as both sites are intermingled. Diffuse drains, stream crossings, and orphan drainpoints are excluded from the ESI_{crit} determination. At this site, an ESI of 12 was determined to be the critical threshold; a lower threshold of 1.25 marks where gully formation becomes possible in locations that are pre-disposed to gully formation (Figures 20 and 21). There is an approximately 5% gully rate for drainpoints with ESI values between 1.25 and 12; above an ESI value of 12, the gully rate is approximately 10%.

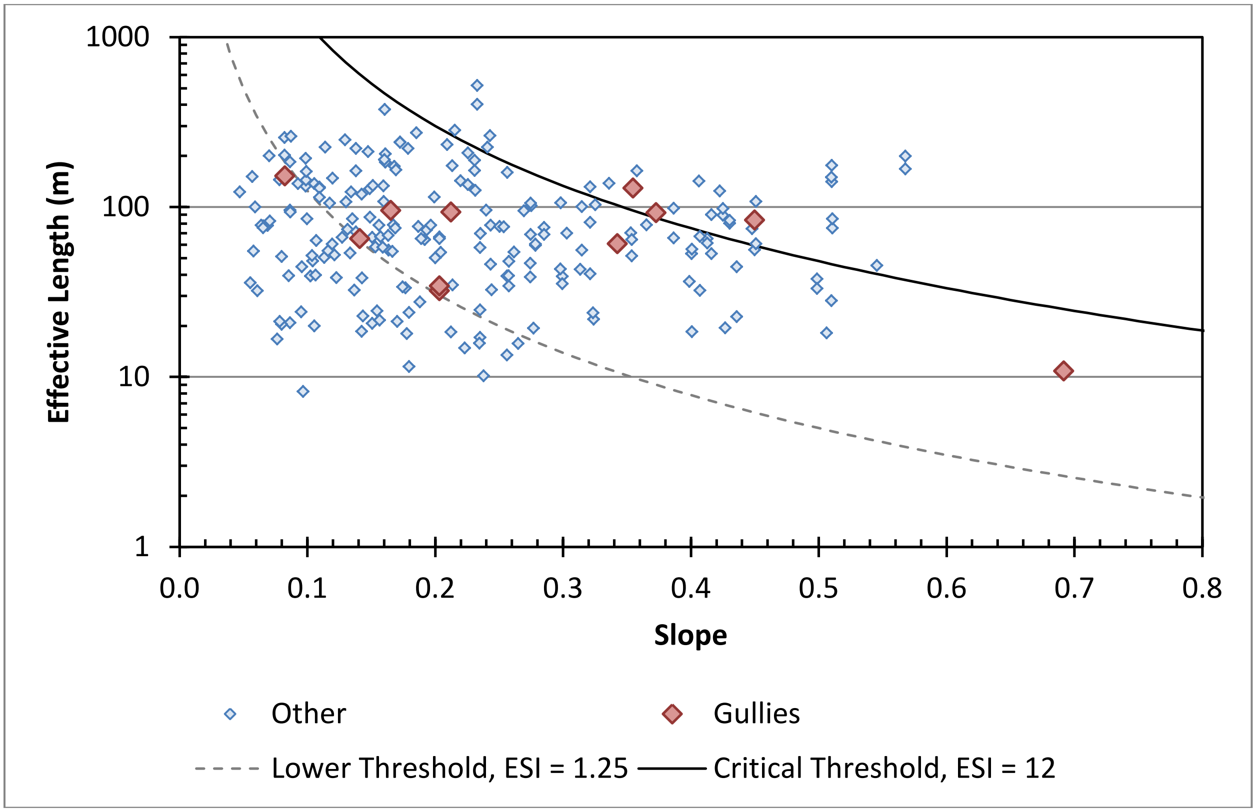

Figure 20: Slope-length plot showing gully risk and possible thresholds.

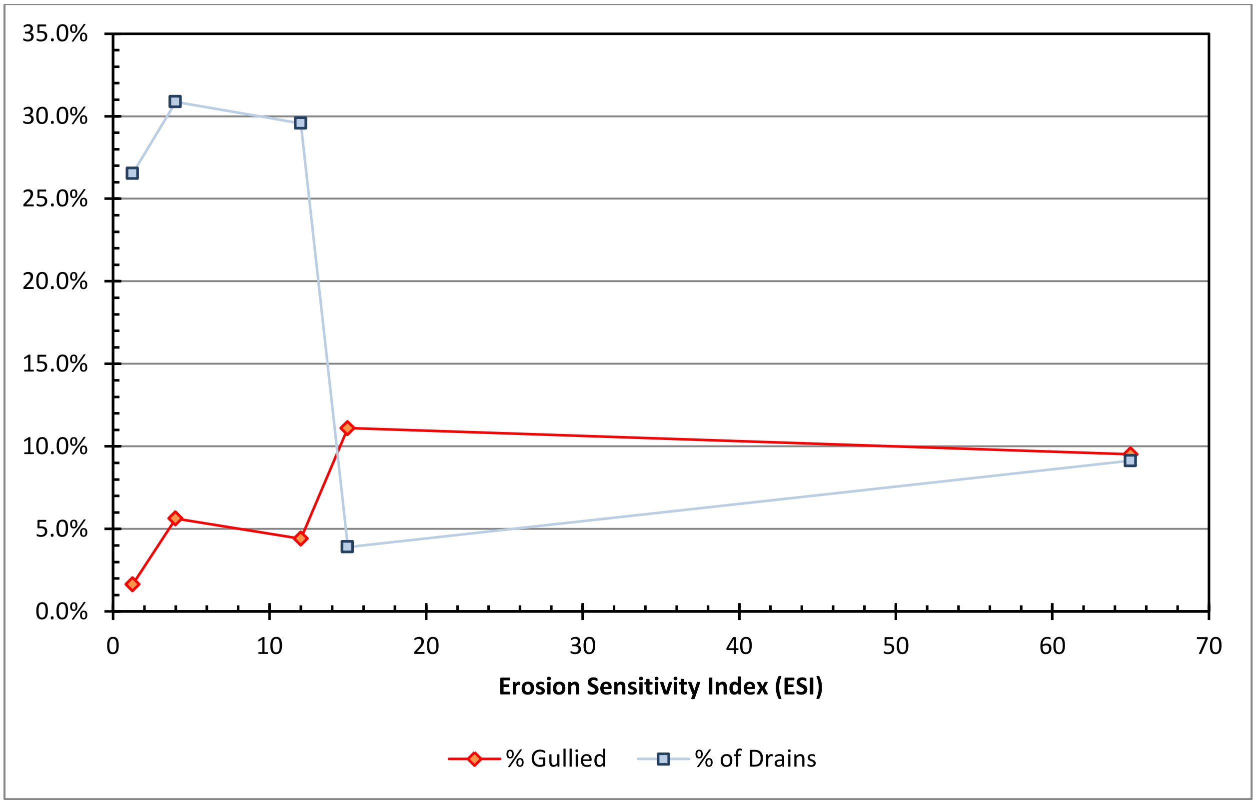

Figure 21: Percent of gullied drains and percent of all drains plotted against ESI. Note stepped behavior of percentage of drainpoints with gullies.

The decommissioned roads had much lower ESI values than did the control roads in this study. The average ESI value prior to treatment was 1.96; after treatment the average ESI value dropped to 1.24 and dropped again to 0.93 at the post-storm inventory due to decreasing contributing road lengths. Only one ditch relief culvert on the pre-treatment road had an ESI value greater than 12; the treatments removed this drainpoint. The storm related damage on the control roads resulted in the average ESI value increasing from 8.82 to 9.12 due to increasing contributing road lengths. The number of drainpoints with ESI values exceeding the critical threshold also increased from 11 to 16 following the storm event. ESI statistics are given in Table 12.

Table 12: ESI statistics for decommissioned and control roads.

	Pre-Decom	**Post-Decom**	**Post-Storm Decom**	**Decom Control**	**Post-Storm Decom Control**
Minimum (non-zero)	0.08	1.10	0.47	0.10	0.13
Maximum	15.56	1.37	1.88	64.20	53.91
Average	1.96	1.24	0.93	8.82	9.12
Standard Deviation	2.72	0.19	0.63	11.03	10.07
# of drains with ESI > 12	**1**	**0**	**0**	**11**	**16**

6.5 Stream Crossing Failure Risk

Besides contributing fine sediment to streams through surface erosion, stream crossings may fail catastrophically when blocked and deliver large sediment pulses to stream channels. Stream crossing failure risks were assessed using the Stream Blocking Index (SBI, Flanagan et al. 1998). The SBI characterizes the risk of plugging by woody debris by calculating the ratio of the culvert diameter to the upstream channel width (w*) and the skew angle between the channel and the pipe inlet.

The SBI values for the pre-treatment stream crossings along the treatment roads were low with an average value of 1.2 for the 7 pre-treatment stream crossings (Figure 22). SBI has a range of 1 to 4, where 1 suggests no risk of blockage. SBI only applies when there is an open culvert present; the one log culvert was already plugged with woody debris. All stream crossing culverts were removed during decommissioning treatments, which completely eliminated the risk of pipe plugging. Thus, the post-treatment SBI score was zero at all crossings. Average SBI values at stream crossings along the control roads were 1.33 in 2008 and 1.25 in 2010; in 2010 one additional crossing was identified with an SBI of 1 while the SBI values at the other three crossings remained the same.

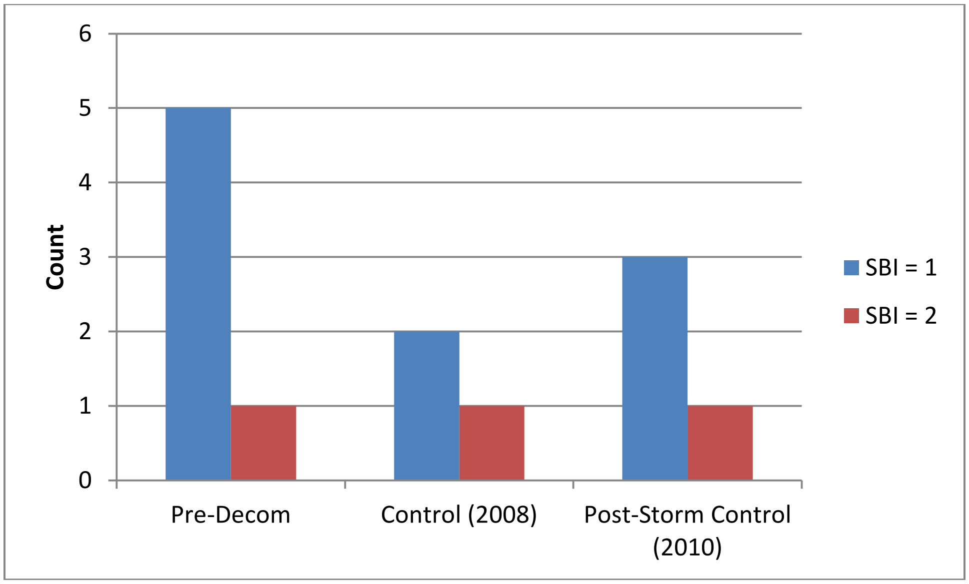

Figure 22: SBI values for pre-treatment and control roads.

The risk of a stream crossing failure can also be viewed in the context of the consequences of failure (Flanagan et al. 1998). A consequence of concern at these stream crossings is the erosion of fill material into the stream channel. We calculated the fill material that would likely be excavated in an overtopping type failure. We modeled the prism of fill at risk as bounded at the base by an area 1.2 times the channel width, with side slopes climbing to the road surface at an angle of 33%. The fill volume at risk in the pre-treatment road configuration was approximately 222 m^3. All of this material, and more adjacent to this material, was excavated during the decommissioning work. Fill volumes at risk at stream crossings on the control roads were 77.5 m^3 in 2008 and 94.6 m^3 in 2010; the additional fill at risk in 2010 is at the new stream crossing identified during the post-storm inventory. This new stream crossing is likely due to changes in the channel head location along a small, ephemeral stream in a swale.

A second, and perhaps greater, consequence of concern at failed stream crossings is the diversion of stream flow onto road surfaces and unchanneled hillslopes. Once a crossing becomes occluded and begins to act as a dam, failure can occur in several ways. If the road grade dips into and rises out of the crossing, the failure is likely to be limited to a localized overtopping of the stream crossing. However, if the road grades away from the stream crossing in one or more directions, the flow may be diverted down the road and ditch and onto adjacent hillslopes, where it can cause gullying and/or landsliding (Furniss et al. 1998, Best et al. 1995). In these situations, volumes of sediment far exceeding those at the crossing can be at risk.

GRAIP addresses this issue by classifying the potential for stream crossings to divert streamflow down the adjacent road as: no potential, potential to divert in one direction, or potential to divert in two directions. Prior to road decommissioning, 71% (5 of 7) of the stream crossings on the treatment roads had the potential to divert streamflow down the road in at least one direction. The excavation of the stream crossings eliminated these risks at all of these stream crossing sites. Of the stream crossings on the control roads, in 2008, 50% had the potential to divert flow in at least one direction. Following the storm event, 60% of the crossings had the potential to divert flow. The increase is due to the inclusion of the new stream crossing, which had the potential to divert flow; there was no change at the previously recorded crossings.

6.6 Drain Point Condition

The GRAIP inventory involves an assessment of the condition of each drain point and a determination of how well it is performing its intended function. Problems with drain point condition are pre-defined for each drain type. Broad based dips are considered to be in poor condition if they are insufficiently outsloped and pond water on the road. Culverts are defined to be in poor condition if they have more than 20% occlusion of the inlet by sediment, substantial inlet crushing, significant rust, or flow around the pipe. Non-engineered features are almost always a problem, most often because of diverted wheel track flow. Stream crossings are considered a problem if they are blocked by sediment or wood, crushed or rusted significantly, incising, scouring or loosing much water from flow around the pipe. Sumps are a problem if they pond water on the road surface or cause fill saturation. Water bars that are damaged, under sized, or do not drain properly are defined as problematic. Diffuse drains (outsloped roads) are rarely observed to have drain point problems.

Prior to treatment, non-engineered drains and stream crossing culverts were observed to have the highest rate of problems (86% and 29%, respectively), while diffusely drained road segments were least likely to have problems (Table 13). While no problems were reported during the post-treatment inventory in 2008, one of the excavated stream crossings had a problem with a landslide in the sideslope of the excavation following the storm event (Figure

23). One water bar had caused 19 ft^3 of fill erosion following the storm event. The overall problem rate dropped from 11% (pre-treatment) to 2% (post-storm).

Figure 23: Excavated stream crossing with log placed to prevent erosion. The field crew recorded a landslide in the sideslope of the excavation at this location.

Drainpoint problems on the control roads occurred more frequently (Table 14), both before and after the storm event. Non-engineered drains, ditch relief culverts, broad based dips, and water bars were some of the problems in 2008. Non-engineered drains and broad based dips were the main sources of problems after the storm event. The overall problem rate increased from 30% (pre-storm) to 41% (post-storm). Three drainpoints had caused fill erosion (36 ft^3) following the storm event.

Table 13: Drainpoint condition problems and fill erosion for treatment roads, pre-treatment and post-storm. No problems were recorded during the post-treatment inventory.

	Pre-Treatment			**Post-Storm**		
Drain Type	**Count**	**Problems**	**Fill Erosion**	**Count**	**Problems**	**Fill Erosion**
Broad Based Dips	15	7%	0%	0	0%	0%
Diffuse Drains	55	0%	0%	23	0%	0%
Ditch Relief Culverts	4	0%	0%	0	0%	0%
Non-engineered Drains	7	86%	0%	0	0%	0%
Stream Crossings	7	29%	0%	7	14%	0%
Sumps	4	25%	0%	0	0%	0%
Water Bars	10	10%	0%	23	0%	4%
Total	**102**	**11%**	**0%**	**53**	**2%**	**2%**
Problems Change	**-9%**					

Table 14: Drainpoint condition problems and fill erosion on control roads, pre-storm and post-storm.

	Pre-Storm			**Post-Storm**		
Drain Type	**Count**	**Problems**	**Fill Erosion**	**Count**	**Problems**	**Fill Erosion**
Broad Based Dips	27	30%	0%	31	35%	3%
Diffuse Drains	19	0%	0%	3	0%	0%
Ditch Relief Culverts	5	40%	0%	6	67%	0%
Non-engineered Drains	7	100%	0%	13	85%	15%
Stream Crossings	4	25%	0%	5	20%	0%
Sumps	3	0%	0%	1	100%	0%
Water Bars	18	39%	0%	16	19%	0%
Total	**83**	**30%**	**0%**	**75**	**41%**	**4%**
Problems Change	**11%**					

7.0 Summary and Conclusions

Crews from the Rocky Mountain Research Station inventoried treatment and control roads within the Granite Creek watershed as part of the Legacy Roads and Trails Monitoring Program. The data from inventories conducted in 2008 and in 2010 were analyzed using GRAIP to determine the effects of road decommissioning treatments applied during 2008.

On the treatment roads, road-stream connectivity increased by 427 m (7%), though by 2010 sediment delivery, after an initial increase following treatment, had declined by 0.8 Mg/yr (34%). In the same time, the hydrologic connectivity along the control roads increased by 130 m (2%) and sediment delivery increased by 11.8 Mg/yr (255%).

Slope stability risks appear to be low in the surveyed areas of Granite Creek, and decommissioning treatments appear to have reduced those risks to near natural conditions. Storm related damage, however, that was observed on the control roads, locally increased slope stability risks.

Gully initiation risks along the decommissioned roads were minimal prior to treatment, though they were considerably higher along the control roads. Two gully initiation thresholds were defined using data from this study and data from SDRR inventories within Granite Creek. Gully initiation risks were virtually eliminated along the decommissioned roads following treatment. Along the control roads, however, risks increased along with the number of drainpoints with an ESI above the upper threshold.

Stream crossing failure risks were low on both the treatment and control roads in this study, and were eliminated along the treatment roads. Problems associated with other drain types were virtually eliminated following road decommissioning treatments, though the number of such problems increased on the control roads.

Table 15: Treatments effects, predictions and observed outcomes.

Impact/Risk Type	Effect of Treatment:	Effect of Treatment:
	Initial GRAIP Prediction	**Post-storm validation**
Road-Stream Hydrologic Connectivity	+466 m (+8%)	+427 m (+7%)
Fine Sediment Delivery	+3,476 kg/yr (+3%)	-751 kg/yr (-34%)
Landslide Risk	Some increases in stability, very low risk	Some increases in stability, very low risk
Gully Risk	-1 drain above ESI_{crit}, none above	-1 drain above ESI_{crit}, none above
Stream Crossing Risk		
- plug potential	-100%, all crossings excavated	-100%, all crossings excavated
- fill at risk	-222 m^3, all fills removed	-222 m^3, all fills removed, one side-slope failure
- diversion potential	-100%, eliminated at all crossings	-100%, eliminated at all crossings
Drain Point Problems	-100%, all problems eliminated	-10 (-91%)

Post-storm validation measured as change from pre-treatment conditions.

Table 16: Observed storm effects for control and treatment roads.

Impact/Risk Type	Control Roads	Treatment Roads
	Effects of Storm	**Effects of Storm**
Road-Stream Hydrologic Connectivity	+130 m (+2%)	-39 m (-1%)
Fine Sediment Delivery	+11,799 kg/yr (+255%)	-4,227 kg/yr (-74%)
Landslides	Storm-related damage may impact stability of recontoured fills on lower roads, but risks are low	No significant change
Gullies	+5 drains above ESI_{crit}, 16 above	No significant change
Drain Point Problems	+6 (11%)	+1 (2%)

Effects of storm, for control and treatment roads, are measured from the most recent inventory prior to the storm; the post-treatment inventory is used for the treated roads. Nearly two years passed between pre- and post-storm inventories. Note that not all inventories covered the same length of road: Pre-treatment, 5,778 m; Post-treatment, 5,831 m; Post-storm Treatment, 5,740 m; Pre-storm Control, 6,048 m; Post-storm Control, 6,042 m.

Appendix A: Sediment Delivery Tables

Pre-Treatment

Drain Type	Count		Sediment Received (kg/yr)	Sediment Delivered (kg/yr)	% Sediment Delivery	% Effective Length Connected
	All	Connected				
Broad Based Dip	15	0	7,249	0	0%	0%
Diffuse Drain	55	0	10,902	0	0%	0%
Ditch Relief Culvert	4	1	330	143	43%	38%
Non-Engineered Drain	7	3	6,440	474	7%	15%
Stream Crossing	7	7	1,587	1,587	100%	100%
Sump	4	0	3,564	0	0%	0%
Water Bar	10	0	5,148	0	0%	0%
All Drains	**102**	**11**	**35,220**	**2,203**	**6%**	**6%**

Post-Treatment

Drain Type	Count		Sediment Received (kg/yr)	Sediment Delivered (kg/yr)	% Sediment Delivery	% Effective Length Connected
	All	Connected				
Broad Based Dip	8	0	0	0	0%	0%
Diffuse Drain	89	14	58,678	5,525	9%	16%
Stream Crossing	7	7	0	0	100%	100%
Water Bar	12	2	154	154	100%	100%
All Drains	**116**	**23**	**58,832**	**5,680**	**10%**	**17%**

Pre-Treatment to Post-Treatment Change

Drain Type	Δ Count		Δ Sediment Received (kg/yr)	Δ Sediment Delivered (kg/yr)	Δ % Sediment Delivery	Δ % Effective Length Connected
	All	Connected				
Broad Based Dip	-7	0	-7,249	0	0%	0%
Diffuse Drain	34	14	47,776	5,525	9%	16%
Ditch Relief Culvert	-4	-1	-330	-143	-43%	-38%
Non-Engineered Drain	-7	-3	-6,440	-474	-7%	-15%
Stream Crossing	0	0	-1,587	-1,587	0%	0%
Sump	-4	0	-3,564	0	0%	0%
Water Bar	2	2	-4,994	154	100%	100%
All Drains	**14**	**12**	**23,612**	**3,476**	**3%**	**11%**

Post-Storm Treatment

Drain Type	Count		Sediment Received (kg/yr)	Sediment Delivered (kg/yr)	% Sediment Delivery	% Effective Length Connected
	All	Connected				
Diffuse Drain	21	8	6,153	1,263	21%	15%
Water Bar	23	1	91	55	60%	12%
Excavated Stream Crossing	6	6	135	135	100%	100%
All Drains	**50**	**15**	**6,379**	**1,452**	**23%**	**16%**

Post-Treatment to Post-Storm Treatment Change

Drain Type	Δ Count		Δ Sediment Received (kg/yr)	Δ Sediment Delivered (kg/yr)	Δ % Sediment Delivery	Δ % Effective Length Connected
	All	Connected				
Broad Based Dip	-8	0	0	0	0%	0%
Diffuse Drain	-68	-6	-52,525	-4,263	11%	-1%
Stream Crossing	-1	-1	135	135	0%	0%
Water Bar	11	-1	-63	-99	-40%	-88%
All Drains	**-66**	**-8**	**-52,453**	**-4,227**	**13%**	**0%**

Pre-Treatment to Post-Storm Treatment Change

Drain Type	Δ Count		Δ Sediment Received (kg/yr)	Δ Sediment Delivered (kg/yr)	Δ % Sediment Delivery	Δ % Effective Length Connected
	All	Connected				
Broad Based Dip	-15	0	-7,249	0	0%	0%
Diffuse Drain	-34	8	-4,749	1,263	21%	15%
Ditch Relief Culvert	-4	-1	-330	-143	-43%	-38%
Non-Engineered Drain	-7	-3	-6,440	-474	-7%	-15%
Stream Crossing	-1	-1	-1,452	-1,452	0%	0%
Sump	-4	0	-3,564	0	0%	0%
Water Bar	13	1	-5,057	55	60%	12%
All Drains	**-52**	**4**	**-28,841**	**-751**	**17%**	**10%**

Pre-Storm Control

Drain Type	Count		Sediment Received (kg/yr)	Sediment Delivered (kg/yr)	% Sediment Delivery	% Effective Length Connected
	All	Connected				
Broad Based Dip	27	1	39,600	2,255	6%	3%
Diffuse Drain	19	0	8,395	0	0%	0%
Ditch Relief Culvert	5	0	398	0	0%	0%
Non-Engineered Drain	7	1	16,075	806	5%	38%
Stream Crossing	4	4	1,573	1,573	100%	100%
Sump	3	0	542	0	0%	0%
Water Bar	18	0	7,015	0	0%	0%
All Drains	**83**	**6**	**73,599**	**4,635**	**6%**	**8%**

Post-Storm Control

Drain Type	Count		Sediment Received (kg/yr)	Sediment Delivered (kg/yr)	% Sediment Delivery	% Effective Length Connected
	All	Connected				
Broad Based Dip	31	3	45,881	7,384	16%	9%
Diffuse Drain	3	0	340	0	0%	0%
Ditch Relief Culvert	6	0	245	0	0%	0%
Non-Engineered Drain	13	4	18,896	8,875	47%	41%
Stream Crossing	5	5	174	174	100%	100%
Sump	1	0	1,461	0	0%	0%
Water Bar	16	0	1,553	0	0%	0%
All Drains	**75**	**12**	**68,551**	**16,434**	**24%**	**10%**

Pre-Storm Control to Post-Storm Control Change

Drain Type	Δ Count		Δ Sediment Received (kg/yr)	Δ Sediment Delivered (kg/yr)	Δ % Sediment Delivery	Δ % Effective Length Connected
	All	Connected				
Broad Based Dip	4	2	6,281	5,129	10%	6%
Diffuse Drain	-16	0	-8,055	0	0%	0%
Ditch Relief Culvert	1	0	-153	0	0%	0%
Non-Engineered Drain	6	3	2,821	8,068	42%	2%
Stream Crossing	1	1	-1,399	-1,399	0%	0%
Sump	-2	0	919	0	0%	0%
Water Bar	-2	0	-5,462	0	0%	0%
All Drains	**-8**	**6**	**-5,048**	**11,799**	**18%**	**3%**

Appendix B: Glossary of Selected Terms

Below is a list of terms, mostly of drainage point types, but also of some other commonly used terms, for the purpose of clarification. Adapted from Black, et al. (2009), Fly, et al (2010), and Moll (1997).

Broad based dip. ***Constructed:*** Grade reversal designed into the road for the purpose of draining water from the road surface or ditch (also called dip, sag, rolling grade, rolling dip, roll and go, drainage dip, grade dip). ***Natural:*** A broad based dip point is collected at the low point where two hillslopes meet, generally in a natural swale or valley. This is a natural low point in the road that would cause water on the surface of the road to drain out of the road prism.

Cross drain. This is not a feature collected specifically in GRAIP, and it can refer to a number of other drainage features. It is characterized by any structure that is designed to capture and remove water from the road surface or ditch. Ditch relief culverts, waterbars, and broad based dips can all be called cross drains.

Diffuse drain. This is a point that is characterized by a road segment that does not exhibit concentrated flow off the road. Outsloped roads or crowned roads often drain half or all of the surface water diffusely off the fillslope. Although collected as a drain point, this feature is representative of an area or a road segment rather than a concentrated point where water is discharged from the road prism. A drop of water that lands on a diffuse road segment will not flow down the road or into the ditch, but more or less perpendicular to the centerline off the road surface and out of the road prism. Also called sheet drainage or inter-rill flow.

Ditch relief culvert. This drain point is characterized by a conduit under the road surface, generally made of metal, cement, or wood, for the purpose of removing ditch water from the road prism. This feature drains water from the ditch or inboard side of the road, and not from a continuous stream channel.

Flow path. This is the course flowing water takes, or would take if present, within the road prism. It is where water is being concentrated and flowing along the road from the place where it enters the road prism, to where it leaves the road prism. This can be either on the road surface, or in the ditch.

Lead off ditch. This drain point is characterized by a ditch that moves flow from the roadside ditch and leads it onto the hillslope. Occurs most often on sharp curves where the cutslope switches from one side of the road to the other. Also known as a daylight ditch, mitre drain, or a ditch out (though this term can also describe other types of drainage features).

Non-engineered drainage. This drain point describes any drainage feature where water leaves the road surface in an unplanned manner. This can occur where a ditch is dammed by debris, and the water from the ditch flows across the road, where a gully crosses the road, where a wheel rut flow path is diverted off the road due to a slight change in road grade, or where a berm is broken and water flows through. This is different from a diffuse drain point, which describes a long section of road that sheds water without the water concentrating, whereas this point describes a single point where a concentrated flow path leaves the road.

Orphan drain point. This is any drain point that does not drain any water from the road at the time of data collection. Examples include a buried ditch relief culvert, or a water bar that has been installed on a road that drains diffusely.

Stream crossing. This drain point is characterized by a stream channel that intersects the road. This feature may drain water from the ditch or road surface, but its primary purpose is to route stream water under or over the road via a culvert, bridge, or ford. A stream for the purposes of GRAIP has an armored channel at least one foot wide with defined bed and banks that is continuous above and below the road and shows evidence of flow for at least some part of most years.

Sump. ***Intentional:*** A closed depression where water is intentionally sent to infiltrate. ***Unintentional:*** Any place where road water enters and infiltrates, such as a cattle guard with no outlet, or a low point on a flat road.

Waterbar. This drain point is characterized by any linear feature that is perpendicular to the road that drains water from the road surface and/or ditch out of the road prism or into the ditch. Waterbars may be constructed by dipping the grader blade for a short segment, or adding a partly buried log or rubber belt across the road. Some road closure features may also act as a waterbar, such as a tank trap (also known as a closure berm or Kelly hump). Cattle guards that have an outlet that allows water to flow out are also considered to be water bars. These features may also be known as scratch ditches if they drain water into the ditch.

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