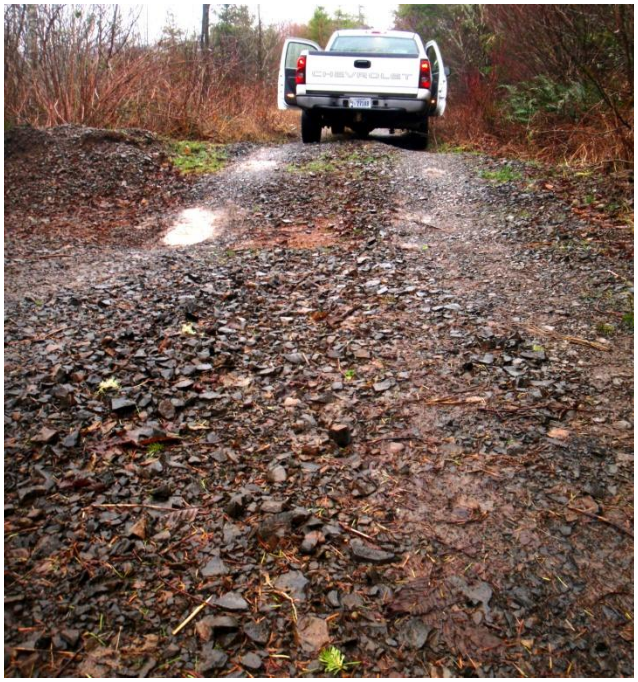
Legacy Roads and Trails Monitoring Project

Storm Damage Risk Reduction Treatment in the Nestucca River Watershed

Siuslaw 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, 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 or heavy maintenance (i.e., storm damage risk reduction; SDRR) treatments have been 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. So far 18 post-treatment inventories were executed, as well as three post-storm validation evaluations. This status report focuses only on SDRR work implemented by the Siuslaw National Forest (SNF) in the Nestucca River watershed. At the SNF sites, treatments included the installation of new water bars at regular intervals of about 70 m.

Before-after comparisons using GRAIP indicate that the SDRR treatment resulted in a moderate to large reduction of many impact-risk metrics, and no change or slight increase in others. Road-stream connectivity was reduced by 360 m (21%), from 1690 m of connected road to 1340 m. Delivery of fine sediment was reduced by 2.3 tonnes/yr (58%), from 3.9 tonnes/year to 1.6 tonnes/year. Values of a stream blocking index were unchanged from an average of 1.9 before treatment (n=7), indicating the risk of stream crossings becoming plugged was not changed by the installation of new water bars. Diversion potential was also unchanged at all 7 crossing sites.

The slope stability risk below drain point locations on the original road was reduced in some places as water was redistributed across the hillslope away from original drainage features to new waterbars. However, landslide risk was not reduced across the entire treated road length because the treatments increased risk in some areas where new waterbars were placed above steep slopes. The net effect is likely a slight increase in shallow landslide risk.

Risk of gully initiation is generally low in this area, and was further reduced by the treatment. An average gully initiation index (ESI) was reduced by 54% pre-treatment to post-treatment, though we do not know if this reduction is significant. There were only four drain points with associated

gullies observed in the watershed, so it is not possible to determine the empirically-derived threshold (ESI_{crit}), above which, the risk of gullying significantly increases. Post-storm monitoring may help to determine the meaningful risk change due to new drainage features.

Before treatment, inventoried road segments had significant infrastructure problems at 12% of 68 inventoried drainage points. Post-treatment monitoring indicates that these problems were not eliminated by the SDRR treatments, though no new problems were observed at the new drainage features.

Taken collectively, preliminary results indicate the SDRR treatments should be effective in significantly reducing some of the hydrogeomorphic impacts and risks to aquatic ecosystems, while other risks remain unchanged or increased. Risks that were reduced were generally reduced along the entire length of road where that risk was high in the pre-treatment. Risks that were not changed are generally not expected to change with the application of the specific treatments applied here. Risk of shallow landsliding likely remains where new drainage features were installed over steep slopes, and some assessment of tradeoffs between more thorough local treatment and greater treated lengths may be warranted for future treatments. GRAIP can be used to address these needs in the design phase of future projects.

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

IMPACT/RISK TYPE	EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION	EFFECT OF TREATMENT: POST-STORM VALIDATION
Road-Stream Hydrologic Connectivity	-21%, -360 m	To be determined.
Fine Sediment Delivery	-58%, -2.3 tonnes/year	To be determined.
Landslide Risk	slight increase likely	To be determined.
Gully Risk	54% decrease in gully index	To be determined.
Stream Crossing Risk		
- plug potential	no change	To be determined.
- fill at risk	no change	To be determined.
- diversion potential	no change	To be determined.
Drain Point Problems	no change	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 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 storm damage risk reduction (SDRR) treatment work completed by the Siuslaw National Forest (SNF) in the Nestucca River 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., 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 and FY2009, pre-treatment evaluations were completed at 19 sites[1] on national forests throughout the Pacific Northwest Region. Decommissioning has been implemented at ten of these sites and nine sites have been treated with SDRR methods[2] (Figure 1, Table 1). Eleven post-treatment inventories and one post-storm validation evaluation were also completed in FY2008 and FY2009. Post-treatment and, to the degree possible, post-storm evaluations will be completed at the remaining sites in FY2010. In 2009, a similar study was begun in Regions 1, 4, and 5.

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

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

Figure 1. Location of monitored sites, FY2008, FY2009, and FY2010, PNW Region.

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	Alsea 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

Nestucca Basin Sites

During the summer and winter of 2009, field crews inventoried storm damage risk reduction sites in the Nestucca River watershed (Table 1, Figure 1). The SDRR treatment sites in this watershed are principally underlain by basalt, but much of the surface is veneered with various landslide and other Quaternary deposits. Other units within the upper Nestucca drainage are predominately fine-grained sedimentary rocks. The average precipitation for the basin is on the order of 80 inches per year. The inventoried sites are located between 200 and 1600 feet above sea level, with the treatment sites located at 250 to 1000 feet above sea level, on the west side of the Oregon Coast Range, in northern Oregon, below the transient snow zone. Figure 2 shows the location of the treatment and control sites. Pre-treatment roads were originally crowned with an inboard ditch, surfaced with gravel and constructed with periodic drainage features. Treatment and control roads were selected on the lower third and upper third of slope positions, and included frequent live stream crossings on the lower-slope positions. SDRR treatments included installation of new water bars at regular intervals of about 70 m. The objective of the treatment was to provide more frequent drainage to reduce sediment delivery to streams and erosion risks.

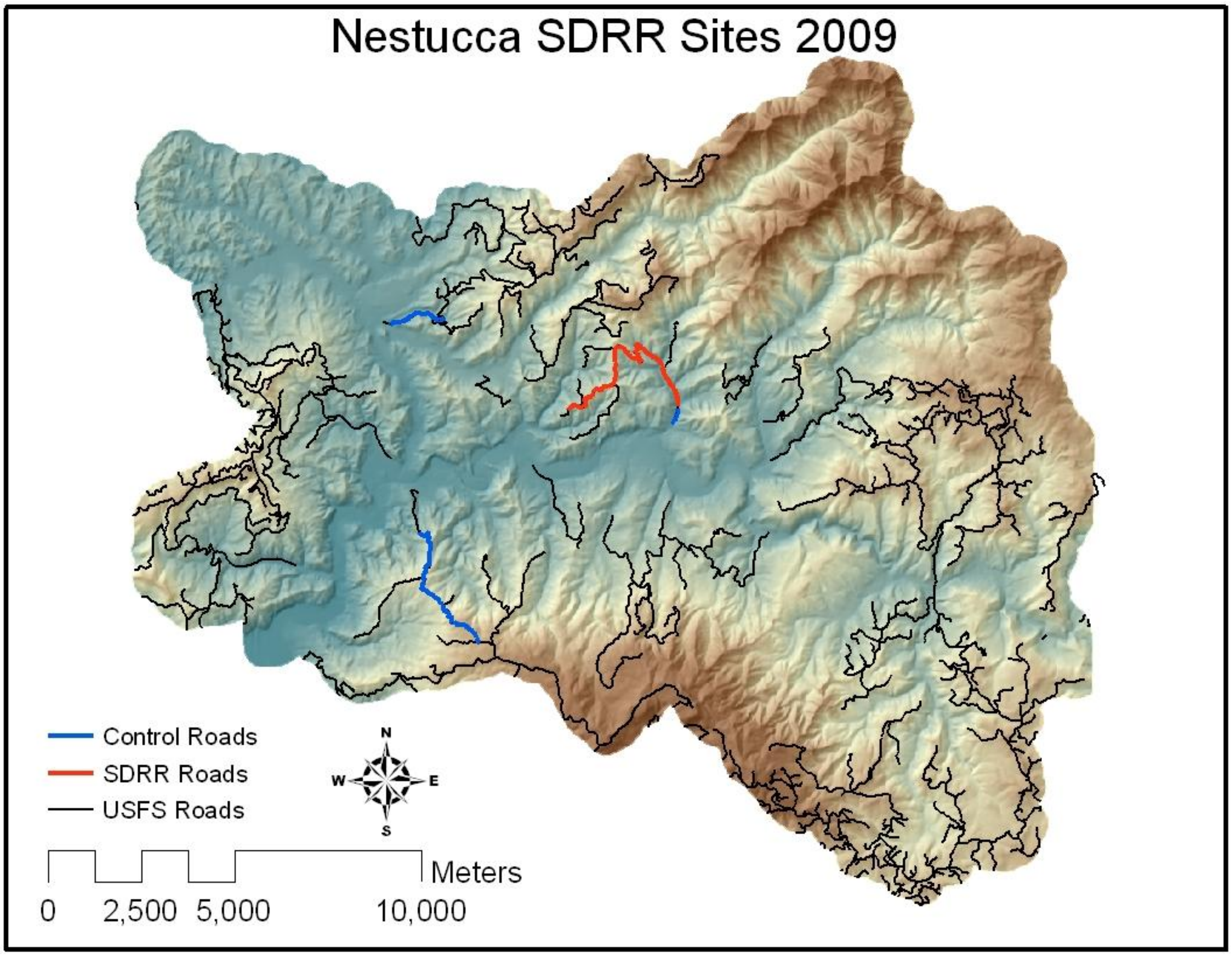

Figure 2. Location of monitored sites in Nestucca River watershed, Siuslaw National Forest.

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

SDRR TREATED ROAD		CONTROL ROADS	
Road #	**Treatment**	**Road #**	**Treatment**
8573	New water bar installation at regular intervals. Spacing intervals ranged from about 40 m to 100 m, with an average spacing of about 70 m.	8573 lower, 8170, 8595	None

5.0 Results

GRAIP inventory and modeling tools were used to characterize the following types of impacts and risks, most of which were expected to be reduced by the SDRR 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 some peak flows (Jones and Grant 1996).

GRAIP calculates the hydrologically-connected portion of the road using the field assessment of drain point connection and a road segment flow routing system. The flow path below each drain point is followed until evidence of overland flow ceases or the flow path reaches a natural channel. In the Nestucca River watershed, the SDRR treatments increased the total number of active drain points and redistributed water back onto the hillslope. This reduced the length of road surface connected to the channel. Prior to the treatments, 1690 m out of 6440 m of inventoried road (26%) were hydrologically connected to the stream. After the treatments, 1340 m out of 6430 m of monitored road (21%) were connected. Thus, the treatments resulted in a net reduction of 360 m of hydrologically connected road, which is 21% less than the pre-treatment condition.

5.2 Fine Sediment Production & Delivery

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

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

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

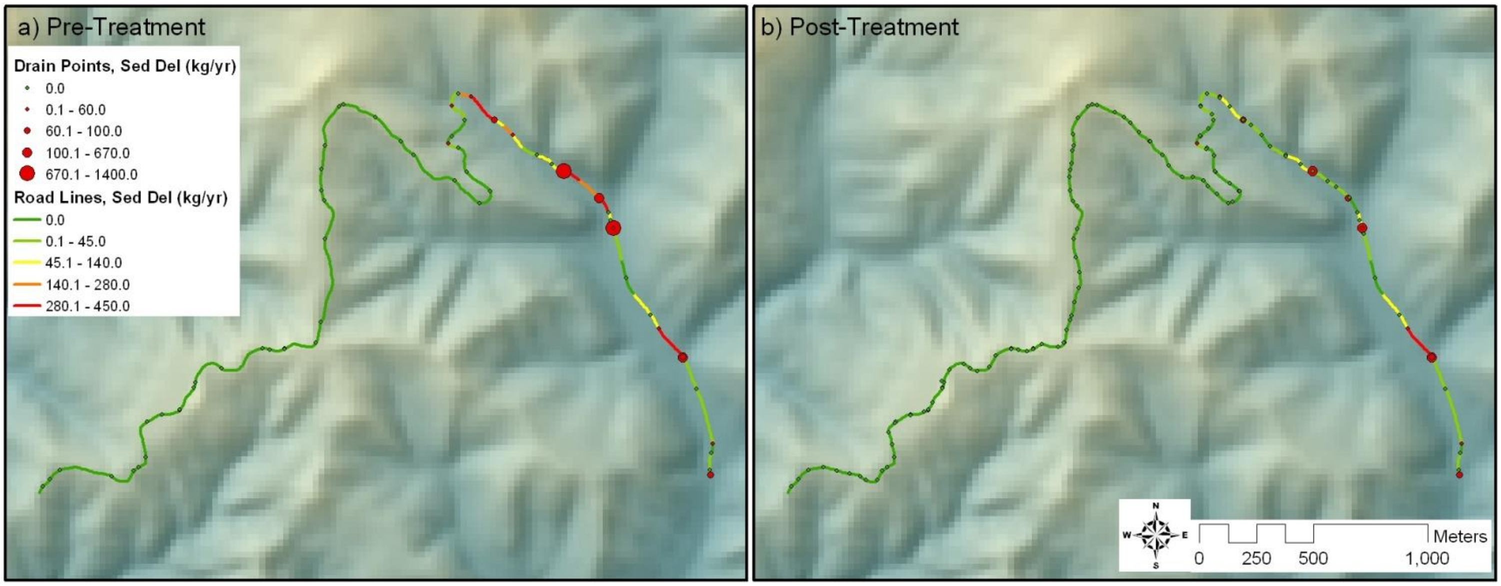

Figure 3. Fine sediment delivery to channels by road segment and drain point, pre-treatment (a) and post-treatment (b) road. The road line is colored to indicate the mass of fine sediment that is generated and delivered to the channel (kg/yr). The size of the circle indicates the accumulated mass of sediment delivered through each drain point (kg/yr).

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

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[3] For this analysis, a base erosion rate of 79 kg/m of road elevation was assumed, based on observations in the Oregon Coast Range (Luce and Black 1999). Further work could determine if this rate is appropriate for this climate, geology and road system. We are looking at change due to treatment, so the absolute number is not a primary concern.

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 8573 road (Figure 3).

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	9	670	1930	29%	380	26%
Diffuse Drain	13	4850	0	0%	0	0%
Ditch Relief Culvert	22	2360	220	9%	340	20%
Lead Off Ditch	15	3590	90	2%	100	8%
Non-Engineered	0	0	0	0%	0	0%
Stream Crossing	7	1700	1700	100%	870	100%
Sump	1	2	0	0%	0	0%
Waterbar	1	0	0	0%	0	0%
All Drains	**68**	**19200**	**3940**	**21%**	**1690**	**26%**

Pre-treatment

Delivery of fine sediment occurs through a mix of road drainage features including ditch relief culverts, diffuse road segments, stream crossings, and others (see Appendix A for more information on the drain point types). 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. Sixty-eight drain points were documented, 21% of which were hydrologically connected to stream channels. These points delivered 3.9 tonnes/year of sediment, or 21% of the sediment generated by the road surfaces and ditches.

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	9	1730	870	50%	250	47%
Diffuse Drain	13	1160	0	0%		0%
Ditch Relief Culvert	22	850	200	23%	340	29%
Lead Off Ditch	15	710	90	12%	100	18%
Non-Engineered	0	0	0	0%	0	0%
Stream Crossing	7	490	490	100%	650	100%
Sump	1	2	0	0%		0%
Waterbar	79	13870	0	0%	0	0%
All Drains	**146**	**18820**	**1640**	**9%**	**1340**	**21%**

Post-treatment

The surface of the road was not affected by the treatments, and so sediment production was nearly unaffected. Changes in flow path length due to the installation of new water bars had a slight affect on sediment production, which decreased negligibly to 18.8 tonnes/year.

The addition of water bars significantly increased the number of drain points by 78. These new features were installed at regular intervals along the length of the road, which broke up long road surface flow paths, as well as some ditch flow paths, decreasing channel connection risks at already existing drain points, and routing water back onto the hillslope more frequently. This had the net effect of substantially reducing sediment delivery. Post-treatment, the 10% of connected drain points delivered 1.6 tonnes/year, or 9% of eroded sediment.

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

DrainType	Count	∑ Sediment Production (kg)	∑ Sediment Delivery (kg)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	0	-4970	-1060	-55%	-140	-36%
Diffuse Drain	0	-3690	0	0%	0	0%
Ditch Relief Culvert	0	-1500	-20	-8%	0	0%
Lead Off Ditch	0	-2880	0	0%	0	0%
Non-Engineered	0	0	0	0%	0	0%
Stream Crossing	0	-1220	-1220	-71%	-220	-25%
Sump	0	0	0	0%	0	0%
Waterbar	78	13870	0	0%	0	0%
All Drains	**78**	**-390**	**-2300**	**-58%**	**-360**	**-21%**

The modeled change in sediment delivery following the treatments shows a decline of 2.3 tonnes/year to a total of 1.6 tonnes/year. The largest reductions occurred at stream crossings and broad based dips, often located over stream crossings. Road segments that drained to stream crossings and broad based dips were substantially shortened by the installation of new water bars which resulted in a decrease in sediment delivery of 1.2 tonnes/year at stream crossings and 1.0 tonnes/year at broad based dips. There was a significant increase in the number of water bars (an increase of 78). The new water bars drained shorter road segments and did not deliver any sediment to the channel.

At the time of inventory, the newly installed water bars had not been through a full winter, or a significant rain event, since they were placed, and so have not had a chance to flow enough water to determine if they connect to the channel under such conditions. As such, the post-storm event verification will determine the final effectiveness of the new drain points at reducing sediment delivery.

5.3 Landslide Risk

Existing Landslides

The Nestucca area has a moderately 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 3 road related landslides; 2 were fillslope failures and one was a hillslope failure with a gully leading to it. They had an estimated volume of 2220 yd^3 (Figure 4). Two failures had an estimated age less than ten years, and one failure had an estimated age less than five years.

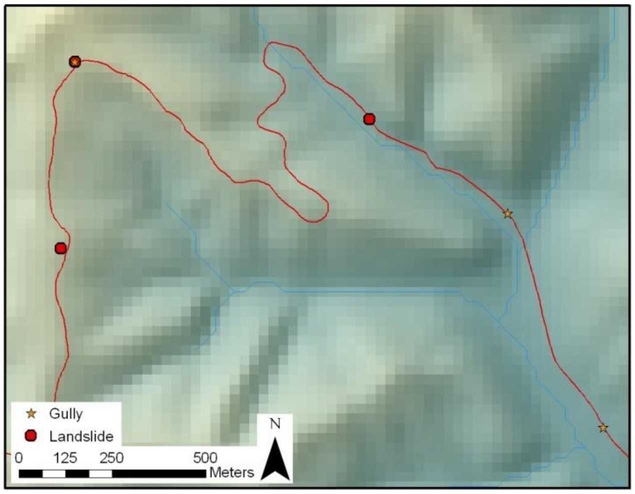

Figure 4. Road related landslide locations along road 8573. One of these landslides is associated with a gully.

Changes in Landslide Risk

The risk of shallow landslide initiation is predicted using SINMAP 2.0 (Pack et al., 2008, http://hydrology.neng.usu.edu/sinmap2/), modified to account for contributions of road runoff, and locally calibrated to known locations of landslides in the rock type underlying the treatment road (basalt; Siuslaw National Forest 1996). 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.

Figures 5 through 8[4] 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 road was generally well-located along the stable ridgetops, though the inherent landslide risk was generally moderate in the greater area of the treated road (Figure 5).

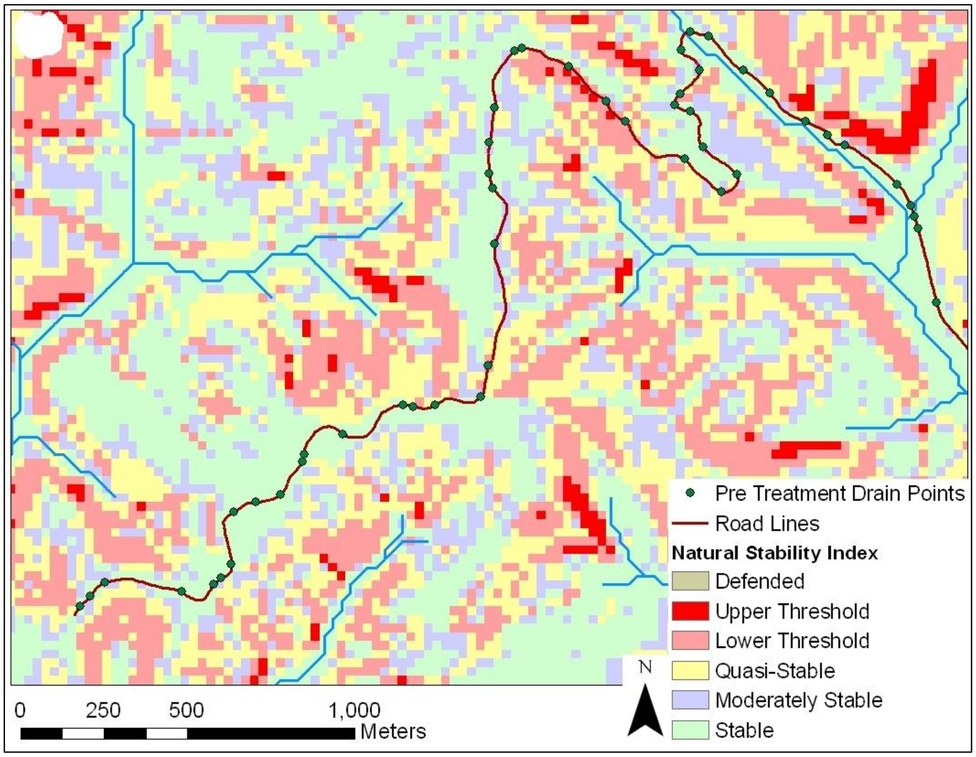

Figure 5. Natural slope stability risk in the area of the 8573 road. The yellow, blue, and green cells are generally qualified as stable, while the pink, red, and tan cells are generally qualified as unstable.

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 8573 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. These are the areas where risk has been sufficiently reduced (green), or where risk has been increased significantly (red).

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

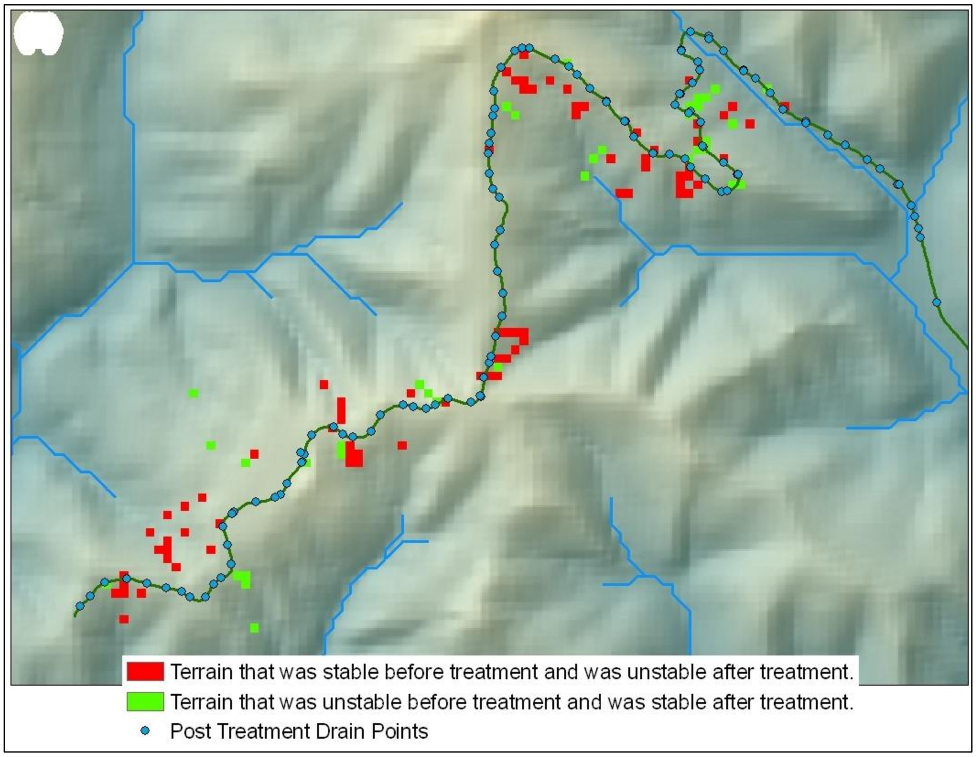

Figure 6. The most significant slope stability risk changes along road 8573. The risk of the areas in green was sufficiently reduced, while the risk in the red areas was significantly increased.

The areas where risk was significantly increased are due to the addition of new drainage (waterbars) over steep slopes that were stable before treatment. Only the waterbars that were added over steep and unstable slopes resulted in this decrease in stability. The waterbars that were added over shallower stable slopes likely increased the risk at those locations, but the increase in drainage was not enough to move those areas from the stable category to the unstable category (i.e. those areas remained stable). The areas where risk was sufficiently decreased are due to the removal of water from those features, usually due to a reduction in the length of road draining to that drain point. Drain points that were located on shallow slopes and were already stable before the treatment may also have experienced a reduction in risk.

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 already unstable without considering the effect of road drainage.

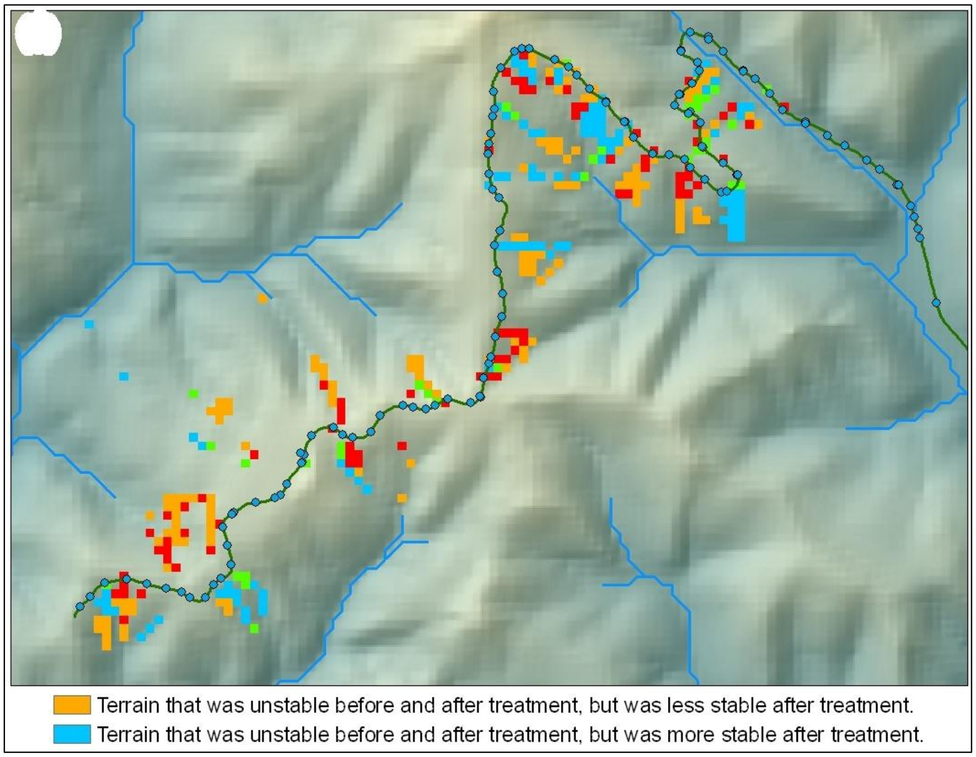

Figure 7. Changes in slope stability risk along road 8573 where the terrain was unstable before and after treatment. The blue areas are locations where the risk was lowered, and the orange areas are where the risk increased.

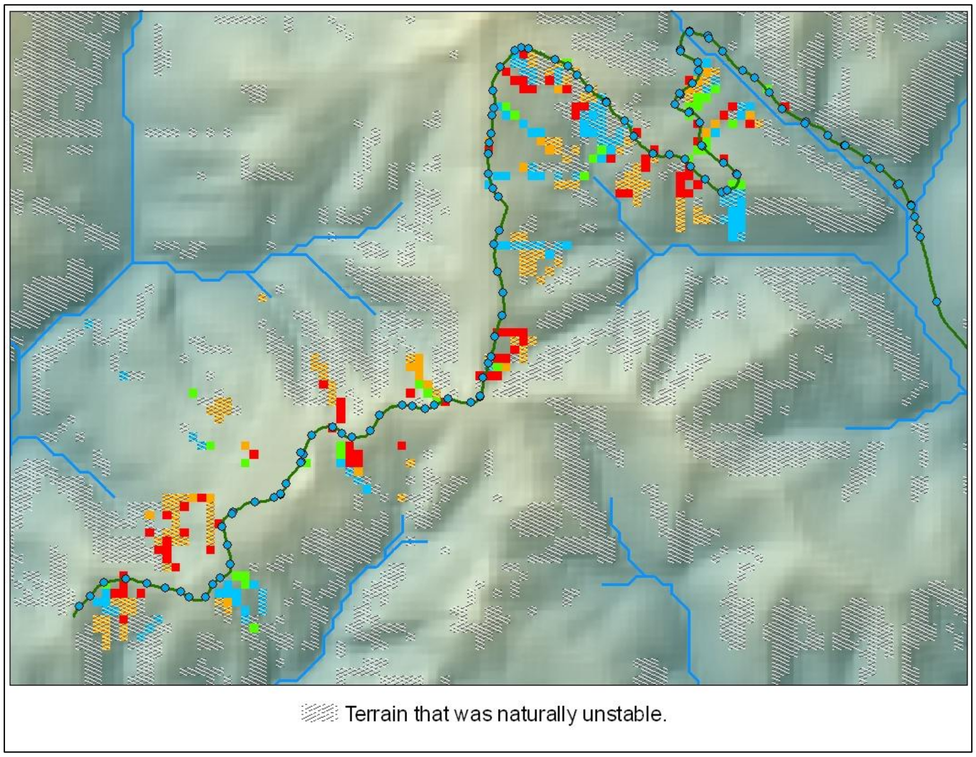

Figure 8. Background slope stability and the changes in slope stability. The cross-hatch pattern is all of the area in the map that was unstable without consideration of road drainage.

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 unstable without consideration of road drainage.

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. However, risks were increased in even more locations because in steep, dissected terrain, it is difficult to redirect discharge from one location without elevating the risk in other locations.

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 waterbars and other 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 (Reid et al. 2010). GRAIP computes the Erosion Sensitivity Index (ESI; Istanbulluoglu et al. 2003), as shown below, at each drain point.

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

L is the road length contributing to the drain point
S is the average slope of the hillslope 150 m below the drain point

When there is sufficient calibration data for a watershed 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. Risk of gullying is generally low in this area, with only three gullies observed along the treatment road, with a total volume of 210 yd^3, and one additional gully observed along the control roads. The four inventoried gullies that were associated with drain points are not enough to determine

ESI_{crit}. ESI calibration from similar roads in the Skokomish River drainage of the Olympic National Forest yielded an ESI_{crit} of 4, for comparison.

Diffuse drain points, stream crossings, and drain points that do not have an associated road surface flow path (i.e. orphan drain points, Appendix A) are not included in the following analysis, because 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.

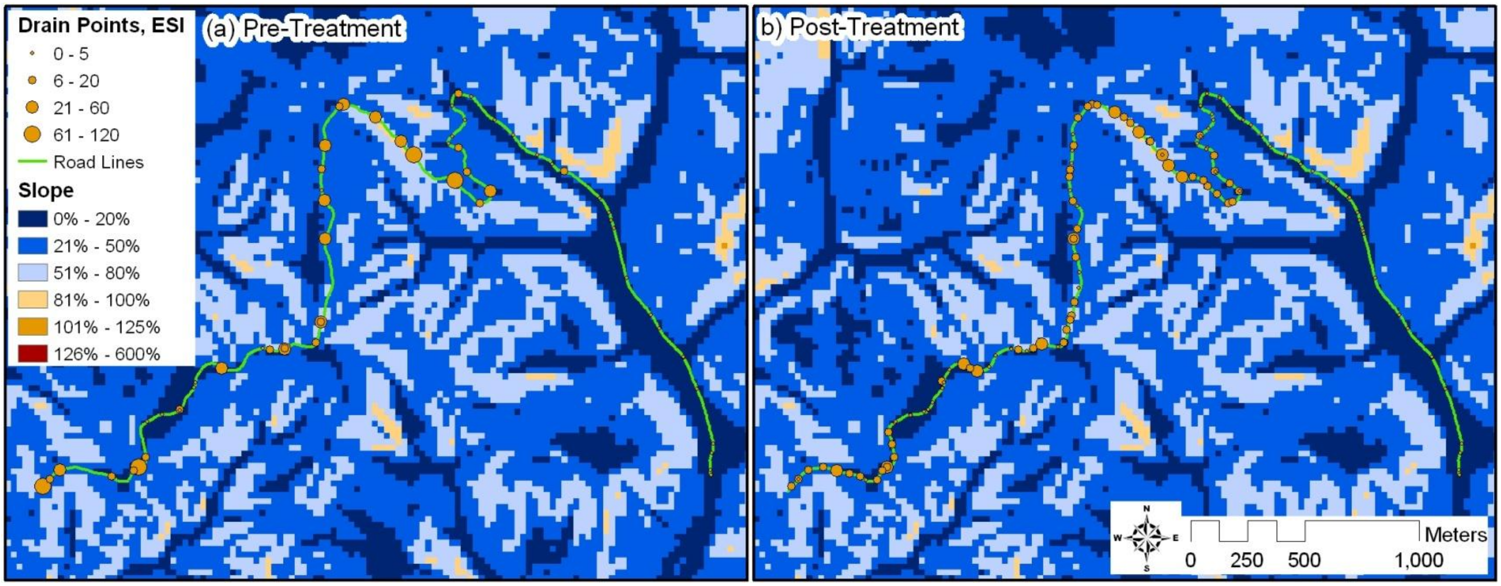

Figure 9. ESI values for drain points concentrating discharge on the 8573 road. The slope map in the background indicates the component of gully risk due to hillslope gradient.

The average pre-treatment ESI was 19.2, with an average contributing road length of 97 m. Post-treatment ESI values had a mean of 8.8. This decrease is due to greatly decreased contributing road length to each drain point, to 48 m (Figure 9). This is a reduction of the average ESI of 54%. However, without a valid ESI_{crit} value, it is not possible to quantify what the effect of this seemingly significant decrease will be.

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 moderate with an average value of 1.9 for the 7 stream crossings (Figure 10). This is out of a range of 1 to 4, where 1 suggests no risk of blockage. The stream crossing with a value of 3 had a skew angle greater than 45 degrees and a pipe diameter to channel width ratio of less than one. The SDRR treatments did not change any of the factors that influence the SBI, so the post-treatment SBI is the same at all crossings as the pre-treatment SBI. However, treatments applied were not intended to reduce these risks.

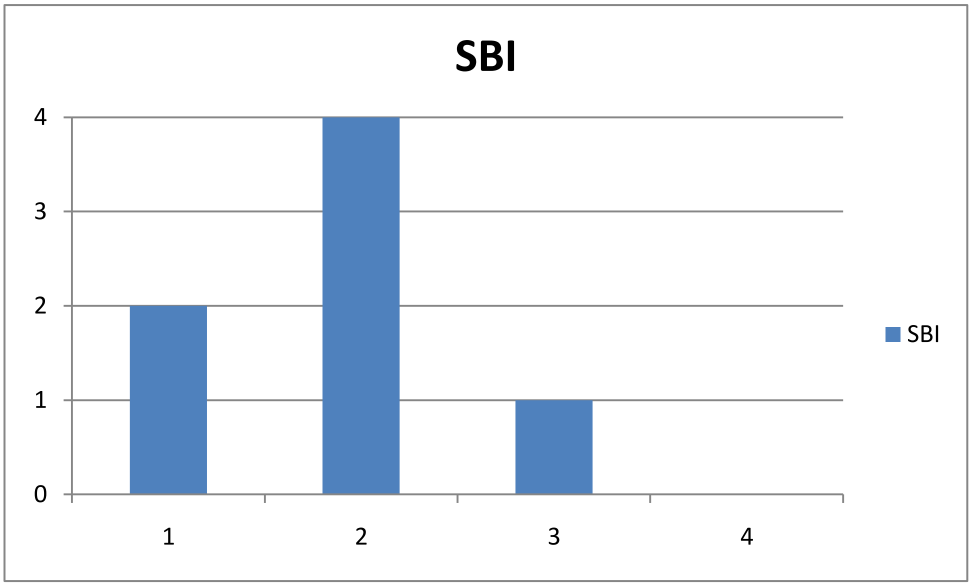

Figure 10. Distribution of Stream Blocking Index values for pre-treatment and post-treatment stream crossings. Values did not change due to the treatments.

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. 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, 43% (3 of 7) of the stream crossings on the original roads had the potential to divert streamflow down the road in at least one direction. The restoration treatments did not change these risks at any of the stream crossing sites.

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 loosing much water from flow around the pipe. Sumps are a problem if they pond water on the road surface or cause fill saturation. Waterbars that are damaged, under sized, or do not drain properly are defined as problematic. Diffuse drains (outsloped roads) are rarely observed to have drain point problems.

At this site, broad based dips, ditch relief culverts, and stream crossing culverts were observed to have the highest rate of problems (44%, 14%, and 14%, respectively), while all other drain types did not have any (Table 6). So far, no problems have been observed at the new water bars. No problems were addressed by the SDRR treatments, and so there was no change in the total number of drain point problems. However, there has been little time for such problems to develop at the new drain points as a result of significant storms. Therefore, final conclusions regarding the new drainage features cannot be made until the post-storm validation monitoring is completed.

Table 6. *Drain point condition problems and fill erosion problems below drain points, pre-treatment and post-treatment roads.*

	Pre-treatment			Post-treatment		
Drain Type	**Count**	**Problems**	**Fill Erosion**	**Count**	**Problems**	**Fill Erosion**
Broad Based Dip	9	44%	0%	9	44%	0%
Diffuse Drain	13	0%	0%	13	0%	0%
Ditch Relief Culvert	22	14%	23%	22	14%	23%
Lead Off Ditch	15	0%	0%	15	0%	0%
Non-Engineered	0	0%	0%	0	0%	0%
Stream Crossing	7	14%	14%	7	14%	14%
Sump	1	0%	0%	1	0%	0%
Waterbar	1	0%	0%	78	0%	0%
Total	**68**	**12%**	**9%**	**146**	**5%**	**4%**
Problems change	**0%**					

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 Siuslaw National Forest, before and after SDRR treatments, as well as a set of control roads. These roads received medium-intensity treatments that included installation of water bars at regular intervals of about 70 m.

The GRAIP model was used to predict the change in level of impact/risk between the pre-existing road and the SDRR-treated road. The restoration treatments reduced the length of the sampled road that was hydrologically connected to streams by 360 m, or 21% from pre-treatment conditions. The model predicts that fine sediment delivery was reduced by 2.3 tonnes/yr (58%), from 3.9 tonnes to 1.6 tonnes annually. The risks presented by stream crossings becoming plugged by debris and sediment were not changed by the installation of water bars along the road. The potential for streamflow to be diverted onto roads and unchannelled hillslopes was not changed at all 7 crossing sites.

The slope stability risk below drain point locations on the original road was reduced in some places as water was redistributed across the hillslope away from original drainage features to new waterbars. However, landslide risk was not reduced across the entire treated road length because the treatments increased risk in some areas where new waterbars were placed above steep slopes. The net effect is likely a slight increase in shallow landslide risk.

Table 7. *Summary of GRAIP road risk predictions for the Nestucca River watershed SDRR project.*

IMPACT/RISK TYPE	EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION	EFFECT OF TREATMENT: POST-STORM VALIDATION
Road-Stream Hydrologic Connectivity	-21%, -360 m	To be determined.
Fine Sediment Delivery	-58%, -2.3 tonnes/year	To be determined.
Landslide Risk	slight increase likely	To be determined.
Gully Risk	54% decrease in gully index	To be determined.
Stream Crossing Risk		
- plug potential	no change	To be determined.
- fill at risk	no change	To be determined.
- diversion potential	no change	To be determined.
Drain Point Problems	no change	To be determined.

Values of a gully index were reduced at nearly all drain points, however, gully risks are low along the treatment road, and there is not enough gully data to determine the significance of this reduction. Post-storm monitoring may help to determine the meaningful risk change due to new drainage features. Existing drain point problems, which were present at 12% (8 of 68) of inventoried pre-treatment sites, were unchanged by the restoration efforts, though the newly installed drainage features did not have any problems. The new drainage features, have not yet been evaluated after a large storm event.

As a whole, these initial results indicate that the SDRR treatments in the Nestucca River watershed should be effective in reducing some of the hydrogeomorphic impacts and risks that these roads posed to aquatic ecosystems, while other risks remain unchanged or perhaps increased slightly (Table 7). Most risk-reduction expectations for this type of moderate-level SDRR treatment were met. The final post storm inventory assessment will enable a closer examination of the hydrologic function of the newly SDRR-treated road system and may answer important questions about gully initiation thresholds and landslide risk. This report will be updated when these data become available.

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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