Legacy Roads and Trails Monitoring Project

Road Decommissioning in the Mill Creek Watershed
Gallatin National Forest

April 2011

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Acknowledgements

We would like to thank the field crews (Laura Hutchinson, Rachel Rowland, and Alice Hatch) for collecting data. We would also like to thank Mark Story of the Gallatin National Forest for help in selecting these sites. Thanks also to Bruce Sims and the Northern Regional Office for supporting this effort. Finally, we would like to thank Brian Staab of the Pacific Northwest Regional Office for his continual support.

Executive Summary

The USFS, Rocky Mountain Research Station and Northern Region are monitoring some of the road decommissioning and maintenance projects in northern Idaho and Montana 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 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 seven locales where decommissioning, heavy maintenance (i.e., storm damage risk reduction; SDRR), or post-fire road 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. Four post-treatment inventories were executed. This status report focuses on decommissioning treatment work implemented by the Gallatin National Forest (GNF) in the Mill Creek watershed. At the GNF sites, treatments included recontouring and local ripping of road surfaces, seeding, culvert and drainage structure removal, and stream crossing culvert and fill removal and reconstruction.

Before-after comparisons using GRAIP indicate that decommissioning treatments resulted in a large reduction of all impact-risk metrics, although most metrics were in the low-risk group pre-treatment. Road-stream connectivity was eliminated; from 40 m of connected road to 0 m. Predicted delivery of fine sediment was reduced from 120 kg/year to 0 kg/year. Values of a stream blocking index were reduced from an average of 1.5 before treatment to zero after treatment (n=2), 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 80 m^3 of earthen material from areas with a high potential for failure and delivery to stream channels. Diversion potential was eliminated at both crossing sites.

The slope stability risk below drain point locations on the original road was reduced to nearly background levels in most locations as water was redistributed across the hillslope as diffuse drainage. Risk of gully initiation, as determined by a gully initiation index (ESI), experienced a reduction from low to negligible across the length of treated road, due to the removal of most concentrated drainage features. Current calculations are based on conservative assumptions; such assumptions will be assessed during future post-storm monitoring.

Before treatment, inventoried road segments had problems at 14 of 92 inventoried drainage points. Post-treatment monitoring indicates that these problems were eliminated by the treatments and that most replacement drainage features may be less vulnerable to failure. One excavated stream crossing had excessive erosion post-treatment.

Taken collectively, preliminary results indicate the decommissioning treatments should be effective in significantly reducing or eliminating each of the hydrogeomorphic impacts and risks to aquatic ecosystems. However, most of the risk metrics were low-risk before treatment. Sediment delivery, hydrologic connectivity, and gully initiation risks were very low, while landslide and stream crossing failure risks were somewhat higher. Although the pre-treatment road inventory found that there was little evidence of hydrogeomorphic response from these roads post-fire, that is not because risk did not exist. Rather, it is likely the Mill Creek area did not have a storm of sufficient intensity during a critical time to actualize the potential hillslope runoff response.

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

IMPACT/RISK TYPE	EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION	EFFECT OF TREATMENT: POST-STORM VALIDATION
Road-Stream Hydrologic Connectivity	-100%, -40 m	To be determined.
Fine Sediment Delivery	-100%, -120 kg	To be determined.
Landslide Risk	Reduced to near natural condition	To be determined.
Gully Risk	Reduced from low to negligible	To be determined.
Stream Crossing Risk		
- plug potential	-100%, eliminated at both sites	To be determined.
- fill at risk	-100%, 80 m^3 removed	To be determined.
- diversion potential	Risk absent pre-treatment	To be determined.
Drain Point Problems	14 problems removed, 1 new problem	To be determined.

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 and other road treatment programs, such as this work completed in the Mill Creek watershed on the Gallatin National Forest, to address hydrogeomorphic risks due to roads post-fire, the USFS, Rocky Mountain Research Station (RMRS) and Northern Region (R1) are implementing a road monitoring project to evaluate the effectiveness of road restoration treatments being implemented on national forests in northern Idaho and Montana. 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 decommissioning treatment work completed by the Gallatin National Forest (GNF) in the Mill 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 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. Although only 2.2 miles of treated road were inventoried here, 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 investigation also includes a final validation evaluation at both treatment and control sites following a substantial storm event (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 and FY2010 pre-treatment evaluations were completed at seven sites[1] on national forests throughout the Northern Region. Decommissioning has been implemented at six of these sites and one site has been treated with storm damage risk reduction methods (SDRR)[2] (Figure 1, Table 1). Four post-treatment inventories were also completed in FY2010. Post-

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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, 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.

treatment and, to the degree possible, post-storm evaluations will be completed at the remaining sites in FY2011. In 2008 and 2009, a similar study was begun in Regions 4, 5, and 6.

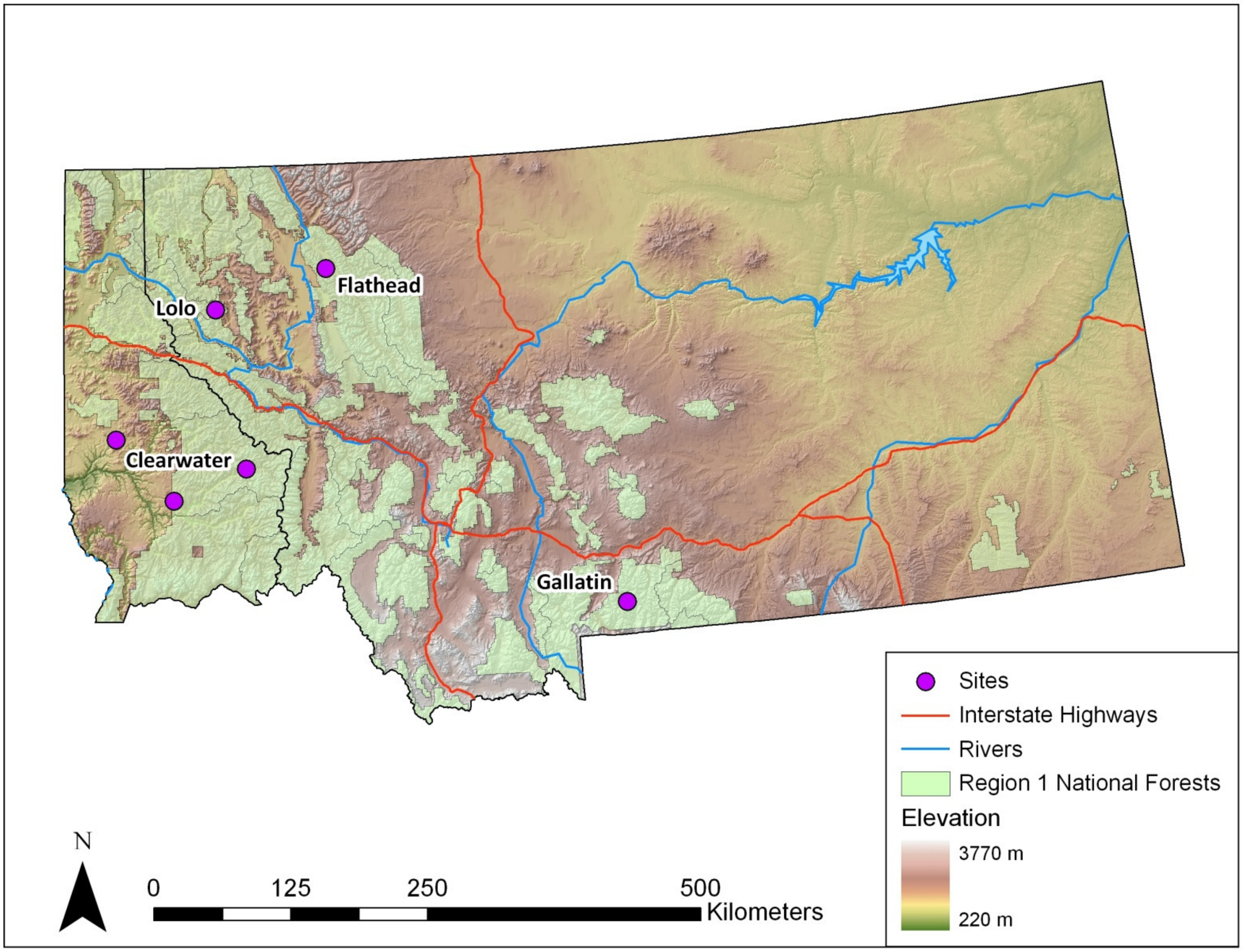

Figure 1. Location of monitored sites, FY2009 and FY2010, Northern Region.

Table 1. *The locations and types of road treatments monitored in Region 1.*

National Forest	Watershed	Treatment
Clearwater	Middle Fork Clearwater River	Decommissioning
	Lochsa River	Storm Damage Risk Reduction
	Little Boulder Creek	Decommissioning
Flathead	Aneas Creek	Decommissioning
Gallatin	Mill Creek	Decommissioning
Lolo	Fishtrap Creek	Decommissioning (Level III)
	Fishtrap Creek	Decommissioning (Level V)

Mill Creek Basin Sites

During the summers of 2009 and 2010, field crews inventoried decommissioning treatment sites in the Mill Creek watershed (Table 2, Figure 2). The decommissioning treatment sites in this watershed are principally underlain by Tertiary volcanic rocks. Other rock units within lower elevation areas of the Mill Creek drainage are predominately hard sedimentary rocks and belt series rocks. The average precipitation for the basin is on the order of 18-22 inches/yr. The inventoried sites are located between 2080 m (6820 ft) and 2170 m (7120 ft) above sea level on the west side of the Absaroka Mountain Range, just north of Yellowstone National Park. The Wicked Creek/Hicks Park Complex fire burned through the area in August of 2007 at a generally high intensity, with some area burning at low to moderate intensity (Story, 2007, BAER). Recently burned soil surfaces can develop water repellant properties, which can result in high runoff rates in the years following fire. About half of the burned area was projected to have

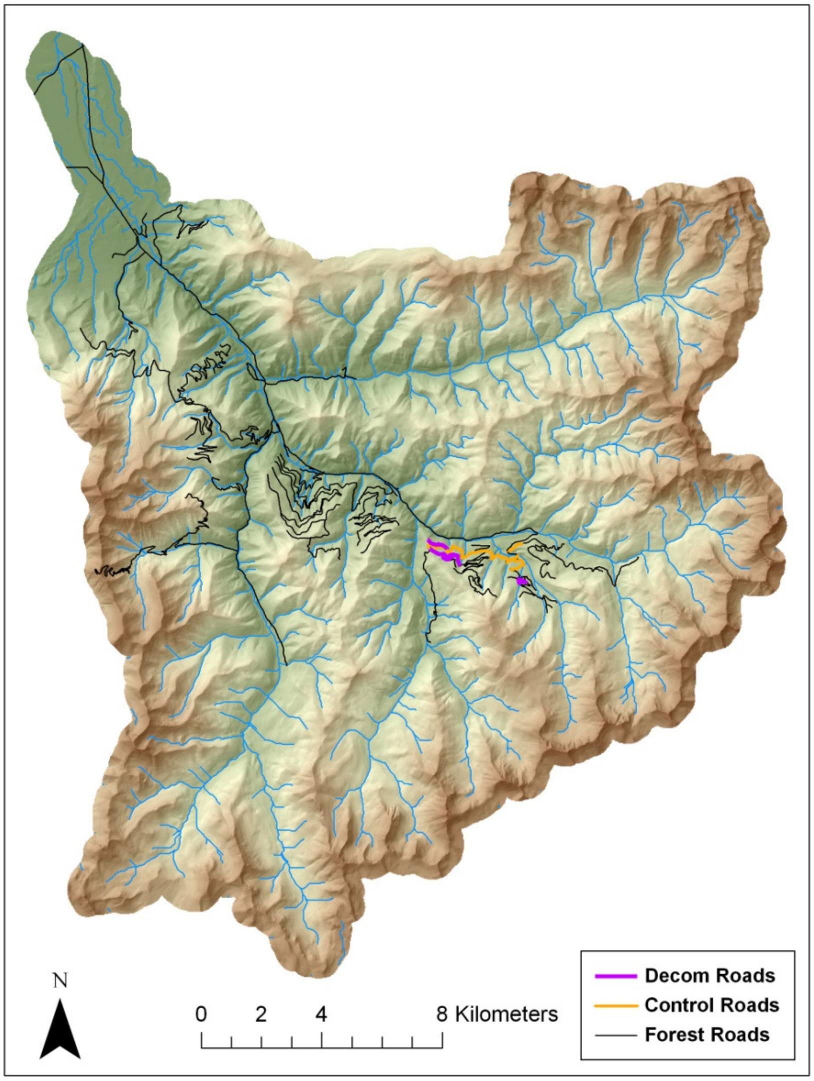

Figure 2. Location of monitored roads within the Mill Creek watershed, Gallatin National Forest.

water repellent properties post-fire (Story, 2007, BAER). Reduced infiltration rates combined with convective storms can result in overland flow from hillslopes, gullies, debris flows, and can compromise road drainage and stream crossing features. However, although 2009 and 2010 rainfall in the Mill Creek area was above average (Mark Story, personal communication), post-fire problems were minimal, likely because the Mill Creek area did not have a storm of sufficient intensity during a critical time to actualize the potential hillslope runoff response. Pre-treatment roads were originally native surfaced without a ditch or frequent drainage structures. Most road surfaces were significantly vegetated at the time of the pre-treatment survey. Both treatment and control sites included roads located at mid-slope hillslope position. At this site, only 2.2 miles of road surveyed pre-treatment could be surveyed after treatment.

Table 2. *Decommissioning treatments applied by road number.*

Decom Treated Road		Control Roads	
Road #	**Treatment**	**Road #**	**Treatment**
2508 spurs and 1799 spurs (2.2 miles)	Recontouring, local ripping, seeding, culvert and drainage structure removal, stream crossing culvert and fill removal and reconstruction.	2508 and 1799 spur (> 2.2 miles)	None

5.0 Results

GRAIP inventory and modeling tools were used to characterize the following types of impacts and risks, all of which were expected to be reduced by the storage treatments:

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

5.1 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 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 Mill Creek watershed, risks of hydrologic connectivity were low pre-treatment. The decommissioning treatments redistributed water back onto the hillslope. Prior to the treatments, 40 m out of 3560 m of inventoried road (1%) were hydrologically connected to the stream. After the treatments, 0 m out of 3470 m of monitored road (0%) was connected. Thus, the treatments resulted in a net reduction of 40 m of hydrologically connected road, which is 100% less than the pre-treatment condition.

5.2 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 contributing 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. A map of the road surface sediment delivery and the accumulated sediment delivered through each drain point is shown for the 2508 spur roads (Figure 3).

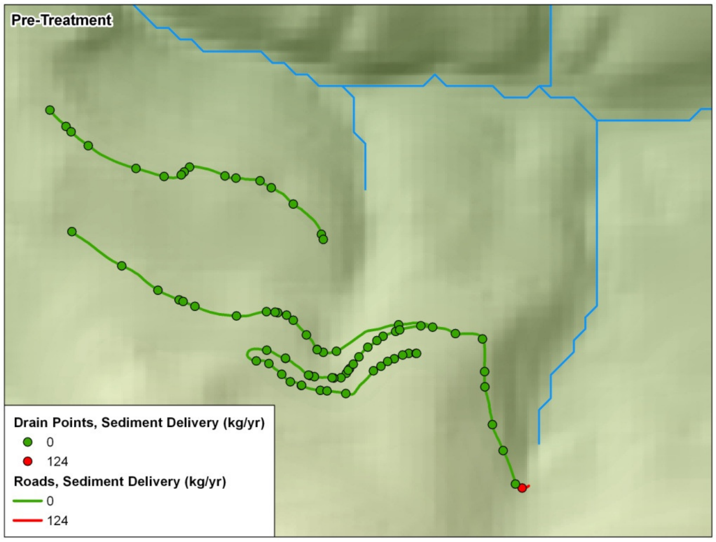

Figure 3. Fine sediment delivery to channels by road segment and drain point, pre-treatment road (2508 spurs). The road lines and drain points are colored to indicate the mass of fine sediment delivered to the channels. Only one road segment and one drain point delivered sediment. Post-treatment, we predicted no sediment delivery.

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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). Further work could determine if this rate is appropriate for this climate, geology and road system. We are looking at change due to treatment, so the absolute number is not a primary concern.

Pre-treatment

Delivery of fine sediment occurs through a mix of road drainage features including broad based dips, non-engineered drains, diffusely draining road segments, stream crossings, and others. In Table 3, sediment delivery is broken out 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. Ninety-two drain points were documented, only one of which was hydrologically connected to stream channels. This point delivered an estimated 120 kg/year of sediment, or 0.4% of the sediment generated by the road surfaces and ditches.

Table 3. *Summary of sediment production and delivery at drain points, pre-treatment road.*

DrainType	Count	∑ Sediment Production (kg)	∑ Sediment Delivery (kg)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	22	4200	0	0%	0	0%
Diffuse Drain	47	17980	120	0.4%	40	2%
Ditch Relief Culvert	1	140	0	0%	0	0%
Lead Off Ditch	0	n/a	n/a	n/a	n/a	n/a
Non-Engineered	19	12800	0	0%	0	0%
Stream Crossing	2	0	0	0%	0	0%
Sump	0	n/a	n/a	n/a	n/a	n/a
Waterbar	1	0	0	0%	0	0%
All Drains	**92**	**35140**	**120**	**0.4%**	**40**	**1%**

Post-treatment

Road surfaces were decompacted and recontoured over most of the treated length. This removed vegetation from the road surface, and increased sediment production significantly. No drain points delivered sediment to the channels post-treatment (Table 4), resulting in 0 kg/year of post-treatment sediment delivery.

Table 4. *Summary of sediment production and delivery, post-treatment road.*

DrainType	Count	∑ Sediment Production (kg)	∑ Sediment Delivery (kg)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	0	n/a	n/a	n/a	n/a	n/a
Diffuse Drain	21	62450	0	0%	0	0%
Ditch Relief Culvert	0	n/a	n/a	n/a	n/a	n/a
Lead Off Ditch	0	n/a	n/a	n/a	n/a	n/a
Non-Engineered	3	100	0	0%	0%	0%
Stream Crossing	2	0	0	0%	0	0%
Sump	0	n/a	n/a	n/a	n/a	n/a
Waterbar	4	390	0	0%	0	0%
All Drains	**30**	**62940**	**0**	**0%**	**0**	**0%**

The modeled change in sediment delivery following the treatments shows a decline of 120 kg/year to a total of 0 kg/year (Table 5).

Table 5. *Changes in sediment production and delivery, pre-treatment vs. post-treatment roads.*

DrainType	Count	∑ Sediment Production (kg)	∑ Sediment Delivery (kg)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	-22	-4200	0	0%	0	0%
Diffuse Drain	-26	44460	-120	-100%	-40	-100%
Ditch Relief Culvert	-1	-140	0	0%	0	0%
Lead Off Ditch	0	n/a	n/a	n/a	n/a	n/a
Non-Engineered	-16	-12700	0	0%	0	0%
Stream Crossing	0	0	0	0%	0	0%
Sump	0	n/a	n/a	n/a	n/a	n/a
Waterbar	3	390	0	0%	0	0%
All Drains	**-62**	**27800**	**-120**	**-100%**	**-40**	**-100%**

5.3 Landslide Risk

Existing Landslides

The Mill Creek area has a fairly low overall incidence of shallow landsliding due to the local geology (M. Story, personal communication). The basin does have evidence of deep landsliding, and the shallow hillslope failures may be related to the deeper hillslope-scale instability. Landslide volume was estimated for all landslides visible from the road that are greater than a

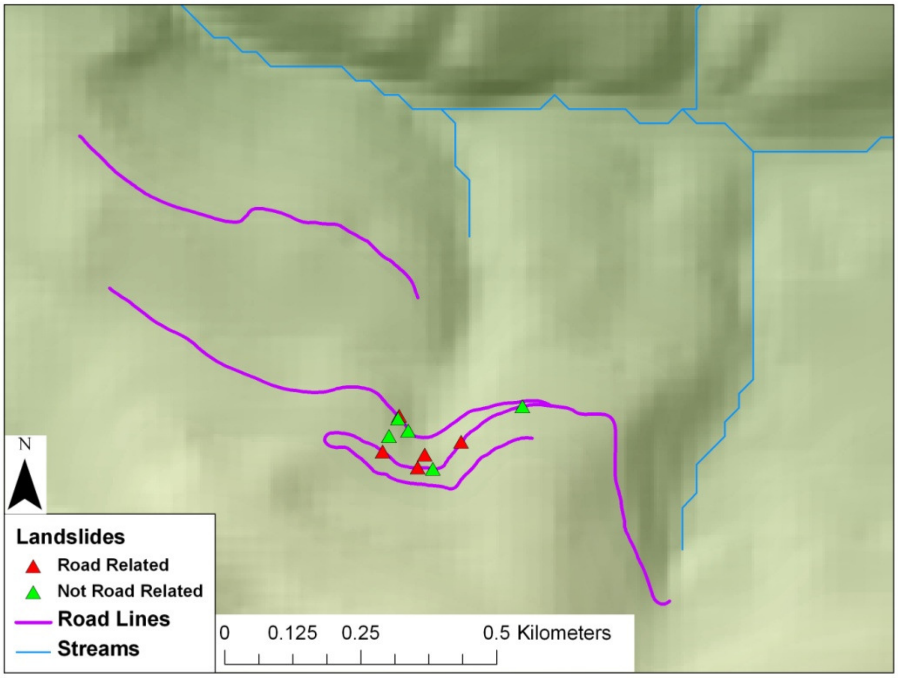

Figure 4. Landslides locations on the monitored Mill Creek roads.

minimum threshold of 6 feet in slope length and slope width. The pre-treatment road inventory recorded 5 road related landslides; 3 fillslope failures with an estimated total volume of 2200 m^3, and 2 hillslope failures with an estimated total volume of 1080 m^3 (Figure 4). The fillslope failures were generally slump/sag types. Three failures had an estimated age between five and ten years, and two failures had an estimated age between ten and fifteen years. Additionally, five landslides were observed that were not road related. All were hillslope failures above the road, with ages 5-15 years and an estimated total volume of 6060 m^3.

Changes in Landslide Risk

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-treatment 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 treatments. These change grids are compared to the natural landslide risk grid to show how the treatment 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 differences that show a risk change from stable to unstable, unstable to stable, or that become more or less stable while remaining unstable after treatment.

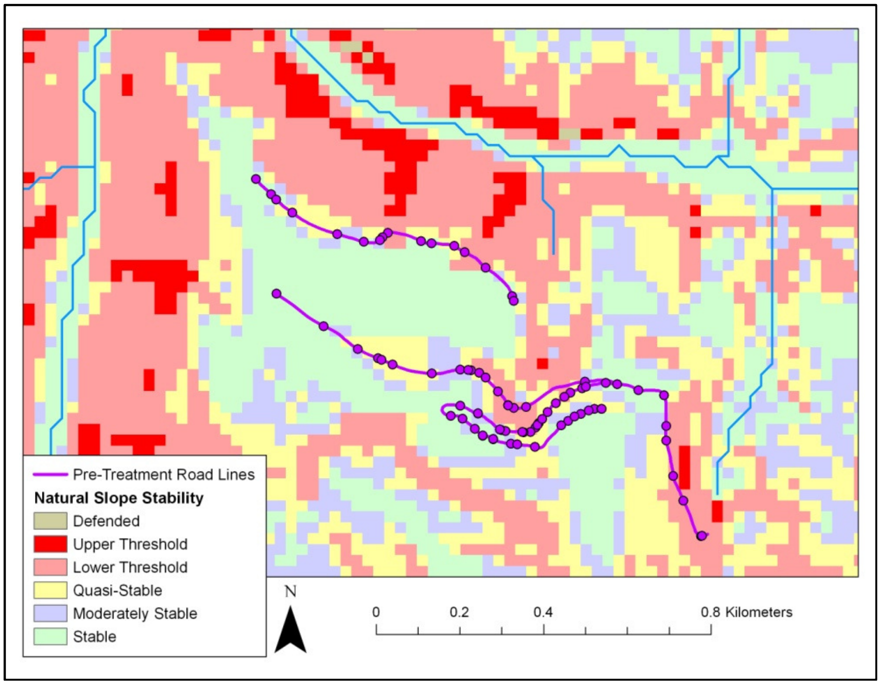

Figure 5. Natural slope stability risk in the area of the monitored 2508 spur roads in the Mill Creek drainage. The yellow, blue, and green cells are generally considered to be stable, while the pink, red, and tan cells are generally considered to be unstable.

Figures 5 through 8[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. The inherent uncalibrated SINMAP landslide risk was generally moderate to high in the area of the treated road (Figure 5).

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. In Figure 6, the areas along the 2508 spur roads where the treatment changed the risk from the unstable category (defended, upper threshold, and lower threshold from Figure 5, 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).

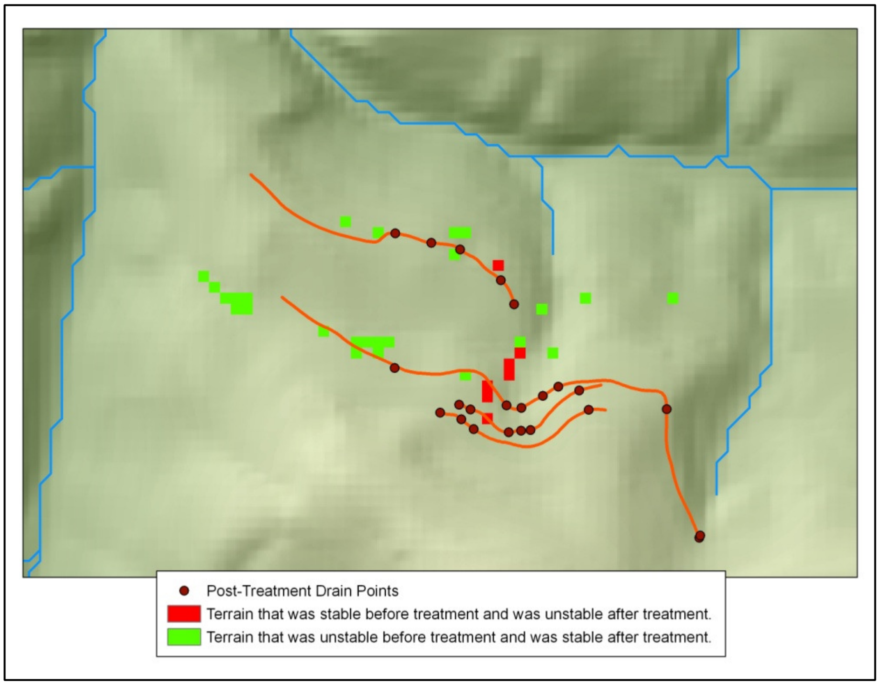

Figure 6. The most significant slope stabilty risk cahnges along the treated roads. The risk of the areas in green was sufficiently reduced, while the risk of the red areas was significantly increased.

The areas where risk was significantly increased are due to the addition of new drainage features over steep slopes that were stable before treatment or due to additional water routed to the same location as a previously existing drain point. The areas where risk was sufficiently decreased are due to the removal of water from those features, or due to the complete removal of the features themselves.

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[4] Figures 5 through 8 are rendered at the same scale. The legend items for each figure are consistent from one figure to the next.

Figure 7 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. This was generally due to the removal of water from a drain point or the removal of the complete drain point over a steep naturally unstable slope. The orange cells are areas where the risk increased (became less stable) after treatment, and the terrain was unstable before treatment. This is generally due to the addition of drainage over slopes that were already unstable without considering the effect of road drainage.

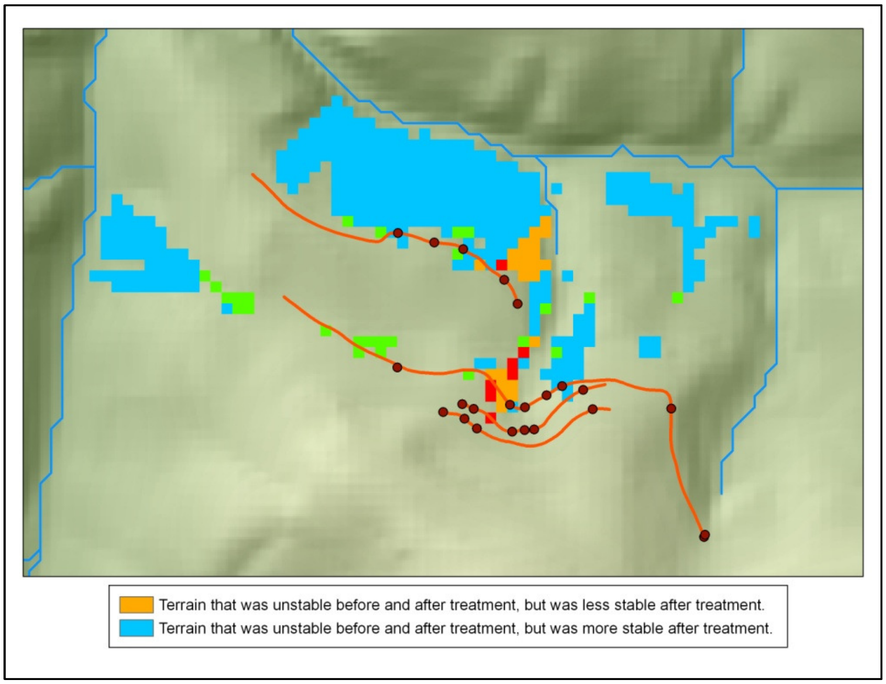

Figure 7. Changes in slope stability risk along the 2508 spur roads where the terrain was unstable before and after treatment. The blue areas are location where the risk was lowered, and the orange areas are where the risk increased.

The locations where the risk of shallow landsliding was naturally high are shown in Figure 8, where the cross-hatch areas were unstable without consideration of road drainage. Cross-hatch over blue shows the areas that experienced reduced risk and cross-hatch over orange shows area that experienced an increase in risk. In these locations, there was no way to reduce the overall shallow landslide risk to be stable. In most of these locations, the treatment may have reduced the stability category to background (natural) levels.

The net effect of the decommissioning treatments, which removed most concentrated drainage features, achieved the goal of greatly reducing risk at most locations in the sample area. However, risks were increased in two general locations because in steep, dissected terrain, it is difficult to redirect discharge from one location without elevating the risk in another location.

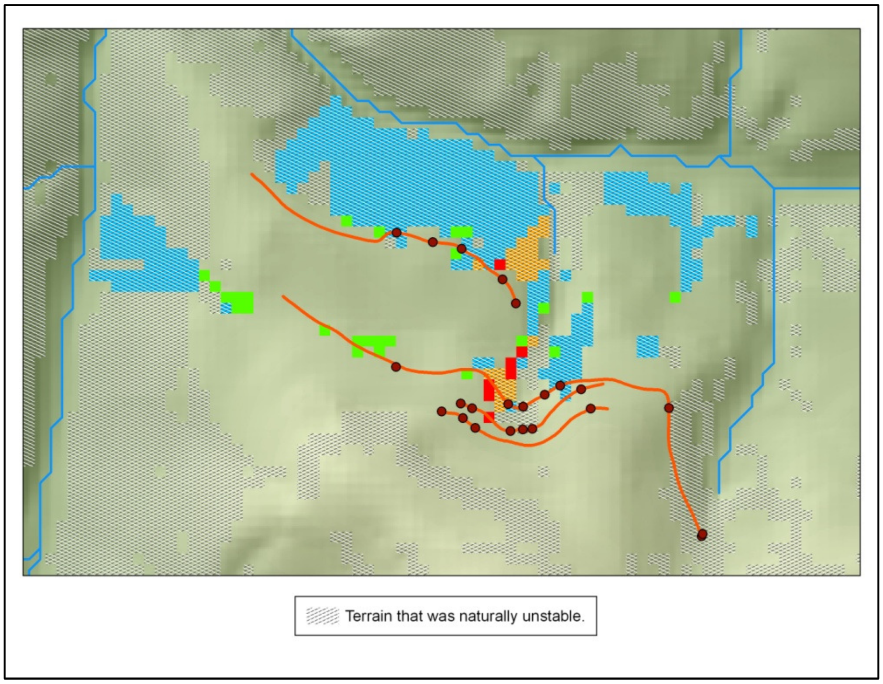

Figure 8. Background slope stability and the changes in slope stability. The cross-hatch pattern indicates areas that were unstable without consideration of road drainage.

The inventory and modeling done here should help better characterize the needs for treatment in these locations and quantify potential risks to downslope resources. For example, in steep areas, additional drainage features may require more frequent placement (to prevent any one location from discharging too much water) or more careful placement (to avoid especially steep and high-risk areas). Post-storm monitoring will help refine these initial results.

5.4 Gully Initiation Risk

Gullying at drain points below roads can be a substantial source of sediment to stream channels. Gully initiation occurs when the shear stress applied by runoff exceeds the strength of the soil surface on the hillslope. GRAIP computes the Erosion Sensitivity Index (ESI) (Istanbulluoglu et al. 2003), as shown below, at each drain point.

$$ESI = L \times S^2$$

L is the road length contributing to the drain point
S is the slope of the hillslope below the drain point

When there is sufficient calibration data for a site, calculated ESI values for each drain point are 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. At this study site, despite the recent fire, there were no recorded gullies. Therefore, it is not possible to calculate a value for ESI_{crit}. While gully formation appeared to be highly uncommon before the treatments were applied, it has become still less likely following the treatments.

Diffuse drain points, stream crossings, and drain points that do not have an associated road surface flow path (i.e. orphan drain points) are not included in the following analysis, because these points do not behave in such a way that the ESI is a useful metric (they are referred to as non-ESI-applicable). Diffuse points represent a road segment that does not concentrate flow, and so does not pose a gully risk. Streams have their own, often non-road related, controls on their propensity to incise, and so cannot be treated the same as other drain points. Orphan drain points have a contributing road length of zero, and so have an ESI of zero, which throws off a meaningful average.

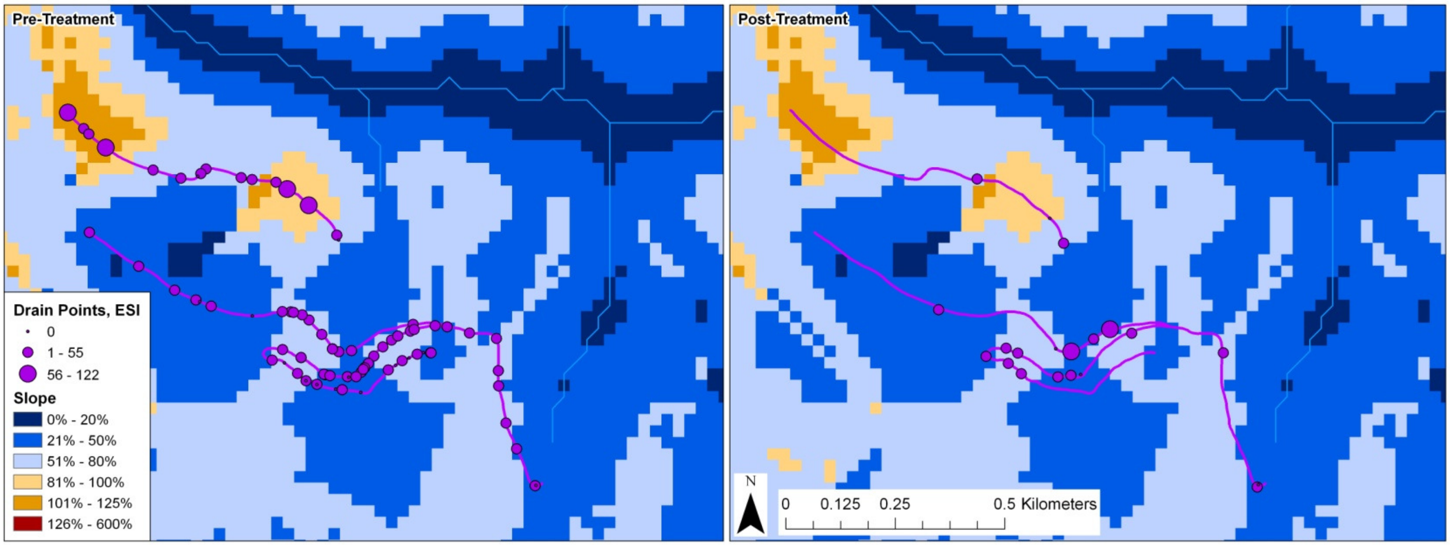

Figure 9. ESI values for drain points concentrating discharge on the 2508 spur roads. The slope map in the background indicates the component of gully risk that is due to hillslope gradient.

The average pre-treatment ESI was 13.8, with an average contributing road length of 45 m (Figure 9). These ESI-applicable drain points drained 1360 m of road length, or about 38% of the total road length. Post-treatment ESI values had a mean of 9.0. These ESI-applicable drain points drained 140 m of road length, or about 4% of the total road length. This is a reduction of the average ESI of 35% and drained road length of 90%. Post-treatment, there were only four drain points that were not diffuse, stream crossings, or orphans. However, without a valid ESI_{crit} value, it is not possible to quantify what the effect of this seemingly significant decrease will be on overall gully risk at the ESI-applicable drain points.

5.5 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 were low to moderate with an average value of 1.5 for the two pre-treatment stream crossings (Figure 10). This is out of a range of 1 to 4, where 1 suggests no risk of blockage. Both stream crossing pipes were removed during decommissioning, which completely eliminated the risk of pipe plugging. Thus, the post-treatment SBI score was zero at all crossings.

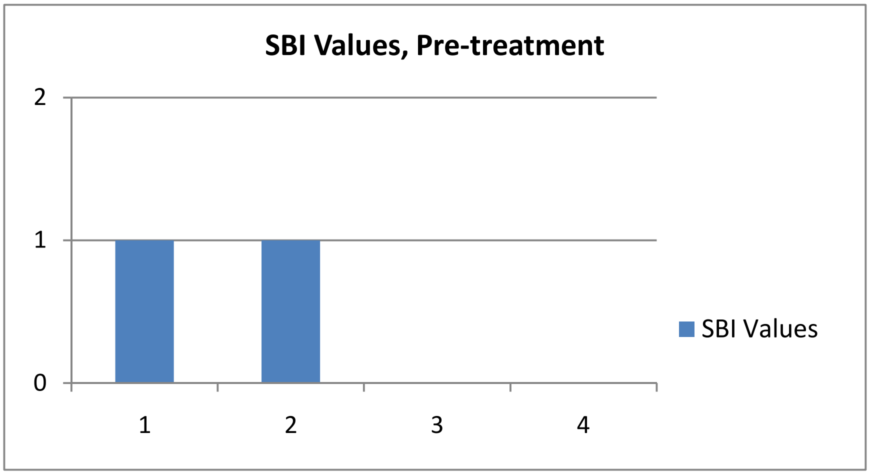

Figure 10. Distribution of Stream Blocking Index values for pre-treatment stream crossings. Values were zero after treatment.

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 80 m^3. All of this material was excavated during the restoration work.

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. At this site, neither of the stream crossings on the original roads had the potential to divert streamflow down the road in at least one direction. The restoration treatments did not change the risk, because the risk was already absent.

In addition to these measurements, data were collected at both excavated stream crossings that detailed the post-treatment, pre-storm event condition of the crossings. Measurements included the grade and width of the crossing bottom, the grade and channel width of the stream reach directly upstream from the crossing, volume of channel adjustment or erosion in the crossing, length and slope of the channel side slopes, and Wolman pebble counts for the crossing and nearest upstream reach. This data is intended to provide baseline metrics against which the amount and type of future stream crossing adjustment can be gauged.

The hypothesis is that the excavated stream crossings with characteristics that most closely match those of the upstream reach will experience less adjustment and erosion post-storm event. One stream crossing had a grade significantly shallower (18% vs. 34%) than the upstream reach (Table 6). The D50 particle size was significantly larger for both crossings than the upstream reaches (33 mm vs. 19 mm and 60 mm vs. 38 mm), indicating coarsening of the crossing bed. The channel bottoms for both crossings were significantly wider than the measured stream width. Both crossings had some incision or side slope erosion (9.4 m^3 and 8.0 m^3).

Table 6. *Stream crossing channel and upstream channel characteristics at excavated stream crossings in Mill Creek.*

	In-Crossing						Upstream		
Crossing ID	**Grade (%)**	**Width (m)**	**Erosion (cu. m)**	**Average Side Slope (%)**	**Average Side Length (m)**	**D50 (mm)**	**Grade (%)**	**Channel Width (m)**	**D50 (mm)**
1215	18	1.5	9.4	48	5	33	34	0.61	19
1009	7	10.7	8.0	33	6.4	60	9	1.5	38

5.6 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. Lead off ditches are considered problematic if they have excess deposition or gullying. Non-engineered features are almost always a problem due to a blocked ditch, a gully, or a broken outside berm. Stream crossings are considered a problem if they are blocked by sediment or wood, crushed or rusted significantly, incising, scouring or losing much water from flow around the pipe. Sumps are a problem if they pond water on the road surface or cause fill saturation. Waterbars 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.

Table 7. *Drain point condition problems and fill erosion problems below drain points, pre-treatment and post-treatment roads.*

	Pre-treatment			Post-treatment		
Drain Type	**Count**	**Problems**	**Fill Erosion**	**Count**	**Problems**	**Fill Erosion**
Broad Based Dip	22	14%	0%	0	n/a	n/a
Diffuse Drain	47	0%	0%	21	0%	0%
Ditch Relief Culvert	1	0%	100%	0	n/a	n/a
Lead Off Ditch	0	n/a	n/a	0	n/a	n/a
Non-Engineered	19	53%	0%	3	0%	0%
Stream Crossing	2	0%	0%	2	50%	0%
Sump	0	n/a	n/a	0	n/a	n/a
Waterbar	1	100%	0%	4	0%	25%
Total	**92**	**15%**	**1%**	**30**	**3%**	**3%**

At this site, non-engineered drains and broad based dip were observed to have the highest rate of problems (53% and 14%, respectively), while only one other drain point was observed to have a problem (the only observed waterbar was damaged; Table 7). So far, only one problem has been observed after the decommissioning treatments (one stream crossing was observed to have excessive erosion). Before treatment, the single observed ditch relief culvert had at least 5 ft^3 (0.14 m^3) of fill erosion. After treatment, fill erosion was observed at one waterbar. There has been little time for new problems to develop as a result of significant storms, however, the new drain points are likely more resistant to the formation of new problems, because they have less drainage length. Final conclusions regarding the new drainage system cannot be made until the post-storm validation monitoring is completed.

Summary & Conclusions

The USFS, RMRS and Northern Region initiated a road treatment monitoring project in the summer of 2009. As part of the study, field crews inventoried road segments on the Gallatin National Forest, before and after decommissioning treatments, as well as a set of control roads. These roads received high-intensity treatments that included recontouring and local ripping of road surfaces, seeding, culvert and drainage structure removal, and stream crossing culvert and fill removal and reconstruction. These treatments were applied after the Wicked Creek/Hicks Park Complex fire of 2007 to reduce the risk of the roads amplifying the effects of post-fire erosion and runoff.

The GRAIP model was used to predict the change in level of impact/risk between the pre-existing road and the decommissioned road. The restoration treatments reduced the length of the sampled road that was hydrologically connected to streams by 40 m, or 100% from pre-treatment conditions. The model predicts that fine sediment delivery was reduced by 100%, from 120 kg to 0 kg annually. The risks presented by stream crossings becoming plugged by debris and sediment were completely eliminated by the excavation and removal of the culverts and fills. These locations may contribute fine sediment to the channel in the short-term, but this treatment will prevent over 80 m^3 of earthen material from eroding into the channel when the stream crossings ultimately become plugged or fail from rusting. The potential for streamflow to be diverted onto roads and unchanneled hillslopes was absent before treatment, and was unchanged at both crossing sites.

The slope stability risk below drain point locations on the original road was reduced to nearly background levels in most locations as water was redistributed across the hillslope as diffuse drainage. Risk of gully initiation, as determined by a gully initiation index (ESI), experienced a reduction from low to negligible across the length of treated road, due to the removal of most concentrated drainage features. Current calculations are based on conservative assumptions; such assumptions will be assessed during future post-storm monitoring.

Before treatment, inventoried road segments had problems at 14 of 92 inventoried drainage points. Post-treatment monitoring indicates that these problems were eliminated by the storage treatments and that most replacement drainage features may be less vulnerable to failure. One excavated stream crossing had excessive erosion post-treatment.

Table 8. *Summary of GRAIP model risk predictions for the Mill Creek decommissioning project.*

IMPACT/RISK TYPE	EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION	EFFECT OF TREATMENT: POST-STORM VALIDATION
Road-Stream Hydrologic Connectivity	-100%, -40 m	To be determined.
Fine Sediment Delivery	-100%, -120 kg	To be determined.
Landslide Risk	Reduced to near natural condition	To be determined.
Gully Risk	Reduced from low to negligible	To be determined.
Stream Crossing Risk		
- plug potential	-100%, eliminated at both sites	To be determined.
- fill at risk	-100%, 80 m^3 removed	To be determined.
- diversion potential	Risk absent pre-treatment	To be determined.
Drain Point Problems	14 problems removed, 1 new problem	To be determined.

As a whole, these initial results indicate that the decommissioning work in the Mill Creek watershed should be effective in reducing or eliminating each of the hydrogeomorphic impacts and risks that these roads posed to aquatic ecosystems. However, most of the risk metrics were low-risk before treatment. Sediment delivery, hydrologic connectivity, and gully initiation risks were very low, while landslide and stream crossing failure risks were somewhat higher.

Appendix A: 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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