



# Legacy Roads and Trails Monitoring Project

Storm Damage Risk Reduction in the Skokomish River Watershed

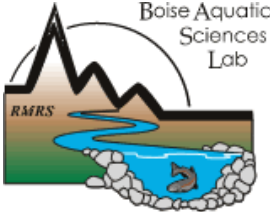

Olympic National Forest

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## Executive Summary

In Fiscal Year 2008, Congress authorized the Legacy Roads and Trails Program, which 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 US Forest Service (USFS) was appropriated \$40 million to begin its implementation in FY2008, followed by \$50 million in FY09 and \$90 million in FY10.

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

To date, pre-treatment inventories have been conducted at 21 locales where decommissioning, heavy maintenance (i.e., storm damage risk reduction; SDRR), or road storage treatments have since or will be implemented. At each of these locations, four miles of road were assessed. Inventories were also completed on four miles of control sites for each locale. Eighteen post-treatment inventories were executed, as well as two post-storm validation evaluations. This status report focuses only on SDRR work implemented by the Olympic National Forest (ONF) in the Skokomish River watershed. At the ONF sites, treatments included replacement and installation of new 24" plastic ditch relief culverts, culvert cleaning and reconditioning, installation of rip rap at drain outlets or inlets, ditch cleaning and armoring at critical locations, stream crossing culvert upgrades with ditch dams, installation of a broad based dip, removal of unstable hillslope material (sidecast pullback), spot resurfacing, and the installation of water bars.

Before-after comparisons using GRAIP indicate that SDRR treatments resulted in a reduction of most impact-risk metrics. Road-stream connectivity was reduced by 38%. Delivery of fine sediment was reduced by 47%. Stream crossing plugging potential was reduced at one site, and stream diversion potential was probably reduced but not eliminated at two sites. Diversion potential was not otherwise changed.

The slope stability risk below drain point locations on the original road was reduced in some locations as water was redistributed across the hillslope by new drainage. However, landslide risk was increased in a few areas where new concentrated drainage features were added above steep slopes. These features were generally installed to break up long road segments that delivered road runoff and sediment directly to streams or posed a risk of gully initiation. There was a net increase in locations at risk of shallow landsliding.

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Gully risk increased somewhat, as determined by comparisons of a gully initiation index (ESI) to an empirically-derived threshold (ESI<sub>crit</sub>). New drainage features reduced the gully index at some of the original drainage points by reducing the length of the road segments discharging to them. In some cases, however, post-treatment index values still exceeded the locally calibrated initiation threshold, indicating elevated risk was still present. Moreover, index values were elevated further at some of the existing drainage points by increasing the contributing road length and exceeded the threshold at some of the new drainage points. The net effect was that treatments increased the number of drainage points with elevated gully risk by nine, though the average ESI decreased from 27 to 18.

Before treatment, problems such as blocked culverts, puddles on the road, or saturated fill were observed at 21 of the inventoried drainage points. Post-treatment monitoring indicates that the total number of problems was reduced by 9, leaving 12 problem sites post-treatment. Eleven of the problems at the post-treatment drainage points were pre-existing, and one problem (an occluded replacement culvert) was new. Ten problem drainage points were removed or repaired by the treatments. The new drainage features will provide an opportunity to learn about potential reduction in maintenance needs afforded by the new structures.

Taken collectively, preliminary results indicate the SDRR treatments should be effective in reducing most hydrogeomorphic impacts and risks to aquatic ecosystems. However, these results also indicate that landslide and gully risks were increased. A post-storm event inventory will be conducted to validate the predictions, and the risk profile will be revised at that time.

*Summary of GRAIP road risk predictions for the Skokomish River watershed SDRR project.*

<b>IMPACT/RISK TYPE</b>	<b>EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION</b>	<b>EFFECT OF TREATMENT: POST-STORM VALIDATION</b>
Road-Stream Hydrologic Connectivity	-38%, -1628 m	To be determined.
Fine Sediment Delivery	-47%, -11.2 tonnes/year	To be determined.
Landslide Risk	Net increase, general re-distribution of risk	To be determined.
Gully Risk	Average ESI reduced from 27 to 18, but 9 more drain points with elevated risk	To be determined.
Stream Crossing Risk		
- plug potential	Slight decrease	To be determined.
- fill at risk	No change	To be determined.
- diversion potential	Slight decrease	To be determined.
Drain Point Problems	10 problems fixed, 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 for implementation. This program is intended to reduce road and trail impacts and risks to watersheds and aquatic ecosystems by decommissioning unneeded roads, removing fish passage barriers, and addressing critical repair and maintenance needs.

Recognizing the importance of this program, the USFS, Rocky Mountain Research Station (RMRS) and Pacific Northwest (PNW) Region are implementing the Legacy Roads and Trails Monitoring Project (LRTMP) to evaluate the effectiveness of road restoration treatments being implemented on national forests in Oregon and Washington. This report briefly describes the overall objectives of the Regional-scale study and the methods being used. Specific results presented herein, however, are focused only on road Storm Damage Risk Reduction (SDRR) work completed by the Olympic National Forest (ONF) in the Skokomish River watershed in FY2008 and 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. Fine sediment production and delivery to stream channels?
  - b. The risk of increased peak flows resulting from road-stream connectivity?
  - c. Shallow landslide risk?
  - d. Gully initiation risk?
  - e. The risk and consequences of stream crossing failures
2. Improving 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, 2009). The GIS models use these data to analyze road-stream hydrologic connectivity, fine sediment production and delivery, shallow landslide potential with and without road drainage, gully initiation risk, and the potential for and consequences of stream crossing failures. Detailed information about the performance and condition of the road drainage infrastructure is also supplied.

Risk profiles are being developed and compared at untreated control segments and treated segments before and after road projects. At a given site, monitored road segments typically comprise 4 miles of both treated and control sites. Control sites were selected based on their similarity to treated sites with respect to road construction methods, maintenance levels, geology, and hydrologic regimes. Each site 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 FY2008, FY2009, and FY2010, pre-treatment evaluations were completed at 21 sites<sup>1</sup> on national forests throughout the Pacific Northwest Region. Decommissioning and storage treatments have been implemented at 14 of these sites and seven sites have been treated with storm damage risk reduction (SDRR)<sup>2</sup> (Figure 1, Table 1). Eighteen post-treatment inventories and two post-storm validation evaluations were also completed in FY2008, FY2009, and FY2010.

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<sup>1</sup> 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.

<sup>2</sup> 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.

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Post-treatment and, to the degree possible, post-storm evaluations will be completed at the remaining sites in FY2011. In 2009, a similar study was begun in Regions 1, 4, and 5.

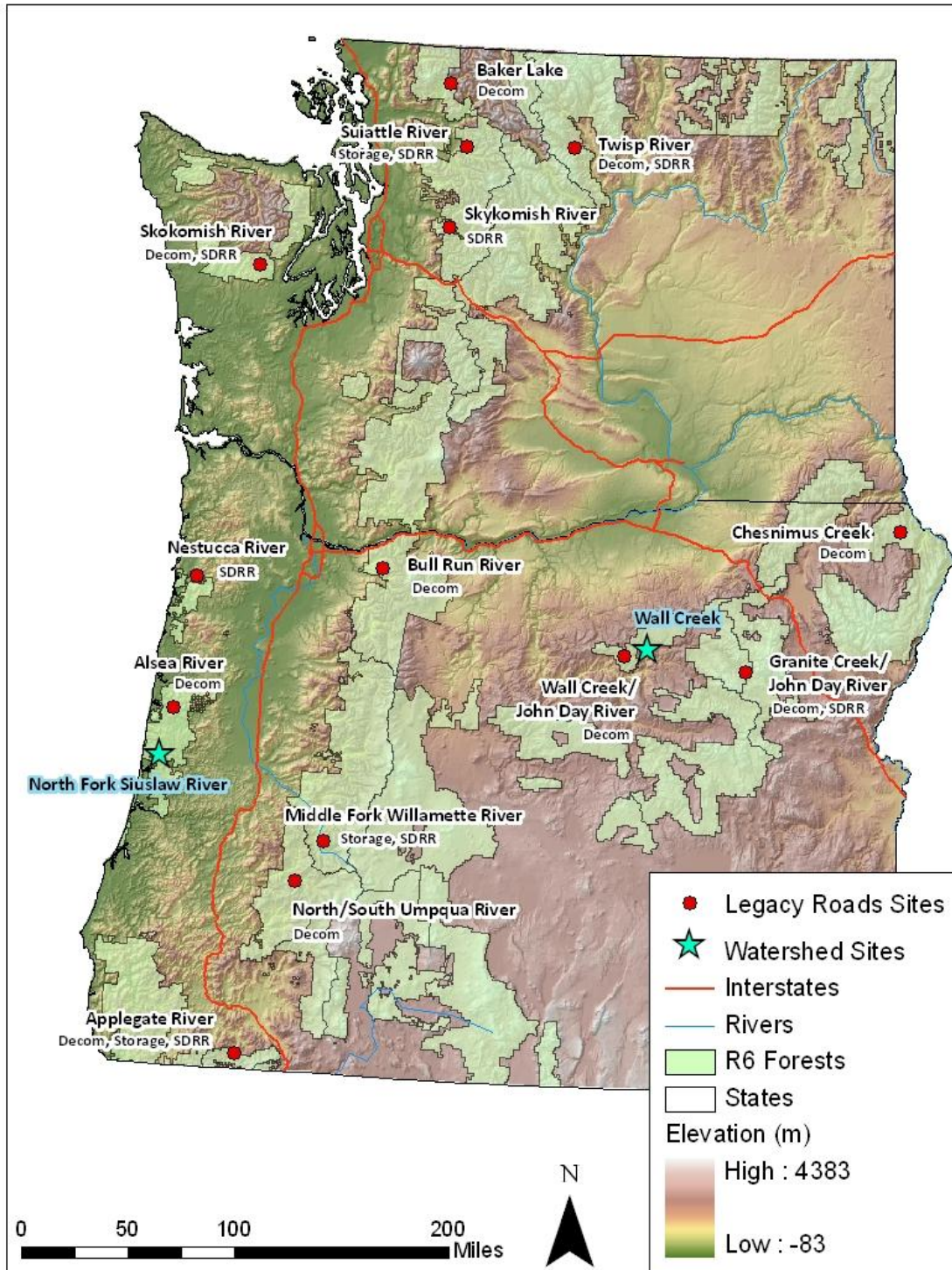


Figure 1. Location of monitored sites, FY2008 through FY2010, PNW Region.



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**Table 1.** The locations and types of road treatments monitored in Region 6.

NATIONAL FOREST	WATERSHED	TREATMENT
Mt. Baker-Snoqualmie	Baker Lake	Decommissioning
	Skykomish River	Storm Damage Risk Reduction
	Suiattle River	Storage
	Suiattle River	Storm Damage Risk Reduction
Mt. Hood	Bull Run River	Decommissioning
Okanogan	Twisp River	Decommissioning
	Twisp River	Storm Damage Risk Reduction
Olympic	Skokomish River	Decommissioning
	Skokomish River	Storm Damage Risk Reduction
Rogue	Applegate River	Decommissioning
	Applegate River	Storage
	Applegate River	Storm Damage Risk Reduction
Siuslaw	Alesea River	Decommissioning
	Nestucca River	Decommissioning
Umatilla	Granite Creek	Decommissioning
	Granite Creek	Storm Damage Risk Reduction
	Wall Creek	Decommissioning
Umpqua	South Umpqua River	Decommissioning
Wallowa-Whitman	Chesnimus Creek	Decommissioning
Willamette	Middle Fork Willamette River	Storm Damage Risk Reduction
	Middle Fork Willamette River	Storage

### Skokomish Basin Sites

During the summer and fall of 2008 and 2009, field crews inventoried both decommissioning and storm damage risk reduction sites in the Skokomish watershed, with follow-up work in the summer of 2010 (Table 1, Table 2, Figure 2). This watershed is principally underlain by basalt, but the bulk of the surface is veneered with glacial outwash and associated quaternary deposits.

The average precipitation for the basin is on the order of 80 inches per year with November through January commonly receiving 10 inches of precipitation per month. The inventoried sites are located between 800 and 1800 feet above sea level on the southeast side of the Olympic Mountains, at the lower edge of the transient snow zone.

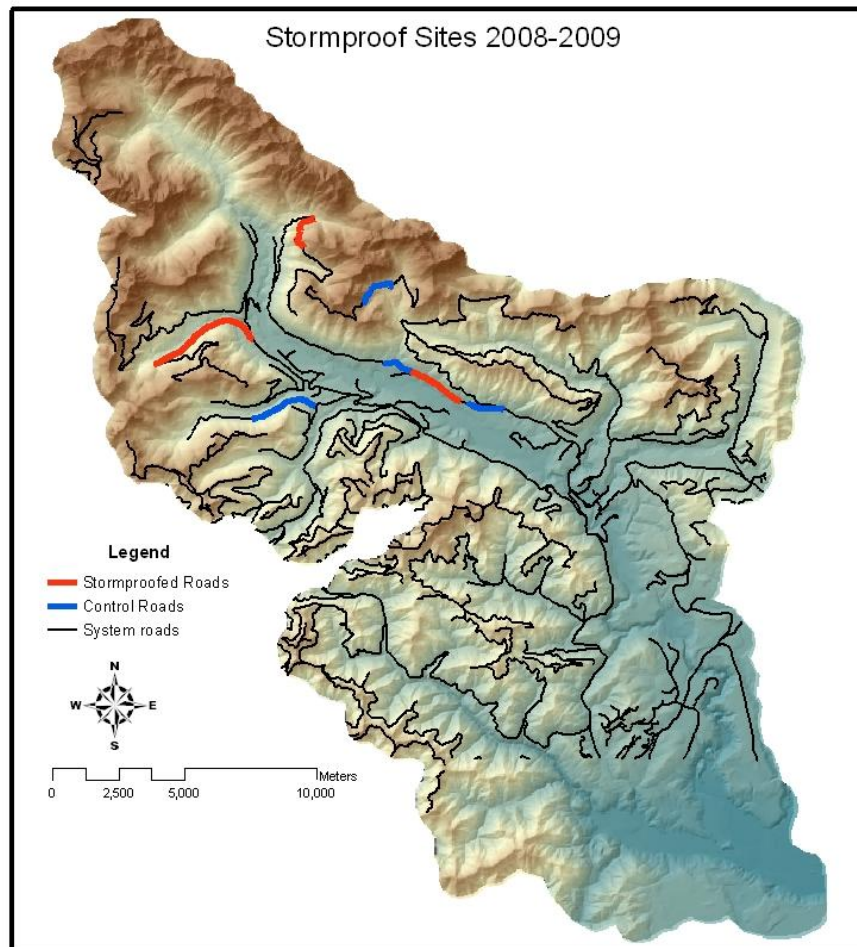
Pre-treatment roads were crowned with an inboard ditch, surfaced with gravel, and constructed with periodic drainage features. Both treatment and control sites included roads

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on a range of hillslope positions and included frequent live stream crossings. The watershed has steep topography, so road cutslopes, fillslopes, and stream crossing fills, are typically large.

SDRR treatments included replacement and installation of new 24" plastic ditch relief culverts, cleaning and reconditioning of culverts, ditch cleaning and armoring at critical locations, rip rap installation at drain points, spot resurfacing, installation of water bars, stream crossing culvert upgrades with ditch dams, fillslope pullback, and a reconstructed stream crossing.



**Figure 2.** Location of monitored sites in Skokomish River watershed, Olympic National Forest.

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

SDRR TREATED ROAD		CONTROL ROAD	
Road #	Treatment	Road #	Treatment
2361600 (MP 0 to MP 2.2)	Several new or replacement 24" plastic ditch relief culverts, clean and recondition culverts, rip-rap at drain outlets, ditch cleaned and armored at critical locations, spot resurfacing, stream crossing culvert upgrades with ditch dams, fillslope pullback, reconstructed stream crossing	2361210 (MP 0.6 to 1.3)	None
2355000 (MP 0.7 to MP 1.9)	Replacement and installation of several new 24" plastic ditch relief culverts, clean and recondition culverts, rip rap at drain outlets, ditch cleaned and armored in critical locations	2355000 (MP 0 to 0.7 and 1.9 to 2.4)	None
2355400 (MP 0.4 to MP 1.2)	Installation of water bars with placement of rip-rap at drain outlets	2353230 (MP 0 to 0.8)	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 but not eliminated by the SDRR treatments:

- Fine sediment delivery
- Road-stream hydrologic connectivity
- 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 Skokomish, the SDRR treatments installed culverts and water bars in critical areas, and otherwise rerouted flow away from delivering drain points (e.g. in one location, a water bar that delivered to a stream was removed, rerouting the water that had drained there to a drain point further down the road that did not connect to a stream). These treatments reduced the length of road surface connected to the channel. Prior to the treatments, 4330 m out of the 6330 m of the inventoried road (68%) was hydrologically connected to streams. After the treatments, 2700 m of monitored road (43%) was connected. Thus, the treatments resulted in a net reduction of 1630 m of hydrologically-connected road, which is 38% 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<sup>3</sup> (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

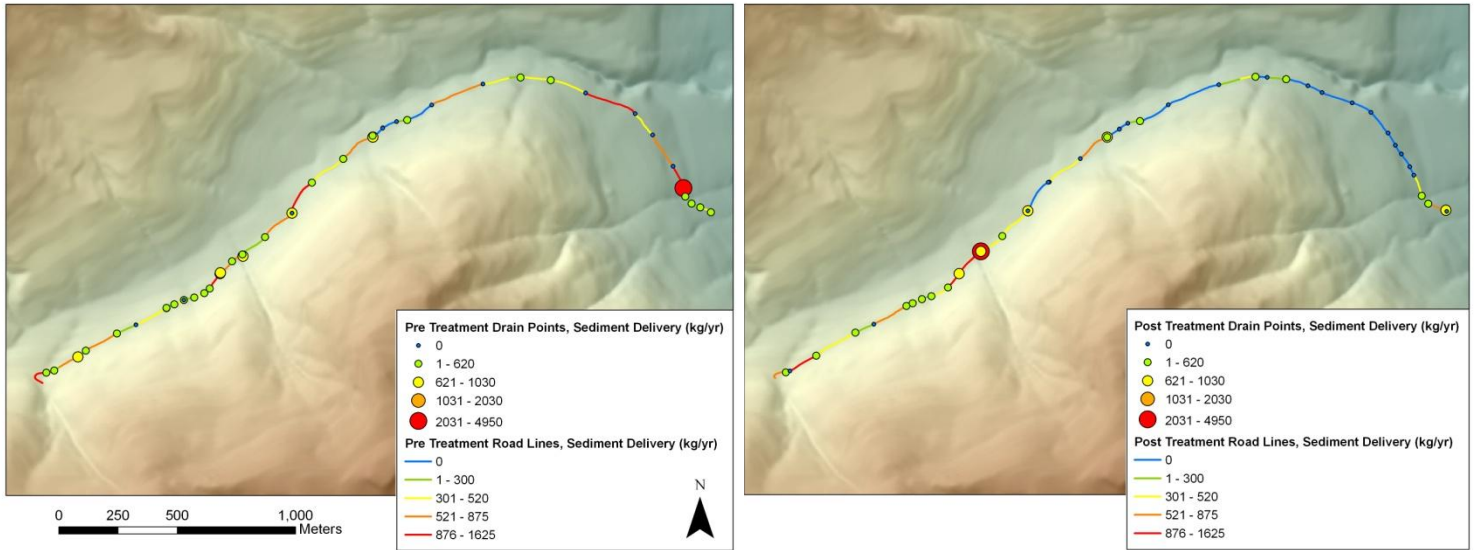
$R$  is the road surfacing factor

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 or not delivering. No estimate of fractional delivery is made because, under most circumstances, there is insignificant hillslope sediment storage in locations where there is a clear connection to the channel. A map of the road surface sediment delivery and the accumulated sediment delivered through drain points is shown for road 2361-600 pre- and post-treatment. (Figure 3).

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<sup>3</sup> 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.

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**Figure 3.** Fine sediment delivery to channels by road segment and drain point for road 2361-600, pre-treatment (left) and post-treatment (right) roads. The road line is colored to indicate the mass of fine sediment that is generated on the road and delivered to the channel (kg/yr).

### Pre-treatment

Delivery of fine sediment occurs through a mix of road drainage features including ditch relief culverts, scratch ditch water bars (water bars that drain to the ditch), stream crossings, diffuse road segments, 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-three drain points were documented, 66% of which were hydrologically connected to stream channels.

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

DrainType	Count	Σ Sediment Production (kg)	Σ Sediment Delivery (kg)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	1	340	340	100%	50	100%
Diffuse Drain	14	5530	940	17%	170	14%
Ditch Relief Culvert	44	19850	14960	75%	2750	63%
Lead Off Ditch	0	n/a	n/a	n/a	n/a	n/a
Non-Engineered	2	850	850	100%	100	100%
Stream Crossing	8	7030	7030	100%	1270	100%
Sump	2	560	0	0%	0	0%
Waterbar	22	0	0	0%	0	0%
Scratch Ditch	22	0	0	0%	0	0%
Drains Out	0	n/a	n/a	n/a	n/a	n/a
<b>All Drains</b>	<b>93</b>	<b>34150</b>	<b>24110</b>	<b>71%</b>	<b>4330</b>	<b>68%</b>

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These points delivered 24.1 tonnes/year of sediment, or 71% of the sediment generated by the road surfaces and ditches.

### Post-treatment

The installation of new ditch relief culverts and water bars increased the number of drain points to 105. These new drain point features were installed to mitigate risk in existing high risk locations. By reducing the length of road draining them, the new drain point features reduced channel connection risks at already existing drain points. Post-treatment, 41% of drain points are were observed to connect to the channel (Table 4). Sediment delivery is expected to be 12.9 tonnes/year, or 38% of the eroded sediment.

**Table 4.** Summary of sediment production and delivery at drain points, all post-treatment roads.

DrainType	Count	∑ Sediment Production (kg)	∑ Sediment Delivery (kg)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	4	8170	4490	55%	500	52%
Diffuse Drain	14	5770	970	17%	160	14%
Ditch Relief Culvert	49	9700	5340	55%	15890	60%
Lead Off Ditch	0	n/a	n/a	n/a	n/a	n/a
Non-Engineered	1	350	0	0%	0%	0%
Stream Crossing	8	2070	2070	100%	460	100%
Sump	3	2340	0	0%	0	0%
Waterbar	26	5920	0	0%	0	0%
<i>Scratch Ditch</i>	9	0	0	0%	0	0%
<i>Drains Out</i>	17	5920	0	0%	0	0%
<b>All Drains</b>	<b>105</b>	<b>34320</b>	<b>12880</b>	<b>38%</b>	<b>2700</b>	<b>43%</b>

The modeled change in sediment delivery following the treatments shows a decline of 11.2 tonnes/year, which is a 47% reduction (Table 5). The largest reductions in sediment delivery occurred where drain points such as water bars and ditch relief culverts were added, with smaller reductions from the removal of problem drain points. The water bars on the pre-treatment roads drained water into the ditch (scratch ditches), which prevented non-engineered drainage, but also increased the chances of the ditch connecting to the stream channel. The removal of scratch ditches and the addition of new water bars that drained out of the road prism disconnected road surface sediment from ditch-draining features (ditch relief culverts and stream crossings), which resulted in large reductions in sediment production and delivery at those features. However, this surface water was redistributed to other drain points, such as drains out water bars and grade reversal broad based dips, which increased production at these points. Some of the broad based dips were stream connected, so sediment delivery increased at those locations. In one location, the removal of scratch ditches resulted in an additional 450 m of road length draining to a water bar directly over a stream crossing.

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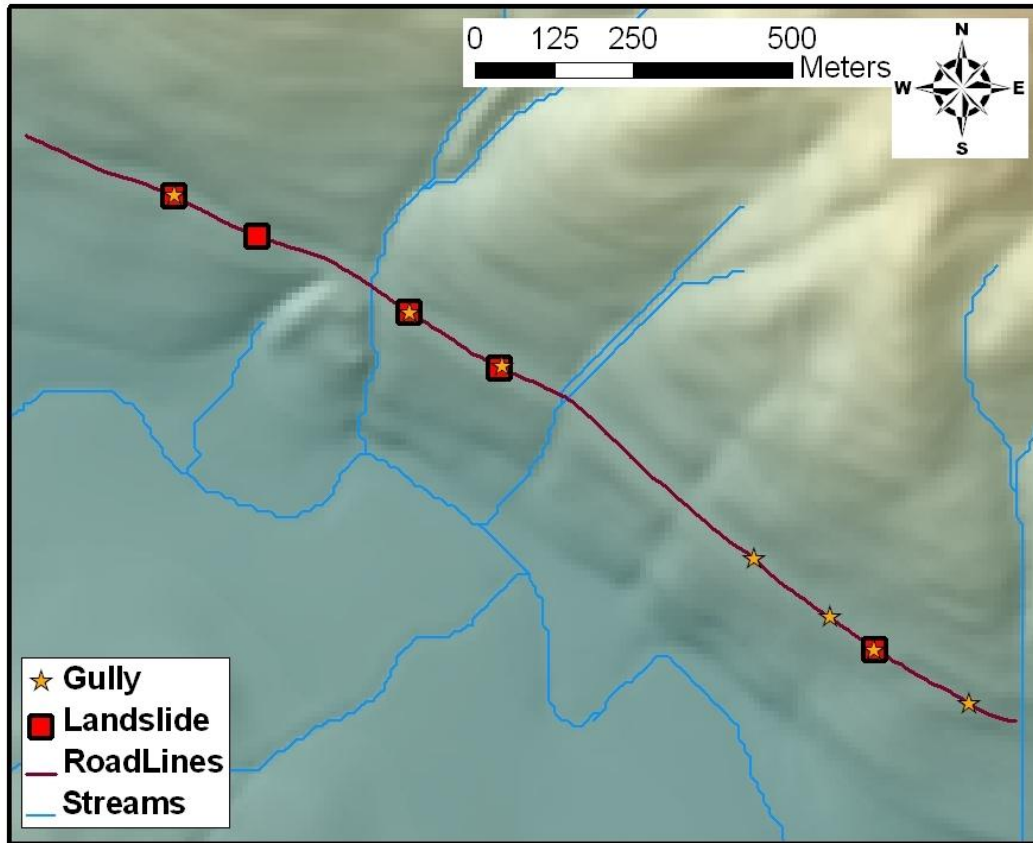
**Table 5.** Changes in sediment production and delivery, pre-treatment vs. post-treatment.

DrainType	Count	∑ Sediment Production (kg)	∑ Sediment Delivery (kg)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	3	7830	4150	1206%	460	1002%
Diffuse Drain	0	250	40	4%	-5	-3%
Ditch Relief Culvert	5	-10150	-9610	-64%	-1170	-42%
Lead Off Ditch	0	n/a	n/a	n/a	n/a	n/a
Non-Engineered	-1	-500	-850	-100%	-100	-100%
Stream Crossing	0	-4960	-4960	-71%	-810	-64%
Sump	1	1790	0	0%	0	0%
Waterbar	4	5920	0	0%	0	0%
<i>Scratch Ditch</i>	-13	0	0	0%	0	0%
<i>Drains Out</i>	17	5920	0	0%	0	0%
<b>All Drains</b>	<b>12</b>	<b>170</b>	<b>-11240</b>	<b>-47%</b>	<b>-1628</b>	<b>-38%</b>

### 5.3 Landslide Risk

#### Existing Landslides

The Skokomish area has a high incidence of shallow landsliding due to the combination of steep slopes and high rainfall. Landslide volume was estimated for all landslides visible from the road that are greater than a minimum threshold of 6 feet in slope length and slope width. The pre-treatment road inventory recorded 14 road related landslides: 4 cutslope failures with an estimated volume of 1,300 yd<sup>3</sup>, 6 fillslope failures totaling 600 yd<sup>3</sup> and 4 hillslope failures that generated 5,400 yd<sup>3</sup>. One road in the SDRR study area (road 2355) had a much higher rate of landslides at about 5 landslides per mile. Many failures were associated with gullies, and were located in high-risk areas. Many of the mass wasting events occurred during the last two decades (Figure 4; R. Stoddard personal communication). One of the main contributors to road-related mass wasting in this area is the interception of shallow groundwater and hillslope water by roads, which re-route the water onto concentrated areas along the hillslope through drainage points such as culverts.



**Figure 4.** Road related landslide locations on road 2355. Many of these landslides are associated with gullies.

### Changes in Landslide Risk

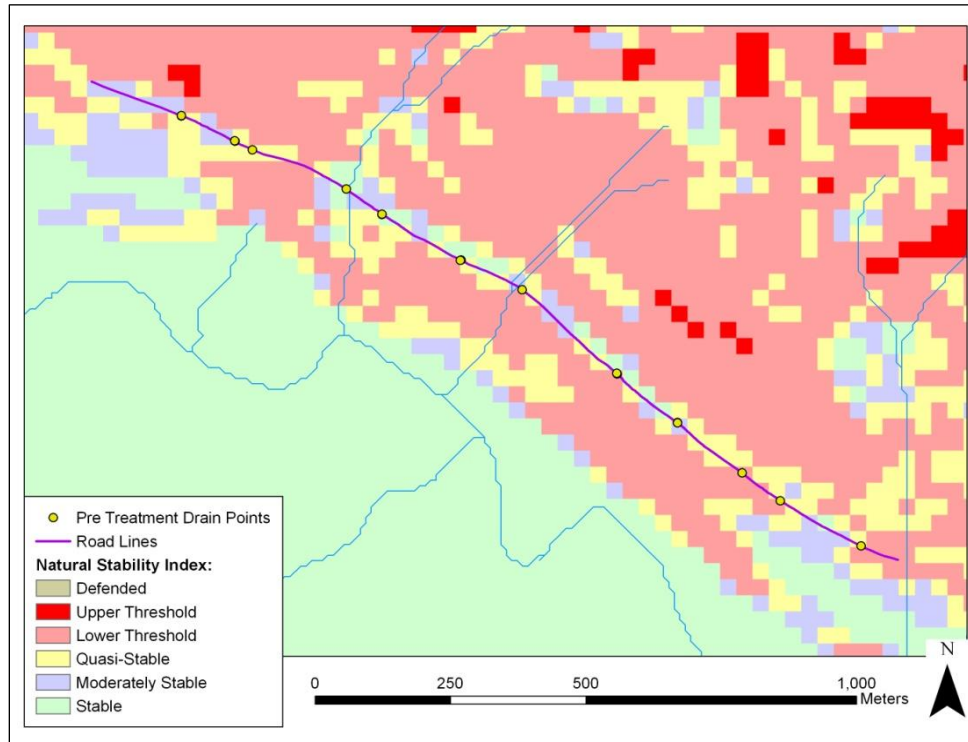
The risk of shallow landslide initiation is predicted using SINMAP 2.0 (Pack et al., 2005, <http://hydrology.neng.usu.edu/sinmap2/>), modified to account for contributions of road runoff, and locally calibrated to known locations of landslides (Washington Division of Geology and Earth Sciences, 2008). 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. 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.



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Figures 5 through 8<sup>4</sup> illustrate the risk and change in risk in the area. SINMAP was calibrated and 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 landslide risk is generally high in the area of the treated road (Figure 5).

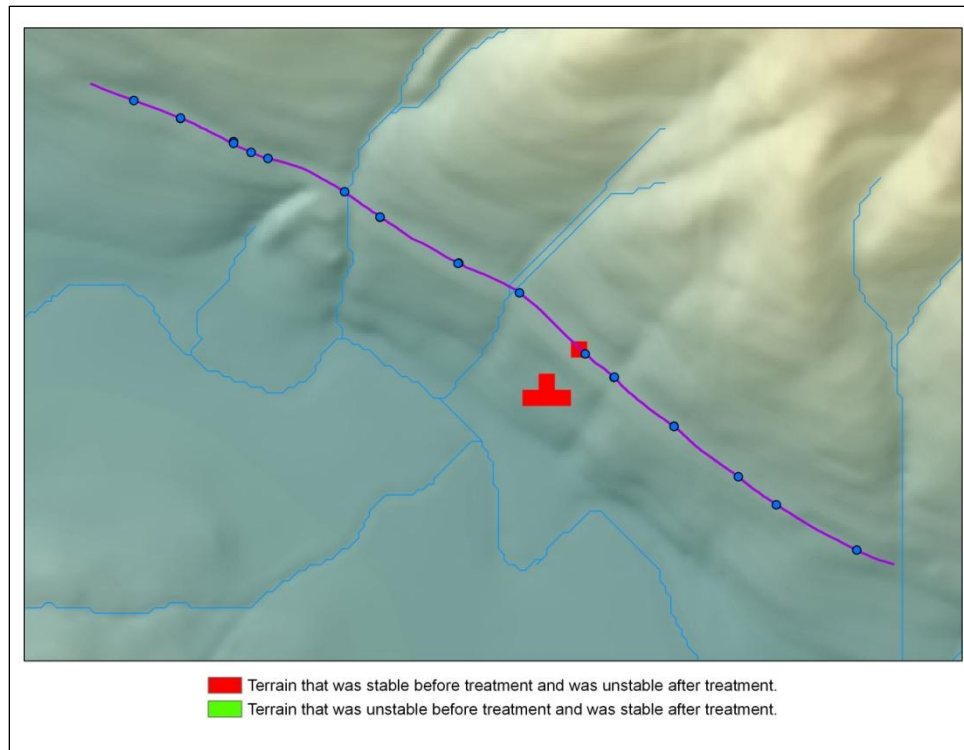


**Figure 5.** Natural slope stability risk in the area of the 2355 road. The yellow, blue, and green cells are generally quantified as stable, while the pink, red, and tan cells are generally quantified as unstable.

A second calibrated 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 calibrated 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 2355 road 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 (there are no green area on Figure 6). These are the areas where risk has been sufficiently reduced (green), or where risk has been increased significantly (red).

<sup>4</sup> Figures 5 through 8 are rendered at the same scale. The legend items for each figure are consistent from one figure to the next.

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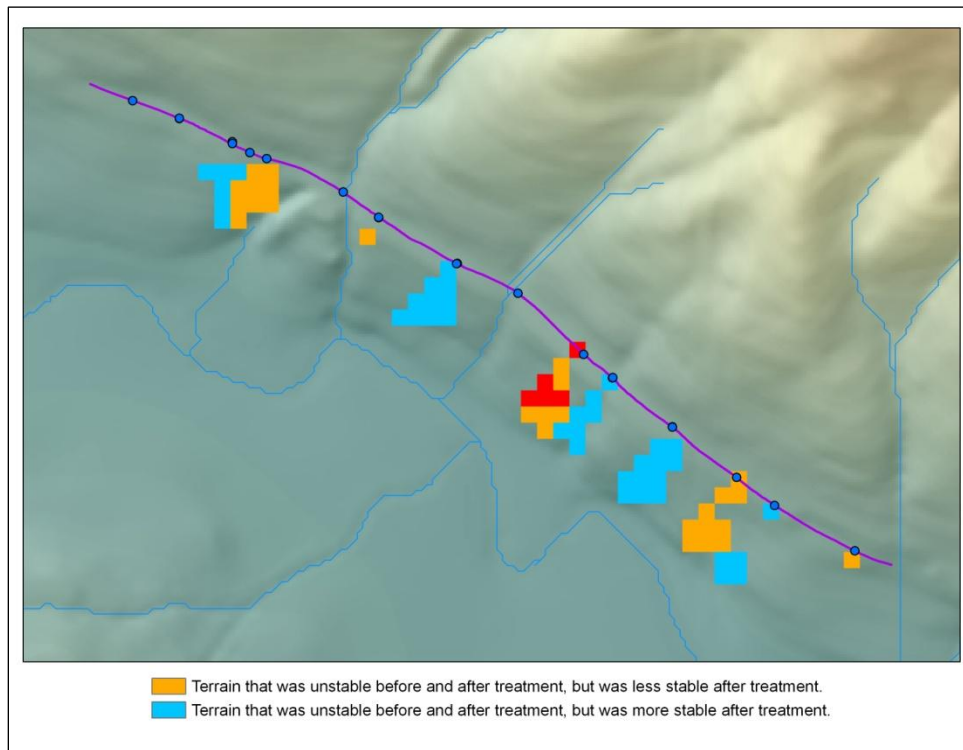


**Figure 6.** The most significant slope stability risk changes along road 2355. The risk of the areas in green was sufficiently reduced, while the risk in the red areas was significantly increased.

The areas where risk was significantly increased are due to the addition of new drainage (ditch relief culverts) over steep slopes that were stable before treatment. If the culverts had been installed over shallow enough slopes, they would have likely increased the risk at those locations, but not enough to move those areas from the stable category to the unstable category (i.e. those areas would have remained stable). Along much of the length of this road, there are no shallow slopes, and so it would be very difficult to find a better location to discharge road water. On the 2355 road, there were no areas where risk was sufficiently decreased to move them to the stable category due to the removal of water from the corresponding drainage features.

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 a decrease in the length of road that drained to each point, but was not enough of a reduction to move the risk category to stable. The orange cells are areas where the risk increased (became less stable) after treatment, and the terrain was unstable before treatment. This is generally due to the addition of drainage over slopes that were naturally unstable (i.e. unstable without considering the effect of road drainage).

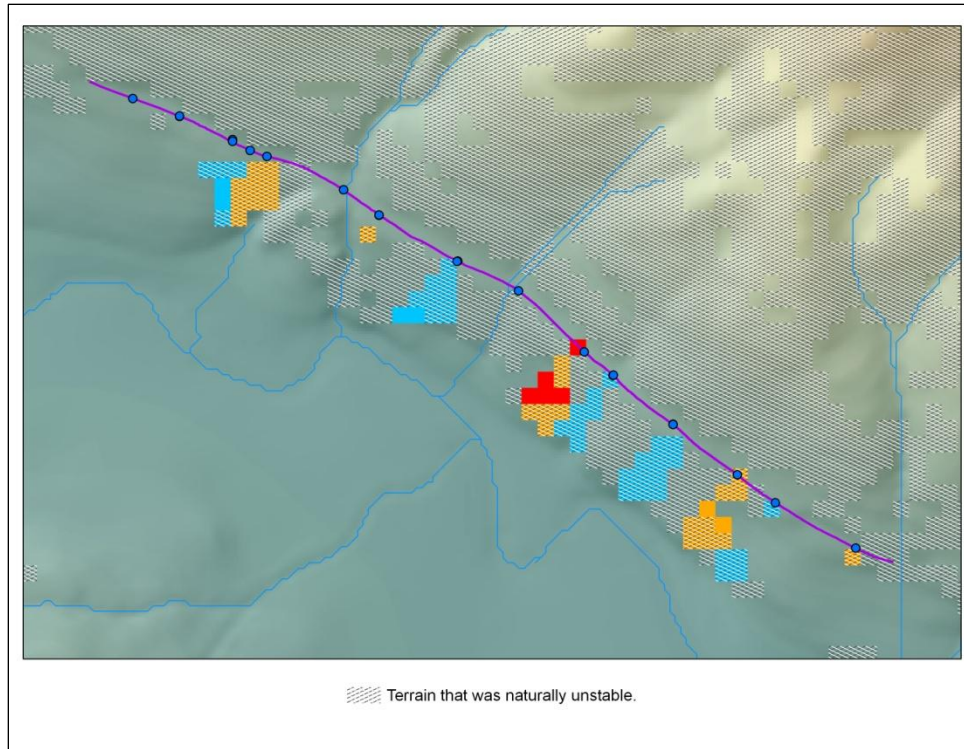
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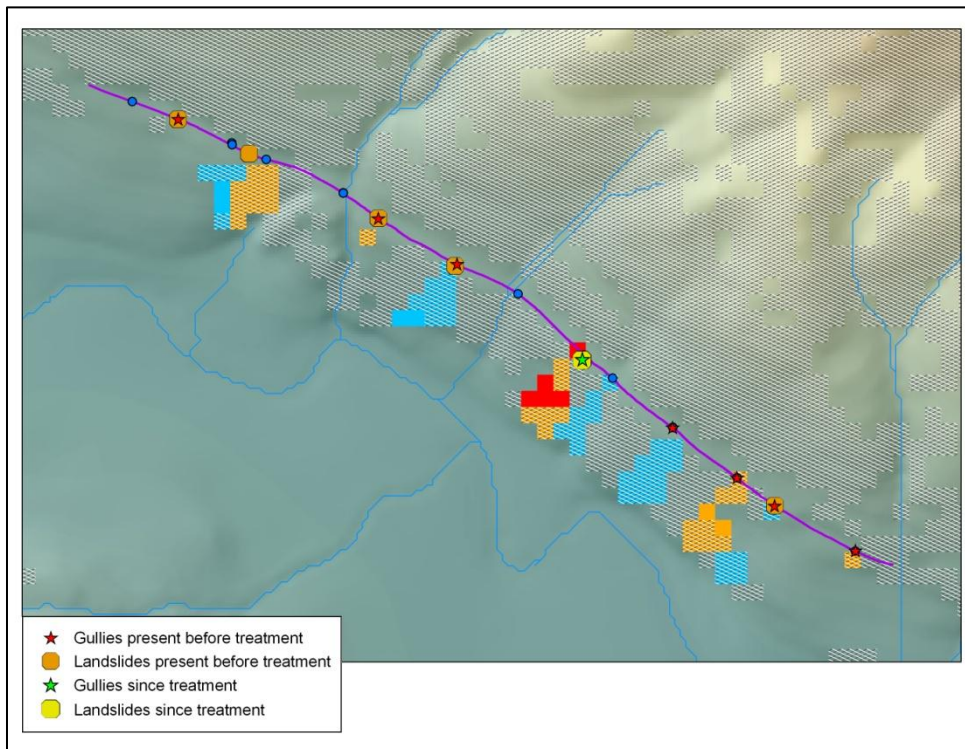
**Figure 7.** Changes in slope stability risk along road 2355 where the terrain was unstable before and after treatment. The blue areas are locations where the risk was lowered, and the orange areas are where the risk increased.

In some locations, a drain point that was located above a slope that was unstable without road drainage consideration received less flow after the treatment, and so became more stable. In these locations, there was no way to reduce the overall shallow landslide risk to be stable. These locations are shown in Figure 8, where the cross-hatch areas were unstable without consideration of road drainage and cross-hatch over blue shows the areas that also experienced reduced risk. In some of these locations, the treatment may have reduced the stability category to nearly background (natural) levels. Reduction to fully background levels would require the removal of the drain points over those unstable slopes. Areas where the underlying risk (without a road) was unstable and the stability risk increased after the treatment (cross-hatch over orange) show that drainage was added over a slope that was naturally unstable.

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**Figure 8.** Background slope stability and the changes in slope stability along road 2355. The cross-hatch pattern is all of the area in the map that was unstable without consideration of road drainage.

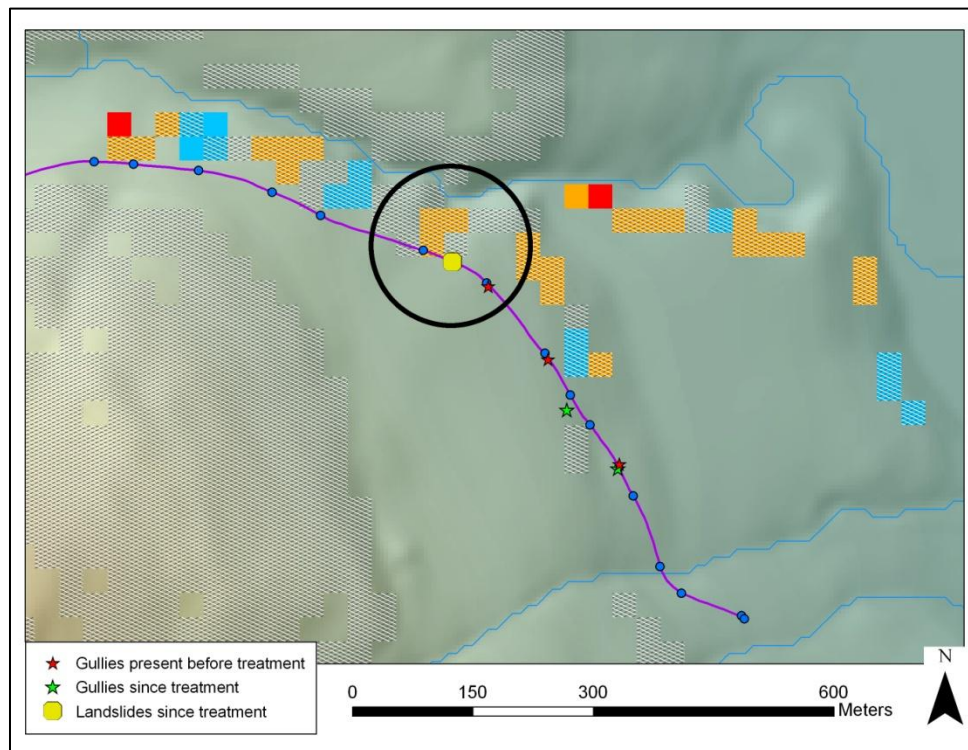


**Figure 9.** Locations where gullies and landslides were observed pre- and post-treatment, along with the changes to the stability risk at those locations on road 2355.

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Figure 9 shows the locations along the 2355 road where landslides and gullies were observed pre-treatment, and where new landslides and gullies formed after the treatment, as well as the stability index changes at those locations. There are eight locations where there was a landslide, a gully, or both along the length of road before treatment. Four of these locations experienced a decrease in stability risk, indicating that the removal of road drainage from those locations will reduce severity of future mass wasting. However, three of these sites experienced an increase in risk, indicating that likelihood and severity of future mass wasting is likely to increase. One site showed no change in stability index. Additionally, at the location along the 2355 road that experienced the largest increase in stability risk due to the installation of a new culvert, a new landslide and gully were observed after the treatment. The volume of the new mass wasting was 2750 yd<sup>3</sup>.

At one location, on the 2361-600 road, a very long flow path was routed away from a high risk drain point with the addition of more closely spaced culverts. While this resulted in a large decrease in stability risk at the location of the old drain point, the new culverts, which were installed on an unstable slope, resulted in an increase in risk at those locations. At one of the high risk new culverts, a landslide occurred in November 2008 (Figure 10; R. Stoddard personal communication). The problem culvert had been removed before the post-treatment survey was conducted, which is why there is no increase in stability risk at the exact location of the new landslide shown in Figure 10. The volume of the new landslide was 5300 yd<sup>3</sup>.



**Figure 10.** The landslide model predicted increased risk in the circled area due to additional discharge from road 2361-600. A new landslide occurred in this location.

The net effect of the SDRR treatments, which increased road drainage frequency, achieved the goal of reducing risk at many of the highest risk locations in the sample area. In addition, some areas along the 2361-600 road had sidecast pullback (removal of excess fill), which is likely to reduce localized landslide risk. However, risks were increased in even more locations because in steep, dissected, and landslide-prone terrain, it is difficult to redirect discharge from one location without elevating the risk in other locations. The slope stability risk generally increased slightly over the entire study 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. For example, in some areas, new drainage features may need to be spaced more closely and placed more strategically to reduce the risk of shallow landslides. 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 drainage point.

$$ESI = L \times S^2, \text{ where:}$$

$L$  is the road length contributing to the drain point (m)

$S$  is the slope of the hillslope below the drain point (%)

Calculated ESI values are then 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. Here,  $ESI_{crit} = 4$ , as the risk of gully initiation increases by a factor of 2.5-3 above that value (Table 6).

**Table 6.** ESI values for all concentrated drain points at the control and pre-treatment SDRR and decommissioning sites. At these sites  $ESI_{crit} = 4$ , as gully frequency increases significantly above that value.

ESI Value	<1.25	1-4	4-18	>18
# of sites with gullies	4	5	24	20
# of sites without gullies	54	59	110	92
% Gullied	7%	8%	22%	22%

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

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these points do not behave in such a way that the ESI is a useful metric. 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.

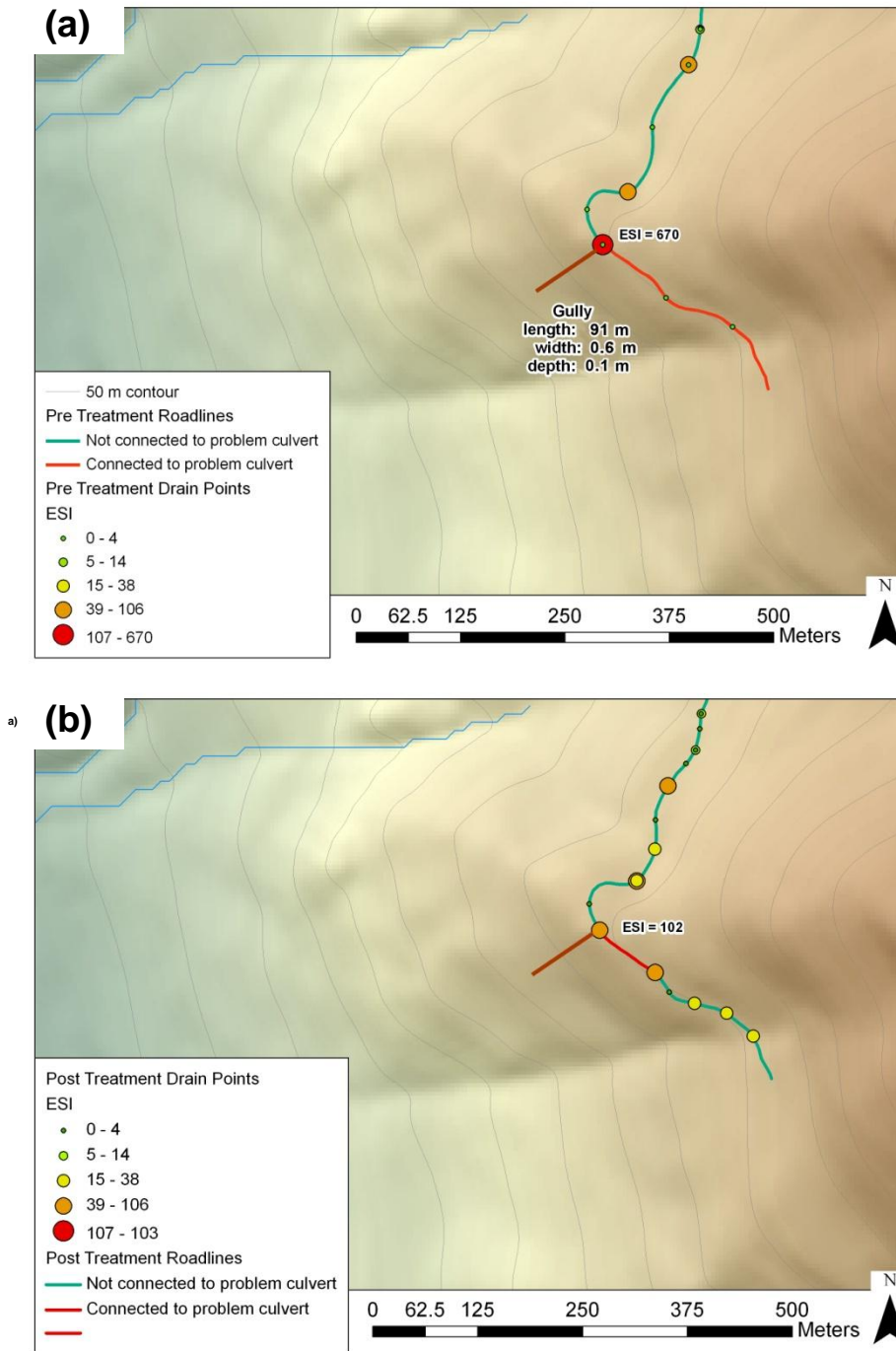
**Table 7.** Maximum contributing road segment length for a given average hill slope required to prevent the drain point from exceeding the  $ESI_{crit}$ .

Average Hill Slope (%)	Max. Road Segment Length (m)
10%	400
20%	100
30%	44
40%	25
50%	16
60%	11
70%	8

The average pre-treatment ESI was 27, with an average contributing road length of 82 m. Sixty-eight percent (39 of 57 of non-diffuse, non-stream-crossing, or non-orphan points) of the pre-treatment drain points fell into this high risk group where ESI is greater than  $ESI_{crit}$  ( $ESI_{crit} = 4$ ). Post-treatment drain points had a mean ESI of 18. The average length of road delivering water to these points was decreased to 65 m, but 67% of them (48 of 72 points) still had ESI values in excess of 4. Therefore, using the conservative assumption that the post-treatment value of  $ESI_{crit}$  is the same as the pre-treatment condition, the total number of drain points with an elevated risk of gully initiation was calculated to have increased at nine locations due to the treatments. As average contributing length decreased significantly, water was discharged to preferentially steeper locations. Though the average ESI decreased from 27 to 18, the risk of gully initiation is still high on much of the sampled landscape.

On the pre-treatment 2355-400 road, there was a 275 m section that drained to a single ditch relief culvert. Within the section, there were two scratch ditch type water bars that drained water into the ditch (i.e., they directed water into the ditch as opposed to off of the road). The ditch relief culvert discharges onto a very steep slope, so the ESI at that point was 670. There is a 300 ft long gully at this location (Figure 11a). The treatment installed three water bars that intersect the ditch and direct water downslope off the road, reducing the flow path to 85 m in length. While the ESI was reduced to 102, it was still well above the  $ESI_{crit}$  value of 4 (Figure 11b). This large reduction in ESI is likely to decrease the effects of run off on the gully. However, risk of landsliding and gullying was elevated at the locations of the newly installed water bars.

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**Figure 11.** Changes in gully risk on road 2355-400. The dark red road line drains to the ditch relief from which the gully initiates. The size and color of the drain point circles indicate the ESI at that drain point.

- Pre-treatment road. 275 m of road length drain to the ditch relief culvert, which has an ESI of 670 and a 91 m long gully.
- Post-treatment road. 85 m of road length drain to the ditch relief culvert, reducing the ESI to 102. Risk is still high at this location, but the large reduction should somewhat reduce risk.

### 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).



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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 relatively high with an average value of 2.8 for the eight stream crossings (Figure 12). This is out of a range of 1 to 4, where 1 suggests no risk of blockage. The stream crossings with values of 3 all had culvert to channel width ratios of  $<1$  (the channel is wider than the culvert). Post-treatment SBI values were improved slightly, with one stream crossing that experienced a reduction in SBI from 3 to 2 through the installation of a larger culvert (24" diameter pre-treatment to 36" diameter post-treatment). On the 2361-600 road, a stream crossing culvert was upgraded from 48" to 72" (though the channel is still wider than the culvert), and an overflow culvert was installed at another. SBI only takes the largest culvert into account if there is more than one, so, although there is a likely reduction in overtopping risk, the SBI remains unchanged. This site also had a ditch dam and broad based dip installed, addressed below.

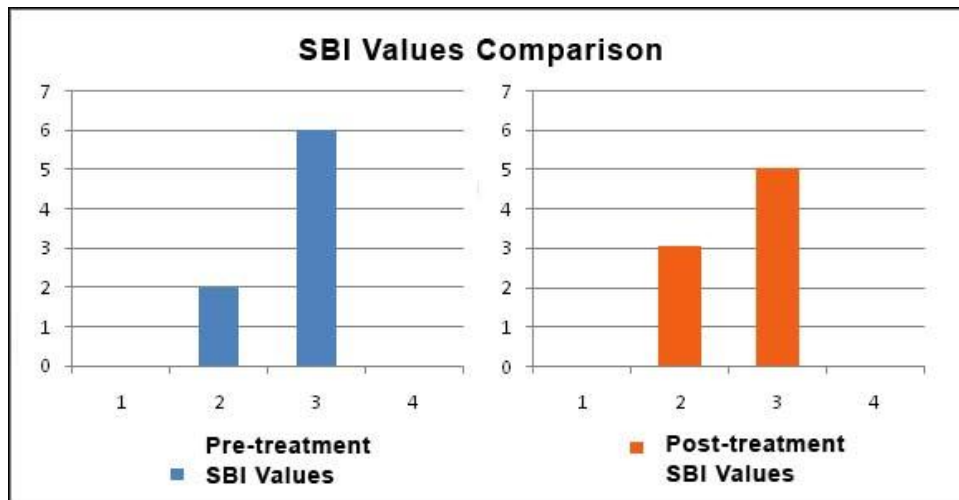


Figure 12. Distribution of Stream Blocking Index values for pre- and post-treatment groups.

A second, and perhaps greater, consequence of concern at failed stream crossings is the diversion of stream flow onto road surfaces and unchannelled 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. 1997, 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, 75% (6 of 8) of the stream crossings had the potential to divert streamflow down the road in at least one direction. In some locations, the road grade was modified to prevent flow from moving very far down the road, but since there is still potential for some reduced down-road flow, the diversion direction remains the same. At these locations, future diversions may discharge back into the native stream valley and into the stream, as opposed to discharging into a neighboring valley or swale, which could result in much more erosion as the stream water creates a new channel. At one stream crossing, large clasts were added on the downhill side of the crossing in the ditch to reduce the risk of diversion in the ditch (Figure 10). The diversion direction at this location is unchanged, because, in an overtopping event, the stream would ultimately flow down the road. However, it is likely that the diversion risk is nonetheless reduced by this treatment. Post-storm monitoring may verify this risk reduction as compared to untreated roads.



**Figure 13.** Stream crossing with large clast rip rap preventing the stream from diverting down the ditch.

## 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, if there is a wetland

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in the ditch, or if the road fill is saturated. 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, flow around the pipe, or if they are diverting a stream from upslope through the draining ditch. Lead off ditches are considered problematic if they have excess deposition, gullying, or are otherwise not functional. Non-engineered features are always a problem unless they occur because of an outsloped section of road without any fill erosion. 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, and if they have an SBI score of 3 or greater, or 2 diversion directions and an SBI score of 2 or greater. 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 8.** Drain point condition problems and fill erosion below drain points, pre- and post-treatment.

Drain Type	Pre-treatment			Post-treatment		
	Count	Problems	Fill Erosion	Count	Problems	Fill Erosion
Broad Based Dip	1	0%	0%	4	0%	0%
Diffuse Drain	14	0%	0%	14	0%	0%
Ditch Relief Culvert	44	30%	7%	49	14%	6%
Lead Off Ditch	0	n/a	n/a	0	n/a	n/a
Non-Engineered	2	50%	50%	1	0%	0%
Stream Crossing	8	75%	13%	8	63%	0%
Sump	2	50%	0%	3	0%	0%
Waterbar	22	0%	0%	26	0%	4%
<b>Total</b>	<b>93</b>	<b>23%</b>	<b>4%</b>	<b>105</b>	<b>11%</b>	<b>4%</b>

Within this study area, ditch relief culverts and stream crossings were observed to have the highest rate of problems before the treatment (13 and 6 total problem points, respectively). The other drain points had no problems or very few problems. (Table 7). The SDRR treatment reduced the ditch relief and stream crossing problems to 7 and 5 total problems, respectively. Ten of the problems from the pre-treatment road were eliminated in the post-treatment road, and one problem (an occluded replacement culvert) was new. These repairs reduce several types of associated risk. An important question for road managers is how durable improvements like these might be, because drainage systems that require less frequent repair are less costly to maintain. Resurveys of these drains with post-storm monitoring may help increase our understanding of how well these improvements last.

## 6.0 Summary & Conclusions

The USFS, RMRS and PNW Region initiated a Legacy Roads and Trails Monitoring Project in the summer of 2008. As part of the study, field crews inventoried road segments on the Olympic National Forest, before and after SDRR treatments, as well as a set of control roads. These roads received medium to high-intensity treatments including replacement and installation of new 24" plastic ditch relief culverts, culvert cleaning and reconditioning, installation of rip rap at drain outlets, ditch cleaning and armoring at critical locations, stream crossing culvert upgrades with ditch dams, removal of unstable fillslope material (sidecast pullback), spot resurfacing, and the installation of water bars.

The GRAIP model was used to predict the change in level of impact/risk between the pre-existing road and the road after SDRR treatment (Table 8). The restoration treatments reduced the length of the sampled road that was hydrologically connected to streams by 1630 m, or 38% from pre-treatment conditions. The model predicts that fine sediment delivery was reduced by 47%, from 24.1 tonnes/yr to 12.9 tonnes/yr. The risks presented by stream crossings becoming plugged by debris and sediment was reduced at one site. The potential for streamflow to be diverted onto roads and unchannelled hillslopes may have been reduced at two sites.

The slope stability risk below drain point locations on the original road was reduced in some areas by decreasing the amount of water discharging to the hill slope, and elevated in other areas by the installation of new drainage features over steep slopes, for a net effect that is probably an increase in risk. Values of a gully index were reduced at many of the original drainage points. Nonetheless, values still exceed conservative initiation thresholds at many sites. The same is true for some of the new discharge points. Thus, across the entire sampled road length, the total number of sites with elevated gully risk was increased by nine (48 in the post-treatment vs. 39 in the pre-treatment). The average value of the gully index was reduced by 33%, but it still exceeded the threshold value for gully risk.

Before treatment, inventoried road segments had problems such as blocked culverts, puddles on the road, or saturated fill at 21 of the inventoried drainage points. Post-treatment monitoring indicates that these problems were reduced by nine to 12 of the post-treatment drainage points. 11 of the problems at the post-treatment drainage points were pre-existing, and one problem (an occluded replacement culvert) was new. Ten problem drainage points were removed or repaired by the treatments. The new drainage features will provide an opportunity to learn about potential reduction in maintenance needs afforded by the new structures.

As a whole, these initial results indicate that the SDRR work in the Skokomish River watershed should be effective in reducing the non-mass wasting impacts and risks that these roads posed to aquatic ecosystems. However, landslide and gully risk may have increased. The final post storm inventory assessment will enable a closer examination of the hydrologic function of the newly SDRR treated road system and will answer important questions about stream blocking

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and diversion potential, gully initiation thresholds, and landslide risk. This report will be updated when these data become available.

**Table 9.** Summary of GRAIP model risk predictions for the Skokomish SDRR project.

<b>IMPACT/RISK TYPE</b>	<b>EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION</b>	<b>EFFECT OF TREATMENT: POST-STORM VALIDATION</b>
Road-Stream Hydrologic Connectivity	-38%, -1628 m	To be determined.
Fine Sediment Delivery	-47%, -11.2 tonnes/year	To be determined.
Landslide Risk	Net increase, general re-distribution of risk	To be determined.
Gully Risk	Average ESI reduced from 27 to 18, but 9 more drain points with elevated risk	To be determined.
Stream Crossing Risk		
- plug potential	Slight decrease	To be determined.
- fill at risk	No change	To be determined.
- diversion potential	Slight decrease	To be determined.
Drain Point Problems	10 problems fixed, 1 new problem	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 hillslope. 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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