Legacy Roads and Trails Monitoring Project

Road Decommissioning in the Lolo Creek Watershed

Clearwater National Forest

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Table of Contents

List of Figures

List of Tables

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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 being its implementation. Based on continued success, the program was allocated $90 million in FY2010. 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 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 Clearwater National Forest (CNF) in the Lolo Creek watershed. At the CNF sites, treatments included recontouring and local tilling of road surfaces, placement of slash, 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. Road-stream connectivity was reduced by 97%, from 2600 m of connected road to 90 m (2510 m reduction). Predicted delivery of fine sediment was reduced by 97%, from 38.1 tonnes/year to 1.3 tonnes/year (36.8 tonnes/yr reduction). Values of a stream blocking index were reduced from an average of 1.9 before treatment to zero after treatment (n=9), 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 268 m^3 of earthen material from areas with a high potential for failure and delivery to stream channels. Diversion potential was eliminated at all nine 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 very 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 17 of 90 inventoried drainage points. Post-treatment monitoring indicates that each of these problems was eliminated by the treatments and that most replacement drainage features may be less vulnerable to failure. Four new non-engineered problem points were observed on the post-treatment road.

Treatments were applied to primarily address hydrologic connectivity, sediment delivery, removal of unneeded road length (and therefore maintenance needs), and the risk of stream crossing failure. Gully initiation risk and shallow landslide risk were less important. Taken collectively, preliminary results indicate the decommissioning treatments should be effective in significantly reducing each of the hydrogeomorphic impacts and risks to aquatic ecosystems. Some of the risk metrics were low-risk before treatment. Shallow landslide and gully initiation risks were very low, while the other risks were moderate to high.

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

IMPACT/RISK TYPE	EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION	EFFECT OF TREATMENT: POST-STORM VALIDATION
Road-Stream Hydrologic Connectivity	-97%, -2510 m	To be determined.
Fine Sediment Delivery	-97%, -36.8 tonnes/yr	To be determined.
Landslide Risk	Reduced to near natural condition	To be determined.
Gully Risk	Reduced from very low to negligible	To be determined.
Stream Crossing Risk		
- plug potential	-100%, eliminated at 9 sites	To be determined.
- fill at risk	-100%, 268 m^3 fill removed	To be determined.
- diversion potential	-100%, eliminated at 3 sites	To be determined.
Drain Point Problems	17 problems removed, 4 new problems	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 program, the USFS, Rocky Mountain Research Station (RMRS) and Northern Region (R1) are implementing the Legacy Roads and Trails Monitoring Project (LRTMP) 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 Clearwater National Forest (CNF) in the Lolo 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 3.5 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 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

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-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.

[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.

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)

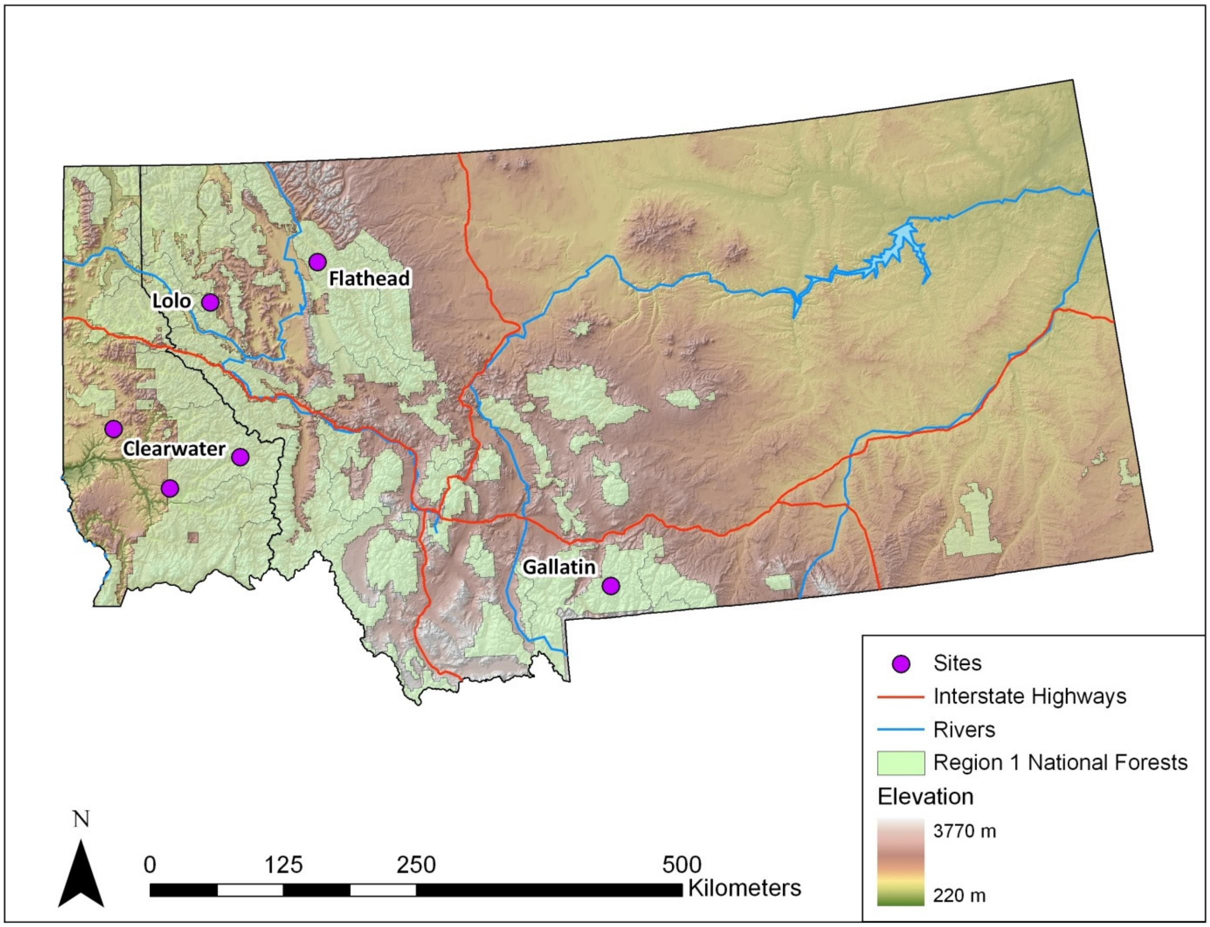

Figure 1. Location of monitored sites, FY2009 and FY2010, Northern Region.

Lolo Creek Basin Sites

During the summers of 2009 and 2010, field crews inventoried decommissioning treatment sites in the Lolo Creek watershed (Table 2, Figure 2). The decommissioning treatment sites in this watershed are principally underlain by schist and quartzite or Columbia River Basalt. Other rock units within the Lolo Creek drainage are predominately metamorphic and granitic rocks.

The average precipitation for the sites is 75-100 cm/yr (30-40 inches/yr), while the average over the basin is on the order of 65-180 cm/yr (25-70 inches/yr). The inventoried sites are located between 900 m (2950 ft) and 1200 m (3940 ft) above sea level on the west side of the Bitterroot Mountain Range and the continental divide, on the eastern edge of the Palouse Prairie. Pre-treatment roads were originally native surfaced. Much of the road length had a ditch with frequent drainage structures, though some road length did not have a ditch. Many roads were significantly vegetated at the time of the pre-treatment survey. Both treatment and control sites included roads located at lower-slope and streamside hillslope positions. At this site, only 3.5 miles of road surveyed pre-treatment could be surveyed after treatment.

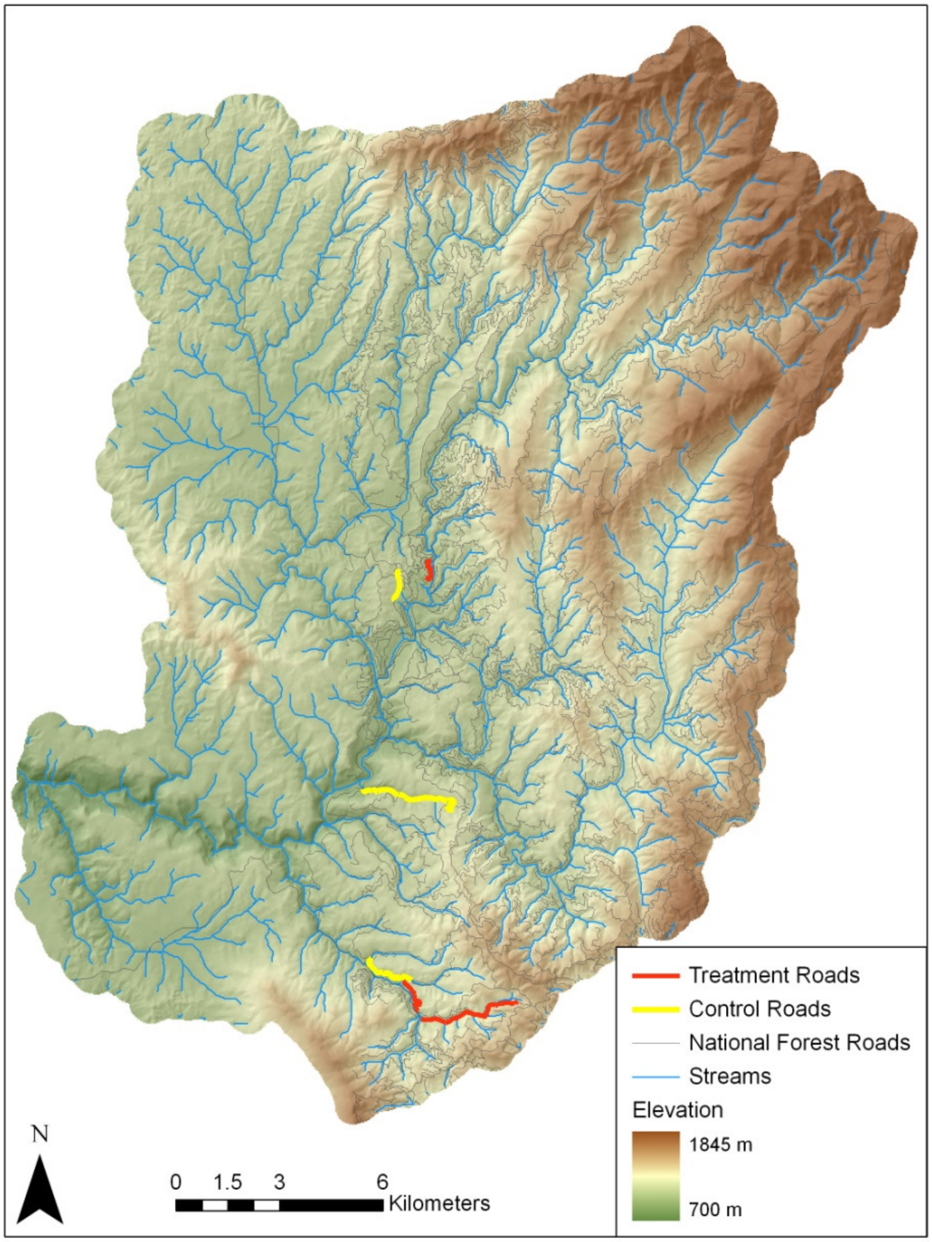

Figure 2. Location of monitored roads within the Lolo Creek watershed, Clearwater National Forest.

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

Decom Treated Road		Control Roads	
Road #	**Treatment**	**Road #**	**Treatment**
5018 (Yakus) (0.9 miles)	Recontouring, culvert and drainage structure removal, stream crossing culvert and fill removal and reconstruction.	5017 (1.1 miles)	None
5105 (Yakus) (2.1 miles)	Recontouring, local tilling, culvert and drainage structure removal, stream crossing culvert and fill removal and reconstruction.	5051 (2.1 miles)	None
5146 (White-White) (0.6 miles)	Recontouring, culvert and drainage structure removal.	5150 (0.7 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 Lolo Creek watershed, the decommissioning treatments redistributed water back onto the hillslope. Prior to the treatments, 2600 m out of 5530 m of inventoried road (47%) were hydrologically connected to the stream. After the treatments, 90 m out of 5690 m of monitored road (2%) was connected. Thus, the treatments resulted in a net reduction of 2520 m of hydrologically connected road, which is 97% less than the pre-treatment condition.

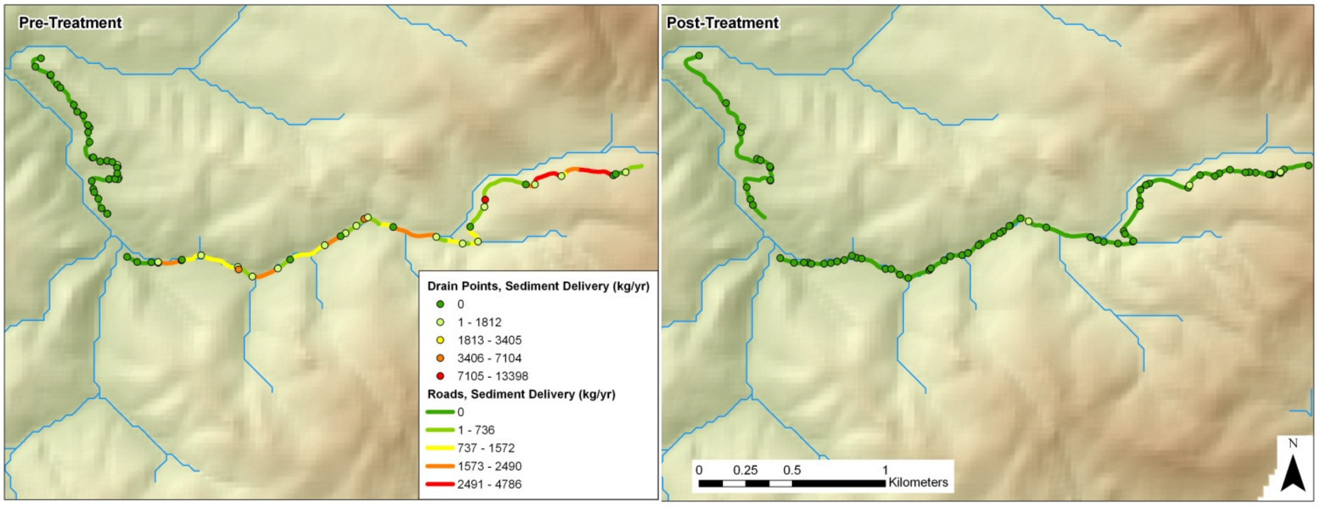

Figure 3. Fine sediment delivery to channels by road segment and drain point, pre-treatment (left) and post-treatment (right), Yakus roads. The road lines and drain points are colored to indicate the mass of sediment delivered to the channels.

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 Yakus roads (Figure 3).

[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). Local data from three erosion plots on Lolo Creek in 2008 and 2009 suggests a base rate of 10 kg/m. 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 ditch relief culverts, diffusely draining road segments, waterbars, 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. 90 drain points were documented, 33% of which were hydrologically connected to stream channels. These points delivered an estimated 55.6 tonnes/year of sediment, or 68% 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	5	11260	3060	27%	120	45%
Diffuse Drain	18	1950	0	0%	0	0%
Ditch Relief Culvert	27	19940	19160	96%	1300	83%
Lead Off Ditch	0	n/a	n/a	n/a	n/a	n/a
Non-Engineered	10	14630	13540	93%	640	67%
Stream Crossing	9	2360	2360	100%	550	100%
Sump	3	1640	0	0%	0	0%
Waterbar	18	3930	0	0%	0	0%
All Drains	**90**	**55710**	**38120**	**68%**	**2600**	**47%**

Post-treatment

Road surfaces were decompacted and recontoured over most of the treated length. The sediment production on the recontoured sections was calculated using a diffusive erosion rate[4], the area of the recontoured surface, and the slope of the hill. Road surfacing and vegetation factors remained the same. This had the effect of decreasing sediment production to 29.2 tonnes/yr.

Most of the new post-treatment drainage features did not drain any length of road, or did not deliver sediment to streams. This is often because the new features were diffusely draining road segments that did not concentrate enough flow to reach a stream. Sediment delivery was reduced to 1.3 tonnes/yr. Sediment production and delivery are expected to decline further as decompacted roads become more vegetated.

[4] The diffusive sediment transport rate is based on observations from freshly disturbed cutslope plots on silty clay loam soils in western Oregon (the same sites used to develop the base erosion rate for the road surfaces). The erosion rate is 1.34 kg/m^2.

Table 4. *Summary of sediment production and delivery at drain points, 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	47	27940	240	1%	50	1%
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	6	210	0	0%	0	0%
Stream Crossing	9	1020	1020	100%	30	100%
Sump	0	n/a	n/a	n/a	n/a	n/a
Waterbar	22	62	60	100%	10	100%
All Drains	**84**	**29230**	**1320**	**5%**	**90**	**2%**

The modeled change in sediment production following the treatments shows a decline of 26.5 tonnes/year to a total of 29.2 tonnes/year (Table 5). Sediment delivery following the treatments shows a decrease of 36.8 tonnes/yr, which is a decrease of 97%. The largest reductions occurred at ditch relief culverts and non-engineered drain points, through removal of the features. Slight increases occurred at diffuse drains and waterbars, because there were more of these features installed during the treatment than there were removed.

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

DrainType	Count	∑ Sediment Production (kg)	∑ Sediment Delivery (kg)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	-5	-11260	-3060	-100%	-120	-100%
Diffuse Drain	29	25980	240	100%	49	100%
Ditch Relief Culvert	-27	-19940	-19160	-100%	-1300	-100%
Lead Off Ditch	0	n/a	n/a	n/a	n/a	n/a
Non-Engineered	-4	-14420	-13540	-100%	-640	-100%
Stream Crossing	0	-1340	-1340	-57%	-520	-95%
Sump	-3	-1640	0	0%	0	0%
Waterbar	4	-3860	60	100%	10	100%
All Drains	**-6**	**-26480**	**-36800**	**-97%**	**-2520**	**-97%**

5.3 Landslide Risk

The Lolo Creek basin has a generally low risk of shallow landsliding, and the areas near to the monitored sites have a low to moderate risk. There were no landslides observed from the roads by field crews. 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 and available data was not sufficient; therefore this analysis uses SINMAP's default values and may over- or under-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.

Figures 4 through 7[5] 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 low to moderate in the area of the treated roads (Figure 4).

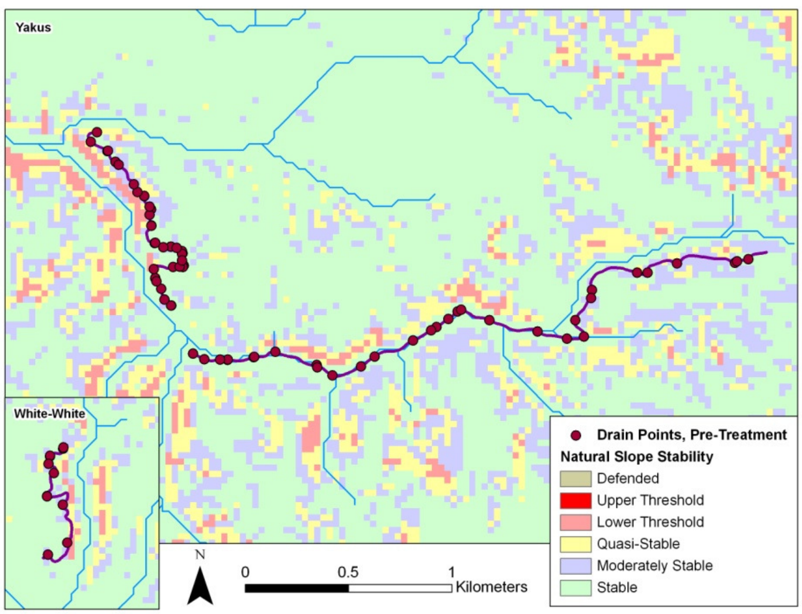

Figure 4. Natural slope stability risk in the area of the monitored roads (Yakus main map, White-White inset). The yellow, blue, and green cells are generally considered to be stable, while the pink, red, and tan cells are generally considered to be unstable.

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 5, the areas along the treatment roads where the treatment changed the risk from the unstable category (defended, upper threshold,

[5] Figures 4 through 7 are rendered at the same scale. The legend items for each figure are consistent from one figure to the next.

and lower threshold from Figure 4, above) to the stable category (quasi-stable, moderately stable, and stable) are shown in green. There were no areas where the treatment changed the risk from the stable category to the unstable category. These are the areas where risk has been sufficiently reduced (green). The areas where risk was sufficiently decreased are due to the removal of water from those features, or more commonly, due to the complete removal of the features themselves.

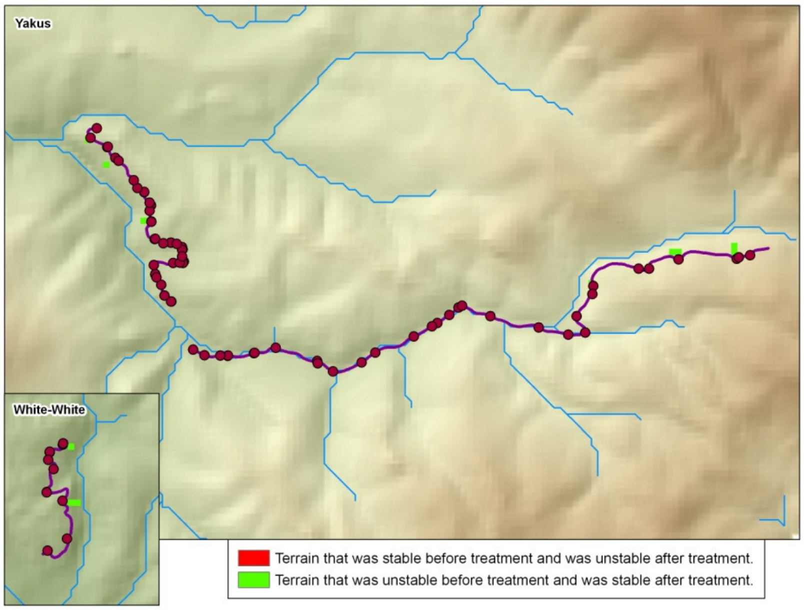

Figure 5. The most significant slope stability risk changes along the treated roads. The risk of area in green was sufficiently reduced. There were no areas where risk was significantly increased.

Figure 6 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. There are no areas where the risk increased after treatment, and the terrain was unstable before treatment.

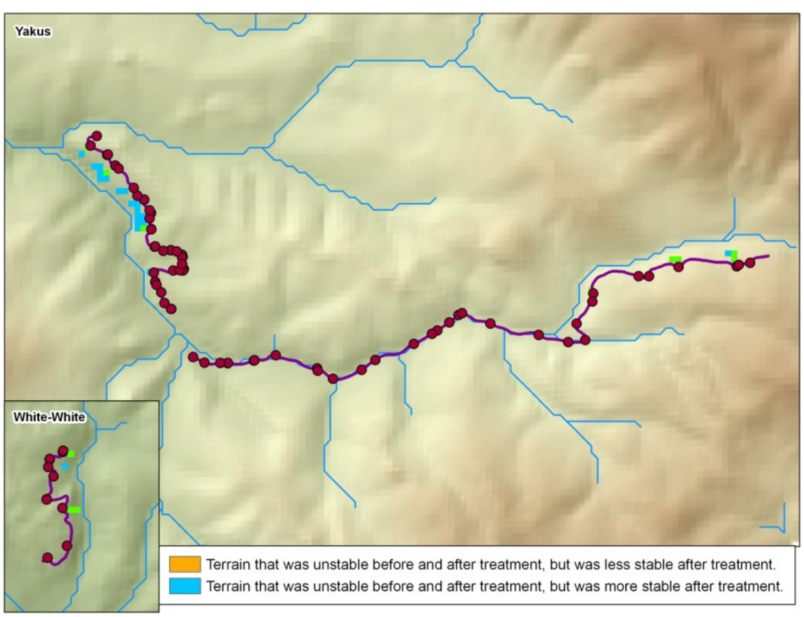

Figure 6. Changes in slope stability risk for Yakus and White-White roads where the terrain was unstable before and after treatment. The blue areas are locations where risk was lowered.

The locations where the risk of shallow landsliding was naturally high are shown in Figure 7, where the cross-hatch areas were unstable without consideration of road drainage. Cross-hatch over blue shows the areas that experienced reduced 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.

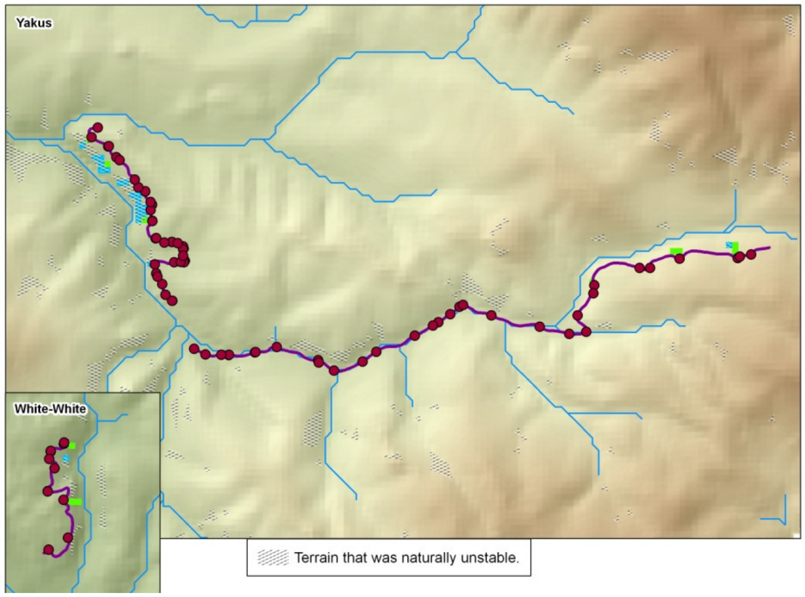

Figure 7. Background slope stability and the changes in slope stability. The cross-hatch pattern indicates areas that were unstable without consideration of road drainage.

The net effect of the decommissioning treatments, which removed most concentrated drainage features, achieved the goal of reducing risk across the sample area. The inventory and modeling done here should help better characterize the needs for treatment in these locations and quantify potential risks to downslope resources. 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, 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.

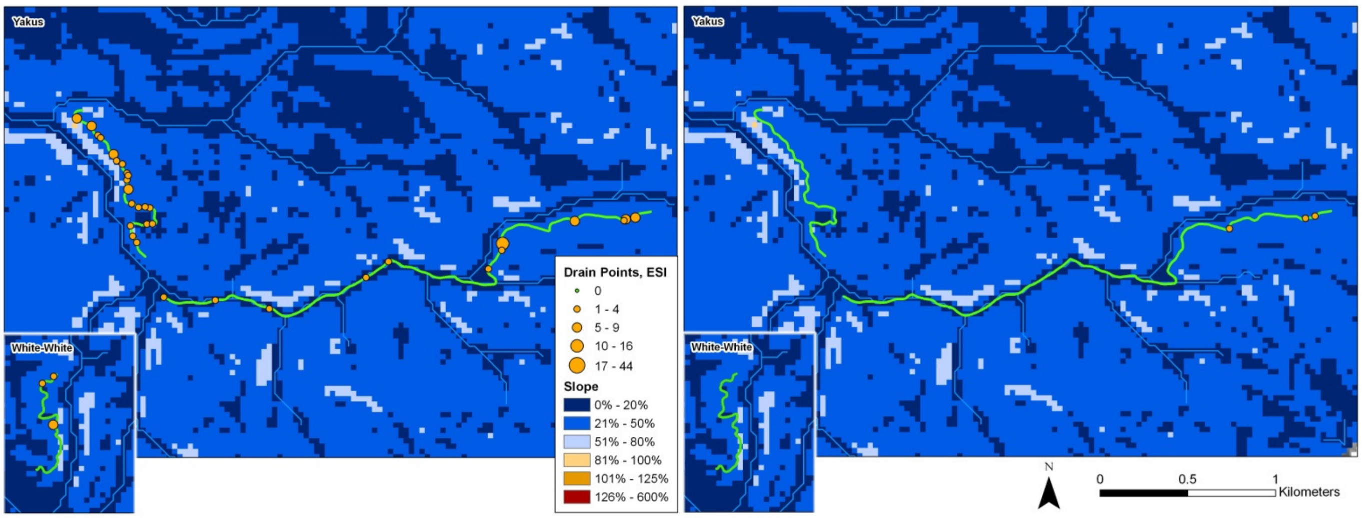

Figure 8. ESI values for drain points concentrating discharge on the Yakus (main map) and White-White (inset) roads. The slope map in the background indicates the component of gully risk that is due to hillslope gradient.

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.

The average pre-treatment ESI was a low 1.8, with an average contributing road length of 64 m (Figure 8). These ESI-applicable drain points drained 3510 m of road length, or about 63% of the total road length. Post-treatment ESI values had a mean of 0.7. These ESI-applicable drain points drained only 18 m of road length, or about 0.3% of the total road length. This is a reduction of the average ESI of 58% and drained road length of 99%. Post-treatment, there were only two drain points that were not diffuse, stream crossings, or orphans. The remaining gully initiation risk post-treatment is negligible.

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 1.9 for the nine stream crossings (Figure 9). This is out of a range of 1 to 4, where 1 suggests no risk of blockage. All nine 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.

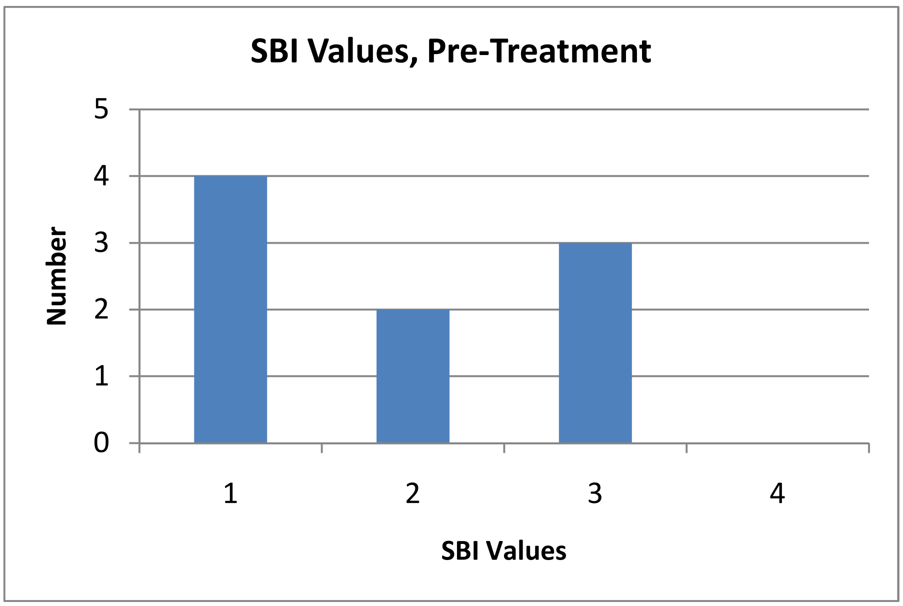

Figure 9. Distribution of Stream Blocking Index values for pre-treatment stream crossings. Values were zero after treatment.

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 268 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, 3 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 eliminated this risk entirely by re-establishing the channel across the former road bed and pulling back fill material to create high side slopes on either side of the channel.

Table 6. *Stream crossing channel and upstream channel characteristics at excavated stream crossings in the Lolo Creek watershed monitored sites.*

	In-Crossing						Upstream		
Crossing ID	Grade (%)	Width (m)	Erosion (m^3)	Average Side Slope (%)	Average Side Length (m)	D50 (mm)	Grade (%)	Channel Width (m)	D50 (mm)
0759	7	1.8	0.8	40.5	4.6	16	7	0.3	4
0902	2	2.8	10.4	28	9.6	15	2	2.7	15
1030	11	1.9	1.5	26	4.6	9	11	0.5	13
0857	23	2.4	0.8	29.5	6.1	2	27	0.6	2
0953	19	2.3	1.3	31.5	5.5	2	11	0.3	2
1409	23	1.8	2.0	39.5	8.2	11	25	0.5	2
1528	7	2.6	3.9	42	5.5	6	3	0.9	13
1645	3	2.4	7.2	39.5	6.0	12	2	2.1	22
1747	9	1.5	1.0	35.5	5.1	18	19	0.3	18

In addition to these measurements, data were collected at each excavated stream crossing 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 (9% vs. 19%) than the upstream reach (Table 6) and one crossing had a significantly steeper grade (19% vs. 11%). The D50 particle size was significantly larger at two crossings than the upstream reaches (16 mm vs. 4 mm and 11 mm vs. 2 mm), indicating coarsening of the crossing bed. The D50 particle size was significantly finer at two other crossings than the upstream reaches (6 mm vs. 13 mm and 12 mm vs. 22mm). The channel bottoms for all crossings were as wide as or wider than the measured stream width. All crossings had some incision or side slope erosion (ranging from 0.8

m^3 to 10.4 m^3, with a mean of 3.2 m^3). Finally, it was observed that most (8 of 9) excavated stream crossings had side slopes that were well-vegetated with grasses, forbs, and/or woody plants (Figure 10).

Figure 10. Excavated stream crossing on road 5105 (Yakus). Note the channel incision and living vegetation on the side slopes. This represents a “typical” excavated stream crossing for these roads.

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. Excavated stream crossings are considered a problem if they have excess erosion in the channel, if there is landslide in the side slopes, or if the stream flows under the fill. 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. Fill erosion is noted separately if there is greater than 5 ft^3 eroded at any drain point.

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

	Pre-treatment				Post-treatment			
			Fill Erosion				Fill Erosion	
Drain Type	**Count**	**Problems**	***Total Volume (ft^3)***	***% of Total***	**Count**	**Problems**	***Total Volume (ft^3)***	***% of Total***
Broad Based Dip	5	20%	0	0%	0	n/a	n/a	n/a
Diffuse Drain	18	0%	0	0%	47	0%	0	0%
Ditch Relief Culvert	27	22%	5	4%	0	n/a	n/a	n/a
Lead Off Ditch	0	n/a	0	n/a	0	n/a	n/a	n/a
Non-Engineered	10	30%	0	0%	6	67%	20	67%
Stream Crossing	9	56%	5	11%	9	0%	0	0%
Sump	3	33%	0	0%	0	n/a	n/a	n/a
Waterbar	18	6%	0	0%	22	0%	50	45%
Total	**90**	**19%**	**10**	**2%**	**84**	**5%**	**70**	**17%**

At this site, ditch relief culverts and stream crossings were observed to have the highest rate of problems pre-treatment (22% and 56%, respectively), while broad based dips, non-engineered drains, sumps, and waterbars had few problems before treatment (Table 7). So far, four problems have been observed after the decommissioning treatments, all at non-engineered drains. There has been little time for new problems to develop as a result of significant storms,

Figure 11. Fill erosion at a waterbar on road 5105 (Yakus). The erosion here is caused by the interception of discontinuous runoff and groundwater.

however, the new drain points are likely more resistant to the formation of new problems, because they have less drainage length (most drainage features are either diffusely draining road segments or do not drain longitudinal road length). Before treatment, one ditch relief culvert and one stream crossing had at least 5 ft^3 (0.14 m^3) of fill erosion, for a total of 10 ft^3 (0.28 m^3). After treatment, fill erosion was observed at four non-engineered drains and ten waterbars, for a total of 70 ft^3 (2.0 m^3). This increase is likely due to the combination of decompaction through recontouring, which decreases the fill resistance to erosion, and interception of runoff (not a continuous stream) or groundwater (Figure 11). 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 Legacy Roads and Trails Monitoring Project in the summer of 2009. As part of the study, field crews inventoried road segments on the Clearwater 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 tilling of road surfaces, culvert and drainage structure removal, and stream crossing culvert and fill removal and reconstruction.

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 2510 m, or 97% from pre-treatment conditions. The model predicts that fine sediment delivery was reduced by 97%, from 38.1 tonnes to 1.3 tonnes 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 268 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 eliminated at all crossings.

The slope stability risk below drain point locations on the original road was reduced to nearly background levels over the treated area 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 very 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 17 of 90 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. However, four new problems were present post-treatment (out of 84 inventoried drainage features). Fill erosion, which was present in two locations pre-treatment, was present in 14 locations post-treatment, due to the decompaction of road surfaces and stream crossings.

Treatments were applied to primarily address hydrologic connectivity, sediment delivery, removal of unneeded road length (and therefore maintenance needs), and the risk of stream crossing failure. Gully initiation risk and shallow landslide risk were viewed as lower risk of occurrence. Taken collectively, preliminary results indicate the decommissioning treatments should be effective in significantly reducing each of the hydrogeomorphic impacts and risks to aquatic ecosystems (Table 8). Some of the risk metrics were low-risk before treatment. Shallow landslide and gully initiation risks were very low, while the other risks were moderate to high.

Table 8. *Summary of GRAIP road risk predictions for the Lolo Creek watershed decommissioning treatment project.*

IMPACT/RISK TYPE	EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION	EFFECT OF TREATMENT: POST-STORM VALIDATION
Road-Stream Hydrologic Connectivity	-97%, -2510 m	To be determined.
Fine Sediment Delivery	-97%, -36.8 tonnes/yr	To be determined.
Landslide Risk	Reduced to near natural condition	To be determined.
Gully Risk	Reduced from very low to negligible	To be determined.
Stream Crossing Risk		
- plug potential	-100%, eliminated at 9 sites	To be determined.
- fill at risk	-100%, 268 m^3 fill removed	To be determined.
- diversion potential	-100%, eliminated at 3 sites	To be determined.
Drain Point Problems	17 problems removed, 4 new problems	To be determined.

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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