Legacy Roads and Trails Monitoring Project

Road Decommissioning 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 and allocated the US Forest Service (USFS) $40 million to begin its implementation. This program is intended to reduce road and trail impacts to watersheds and aquatic ecosystems by decommissioning unneeded roads, removing fish passage barriers, and addressing critical repair and maintenance needs.

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

To date, pre-treatment inventories have been conducted at twelve locales on road segments each having four miles where decommissioning or heavy maintenance (i.e., stormproofing) treatments have been implemented. Inventories were also completed on four miles of control sites for each locale. Five post-treatment inventories were executed, as well as one post-storm validation evaluation. This status report focuses only on decommissioning work implemented by the Olympic National Forest (ONF) in the Skokomish River watershed. At the ONF sites, treatments included removal of culverts and fills at stream crossings, replacement of culverts with armored waterbars or broad-based dips, construction of new waterbars and dips, outsloping of road surfaces, pullback of unstable sidecast material, deep scarification of the roadway and ditches, placement of vegetative material on disturbed areas, revegetation of select sites, and seed and/or mulching of disturbed areas. At one site, a road was converted to a trail.

Before-after comparisons using GRAIP indicate that decommissioning treatments resulted in a large reduction of most impact-risk metrics. Road-stream connectivity was reduced by 70%, from 3,474 m of connected road to 1,032 m. Delivery of fine sediment was reduced by 81%, from 27.1 tons/year to 5.2 tons/year. Values of a stream blocking index were reduced from an average of 1.7 before treatment to zero after treatment (n=15), indicating the risk of stream crossings becoming plugged was completely eliminated by excavation and removal of culverts and associated fills. While former crossings sites may contribute fine sediment to streams in the short term, the restoration treatments removed over 4,000 m^3 of earthen material from areas with a high potential for failure and delivery to stream channels. Diversion potential was eliminated at 89% (8 of 9) of crossing sites.

The slope stability risk below drain point locations on the original road was reduced as water was redistributed across the hillslope to waterbars and diffuse drainage. It is unclear, however, if landslide risk was reduced across the entire treated road length because the treatments slightly increased risk in some 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.

Reductions in gully risk, as determined by comparisons of a gully initiation index (ESI) to an empirically-derived threshold (ESI_{crit}), were modest across the length of treated road. 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 initiation threshold, indicating elevated risk was still present. Moreover, index values were increased at some of the new drainage points. The net effect was that treatments reduced the number of drainage points with elevated gully risk by only one. Current calculations are based on conservative assumptions, so the actual performance of the treatments may exceed these initial expectations. Such assumptions will be assessed during future post-storm monitoring.

Before treatment, inventoried road segments had problems at 49% of 75 inventoried drainage points. Post-treatment monitoring indicates that these problems were almost entirely eliminated by the decommissioning treatments and that most replacement drainage features are less vulnerable to failure.

Taken collectively, preliminary results indicate the decommissioning treatments should be effective in significantly reducing most hydrogeomorphic impacts and risks to aquatic ecosystems. Some risk of shallow landsliding and gully formation may remain where complete recontouring was not used, and some assessment of tradeoffs between more thorough local treatment and greater treated lengths is 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 Skokomish River watershed decommissioning project.

IMPACT/RISK TYPE	EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION	EFFECT OF TREATMENT: POST-STORM VALIDATION
Road-Stream Hydrologic Connectivity	-70%, -2,442 m of connected road	To be determined.
Fine Sediment Delivery	-81%, -21.8 tons/year	To be determined.
Landslide Risk	uncertain, slight reduction likely	To be determined.
Gully Risk	1 less drain point with elevated gully risk (32 vs. 33), greater reductions possible	To be determined.
Stream Crossing Risk		
- plug potential	-100% (eliminated at 15 sites)	To be determined.
- fill at risk	-100% (-4098 m^3)	To be determined.
- diversion potential	-89% (eliminated at 8 of 9 sites)	To be determined.
Drain Point Problems	-98% (1% vs. 49% of drain points)	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 allocated the US Forest Service (USFS) $40 million to begin its implementation. This program is intended to reduce road and trail impacts and risks to watersheds and aquatic ecosystems by decommissioning unneeded roads, removing fish passage barriers, and addressing critical repair and maintenance needs.

Recognizing the importance of this program, the USFS, Rocky Mountain Research Station (RMRS) and Pacific Northwest (PNW) Region are implementing the Legacy Roads and Trails Monitoring Project (LRTMP) to evaluate the effectiveness of road restoration treatments being implemented on national forests in Oregon and Washington. This report briefly describes the overall objectives of the Regional-scale study and the methods being used. Specific results presented herein, however, are focused only on road decommissioning work completed by the Olympic National Forest (ONF) in the Skokomish River watershed in FY2008. As other data become available, similar reports will be developed for additional sites. In addition, syntheses of results at multiple sites will be produced throughout and at the end of this monitoring project.

2.0 Study Objectives

The LRTMP is designed to assess the effectiveness of decommissioning and maintenance 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. 2007, 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 and Luce, 2007). 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 also includes a final validation evaluation at both treatment and control sites following a substantial storm event (5-10 year recurrance interval). This will allow testing of the initial GRAIP risk predictions and provide an unbiased comparison between the treated and the untreated roads.

4.0 Monitoring Locations

Regional Monitoring Sites

In FY2008, pre-treatment evaluations were completed at twelve sites[1] on national forests throughout the Pacific Northwest. Decommissioning has or will be implemented at seven of these sites and five sites have or will be "stormproofed[2]" (Figure 1, Table 1). Five post-treatment inventories and one post-storm validation evaluation were also completed in FY2008. Post-treatment and, to the degree possible, post-storm evaluations will be completed at the remaining sites in FY2009. In addition, evaluations will be initiated at six new sites, the locations of which have not yet been determined.

[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] "Stormproofing" (also referred to as Storm Damage Risk Reduction) 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.

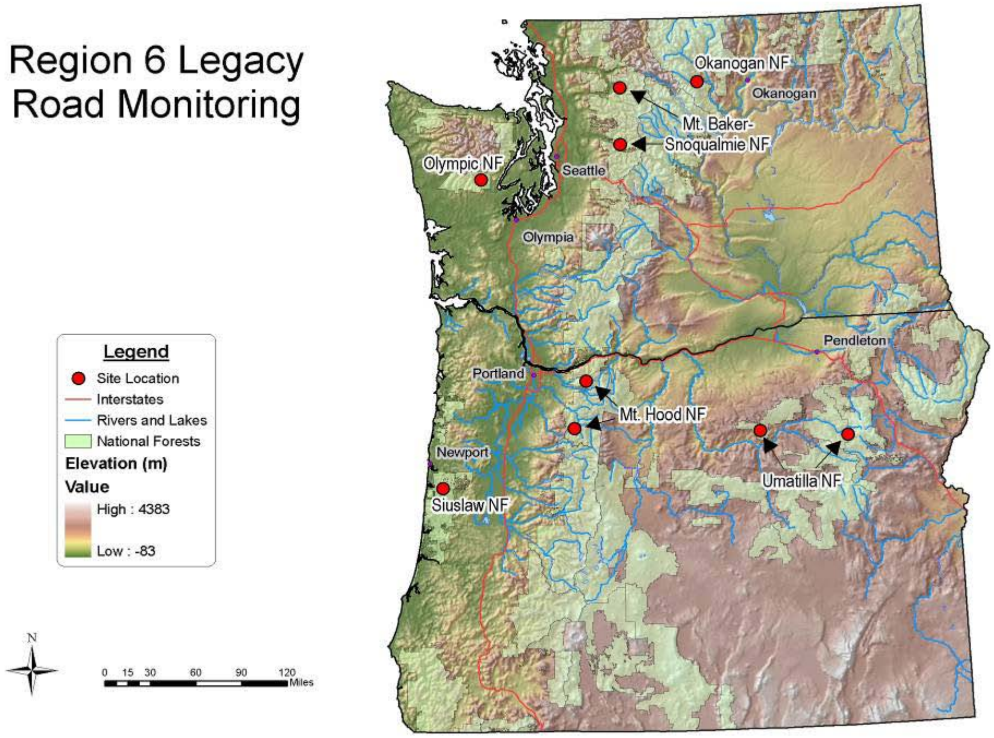

Figure 1. Location of monitored sites, FY2008, PNW Region.

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

NATIONAL FOREST	TREATMENT	WATERSHED
Okanogan-Wenatchee	Decommissioning	Methow\Twisp River
	Storm Damage Risk Reduction	Methow\Twisp River
Olympic	Decommissioning	Skokomish
	Storm Damage Risk Reduction	Skokomish
Mt Hood	Decommissioning	Bull Run
	Storm Damage Risk Reduction	Collawash
Mt Baker-Snoqualmie	Decommissioning	Suiattle River
	Storm Damage Risk Reduction	Skykomish
Umatilla	Decommissioning	John Day\Wall Creek
	Decommissioning	John Day\Granite Creek
	Storm Damage Risk Reduction	John Day\Granite Creek
Siuslaw	Decommissioning	Alsea River

Skokomish Basin Sites

During the summer and fall of 2008, field crews inventoried both decommissioning and storm damage risk reduction sites in the Skokomish watershed (Table 1, Figure 1). 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 South east side of the Olympic Mountains, at the lower edge of the transient snow zone.

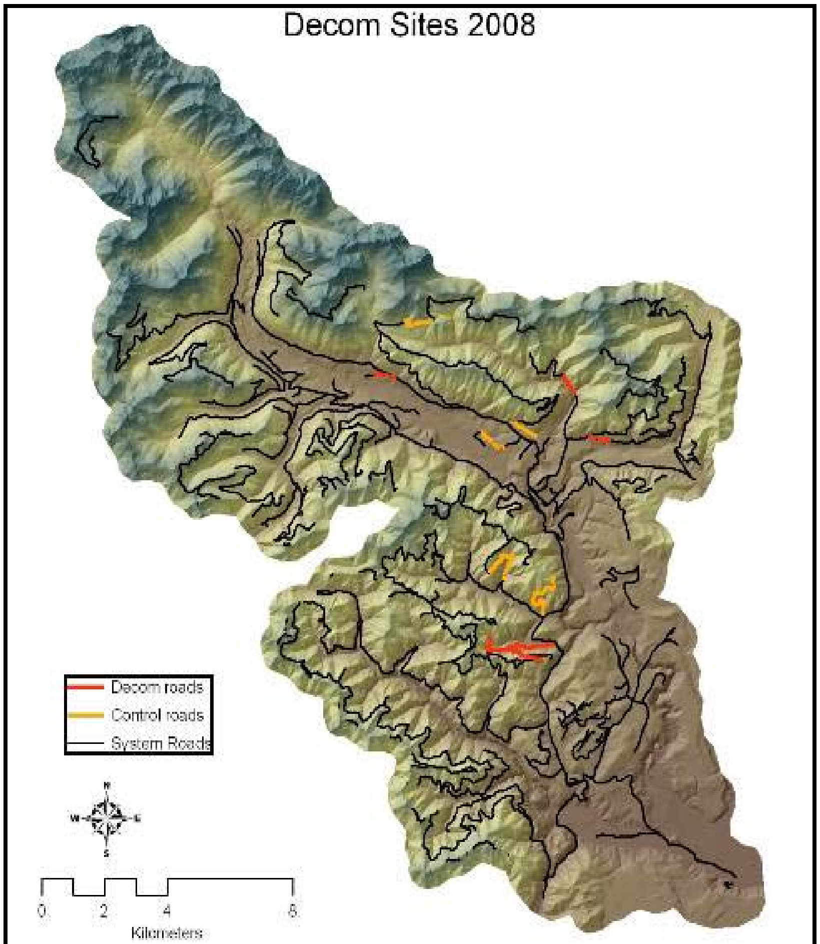

Figure 2. Location of monitored sites in Skokomish River watershed, Olympic National Forest.

To date, only the results from the decommissioning sites are available and are the therefore focus of this report (Figure 2). Pre-treatment roads were crowned with an inboard ditch, surfaced with gravel (except the native surfaced 2355-100) and constructed with periodic drainage features. Both treatment and control sites included roads on a range of hillslope positions and included frequent live stream crossings. The watershed has steep topography, so stream crossing fills, cutslopes and fillslopes are typically large.

Decommissioning treatments included removal of culverts and fills at stream crossings, replacement of culverts with armored waterbars or broad-based dips, construction of new waterbars and dips, outsloping of road surfaces, pullback of unstable sidecast material, deep scarification of the roadway and ditches, placement of cleared vegetative material on disturbed areas, revegetation of select sites, and seed and/or mulching of disturbed areas. At one site, a road was converted to a trail.

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

DECOMMISSIONED ROAD		CONTROL ROAD	
Road #	**Treatment**	**Road #**	**Treatment**
2354-300	Deep scarification, stream crossing excavation, drainage improvement	2353-000	None
2300-100 Lower	Deep scarification, local partial-recontouring, stream crossing excavation, drainage improvement	2352-000	None
2300-100 Upper	Deep scarification, stream crossing excavation, drainage improvement	2300-200	None
2300-130	Deep scarification, partial-recontouring, stream crossing excavation, drainage improvement	2300-200	None
2354-200	Deep scarification, outsloping, drainage improvement, stream crossing excavation	2353-210	None
2355-100	Road to trail conversion, drainage improvement, stream crossing excavation	2353-140	None

5.0 Results

GRAIP inventory and modeling tools were used to characterize the following types of impacts and risks, all of which were expected to be reduced by the decommissioning 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 suggests 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 decommissioning treatments increased the total number of drain points and redistributed water back into the hillslope. This substantially reduced the length of road surface connected to the channel. Prior to the treatments, 3,474 m out of the 6,420 m of inventoried road (54%) were hydrologically connected to stream. After the treatments, 1,032 m of the 6,793 m of monitored road (15%) were connected. Thus, the treatments resulted in a net reduction of 2,442 m of hydrologically-connected road, which is 70% 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 hillslope (m/m) below the drainpoint
V is the vegetation cover factor for the flow path
R is the road surfacing factor

Delivery of eroded sediment to the channel network is determined by observations of each place that water leaves the road. Each of these drain points is classified as delivering, not delivering, or uncertain. No estimate of fractional delivery is made because there is insignificant hillslope sediment storage in locations where there is a clear connection to the channel under most circumstances. For this analysis, uncertain observations were treated as delivering. A map of the road surface sediment delivery and the accumulated sediment delivered through drain points is shown for the 2300-100 and 2300-130 roads (Figure 3).

[3] For this analysis, a base erosion rate of 79 kg/m of road length 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.

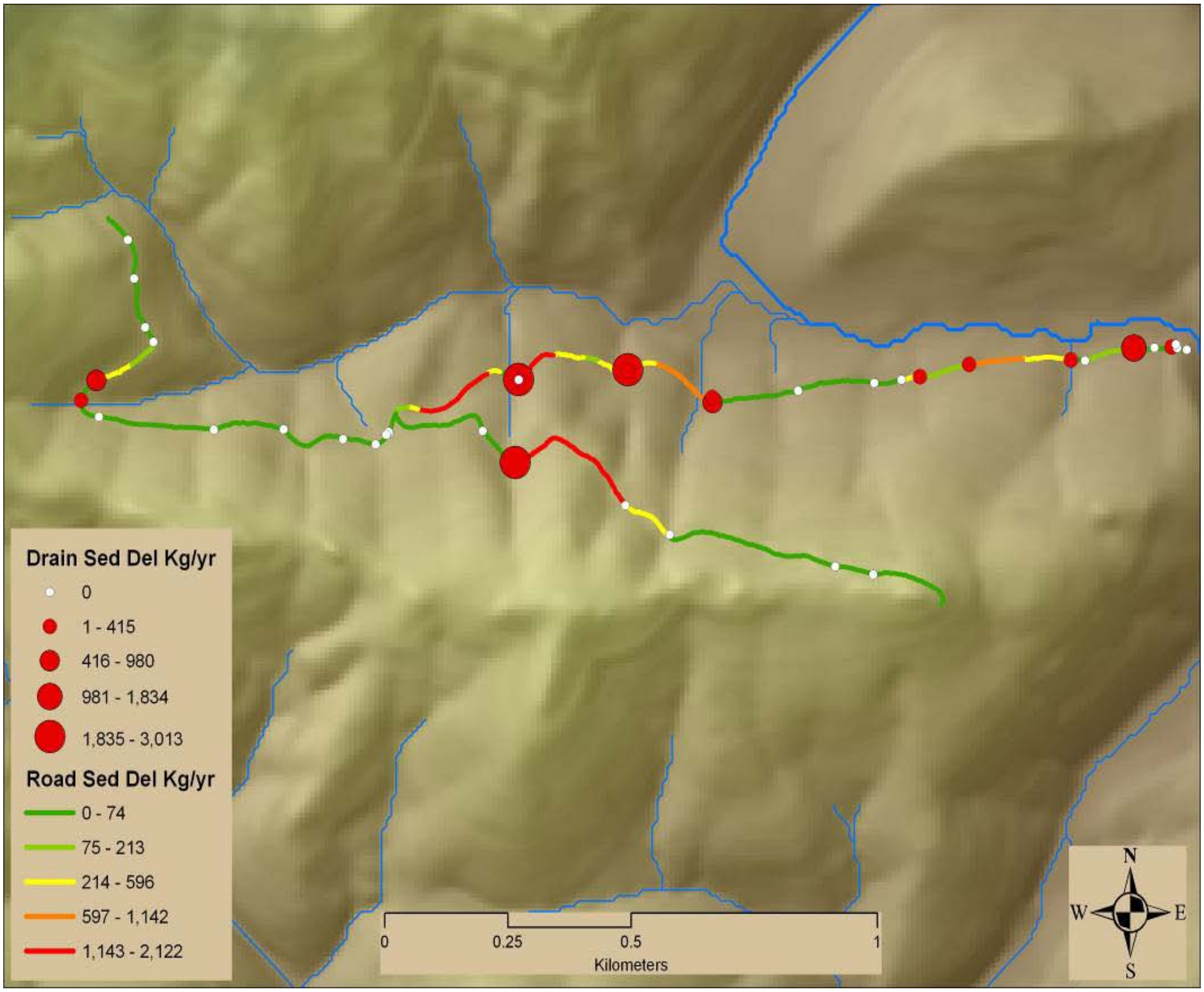

Figure 3. Fine sediment delivery to channels by road segment and drain point, pre-treatment road. The road line is colored to indicate the mass of fine sediment that is generated on the road and delivered to the channel. The size of the circle indicates the accumulated mass of sediment delivered through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

Pre-treatment

Delivery of fine sediment occurs through a mix of road drainage features including ditch relief culverts, non-engineered drain points, stream crossings and others. In Table 3, sediment delivery is broken out by drain type to assess their effectiveness in preventing sediment from entering the channel. However, the sample shown here is too small for extensive statistical analysis by drain point. Eighty-five drain points were documented, 49% of which were hydrologically connected to stream channels. These points delivered 27.1 tons/year of sediment, or 65% of the sediment generated by the road surfaces and ditches.

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

Drain Type	Count	Σ Sediment Production (kg)	Σ Sediment Delivery (kg)	% Sediment Delivery	% length connected
Broad Based Dip	1	104	104	100%	100%
Diffuse Drain	7	2,725	975	36%	29%
Ditch Relief Culvert	25	6,105	3,995	65%	47%
Lead Off Ditch	0				
Non-Engineered	23	16,217	9,296	57%	48%
Stream Crossing	15	10,105	10,105	100%	100%
Sump	11	2,742	0	0%	0%
Waterbar	3	3,432	2,621	76%	33%
All Drains	**85**	**41,430**	**27,096**	**65%**	**49%**

Post-treatment

The addition of waterbars, outsloping of the road surfaces, and creation of diffuse drainage flow paths dramatically increased the number of drain points to 179. With the exception of the stream crossings, very few of these new drain points were connected to stream channels. In addition, the segments contributing to the stream crossings were shorter. The modeled sediment production increased because the construction work exposed bare erodible soil where a gravel surface was once in place. This is expected to be a short-term effect that will dissipate as the former road surface revegetates, at which point sediment production should decline to below pre-treatment levels. No adjustment of GRAIP sediment production estimates were made to account for reduced runoff from the ripping and recontouring treatments because of uncertainties about how much they will reduce runoff from extended storms. In spite of the projected increases in sediment production, expectations for sediment delivery declined dramatically because the disturbed surface was disconnected from the channel. The 18% of drain points connected to the channel after the treatments delivered 5.2 tons/year of sediment, or 11% of the eroded sediment.

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

Drain Type	Count	Σ Sediment Production (kg)	Σ Sediment Delivery (kg)	% Sediment Delivery	% length connected
Broad Based Dip	36	7,073	966	14%	3%
Diffuse Drain	82	28,204	409	1%	5%
Ditch Relief Culvert	1	0	0	0%	0%
Lead Off Ditch	0				
Non-Engineered	0				
Stream Crossing	15	3,412	3,412	100%	100%
Sump	0				
Waterbar	45	8,899	454	5%	13%
All Drains	**179**	**47,588**	**5,241**	**11%**	**18%**

The modeled change in sediment delivery following the treatments shows a decline of 21.8 tons/year to a total of 5.2 tons/year. The largest reductions occurred at non-engineered features (through removal of the features) and stream crossings (through shortening of contributing segments), with smaller reductions from the removal of ditch relief culverts. There was a large increase in the number of waterbars (42). The new waterbars drained shorter road segments and were placed to avoid delivery to the channels, so they ultimately show a reduction in delivery of 2 tons/year. Similarly, more than half of the sediment production on the treated road is generated from the outsloped portion, which is designed to drain in a diffuse manner away from streams. This is the largest sediment production source immediately post-treatment, but only 1% of the eroded sediment is delivered. Rapid revegetation of recontoured sites is expected to reduce the production estimates substantially in the future.

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

Drain Type	Count	Δ Sediment Production (kg)	Δ Sediment Delivery (kg)	Δ Sediment Production (%)	Δ Sediment Delivery (%)
Broad Based Dip	35	6,969	862	6701%	829%
Diffuse Drain	75	25,479	-566	935%	-58%
Ditch Relief Culvert	-24	-6,105	-3,995	-100%	-100%
Lead Off Ditch	0	0	0	-	-
Non-Engineered	-23	-16,217	-9,296	-100%	-100%
Stream Crossing	0	-6,693	-6,693	-66%	-66%
Sump	-11	-2,742	0	-100%	-
Waterbar	42	5,467	-2,167	159%	-83%
All Drains	**94**	**6,158**	**-21,855**	**15%**	**-81%**

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 33 road related landslides: 12 cutslope failures with an estimated volume of 8,000 yd^3, 19 fillslope failures totaling 92,000 yd^3 and a single hillslope failure that generated 39,000 yd^3. One road contained the majority (13) of the landslides in the decommissioning study area. Many failures were related to gullies, landslides and diverted drainage from the two upslope roads, much of which occurred during the last decade (R. Stoddard personal communication) (Figure 4).

Figure 4. Landslide locations on road 2355-100. These were caused by several upslope roads that routed water and sediment through gullies.

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. An example from the 2354-200 road is shown in Figure 5 to illustrate the change in risk in an area where the inherent landslide risk is high. SINMAP was run initially to determine the intrinsic stability of the slopes over which the road traverses and to identify locations that are at high risk of failure without a road (Figure 5a).

A second stability index (SI) run was performed to address the effects of road water contribution to drain points on the original road network. The grid cells with increased risk of landsliding due to the original road drainage are shown in Figure 5b. This example illustrates the redistribution of intercepted groundwater to a waterbar that discharges to a swale. The swale location (shown in orange and red) was previously mapped as within the area of highest risk and the additional drainage expanded the area at risk of failure. Further down the road there was a non-engineered drainage feature that discharged to a concave slope position with high SI values. Below this point on the road there were two stream crossings and a non-engineered drain point that did not discharge enough water to change the stability. The landsliding risk was not increased in these areas because the water was mostly routed from the road directly to the channel, without impacting the hillslope.

A third model run was performed to illustrate the change in risk of shallow landsliding with the modified road drainage system resulting from the restoration treatments (Figure 5c). Three waterbars were added to the road above the high risk swale location, one just upslope of the problem location. This resulted in a net reduction in risk at the pre-existing, non-engineered point due to a reduction in discharge. Further down the road, the addition of four new waterbars resulted in small localized increases in SI values as more water was added to steep locations. The net effect of the decommissioning treatments, which increased road drainage frequency, achieved the goal of reducing risk at the two highest risk locations in the sample area. However, risks were slightly increased in other locations because in steep, dissected terrain, it is difficult to redirect discharge from one location without elevating the risk in others. These findings are consistent with Madej (2001), who concluded that decommissioned roads in high risk areas commonly experience failures after treatment because their effects cannot always be fully mitigated.

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, recontouring may be more important, or 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 calibrate the SI values used in this analysis and refine these initial results. Questions to be evaluated include the amount of runoff still intercepted by cutslopes and runoff generated from ripped surfaces following treatment.

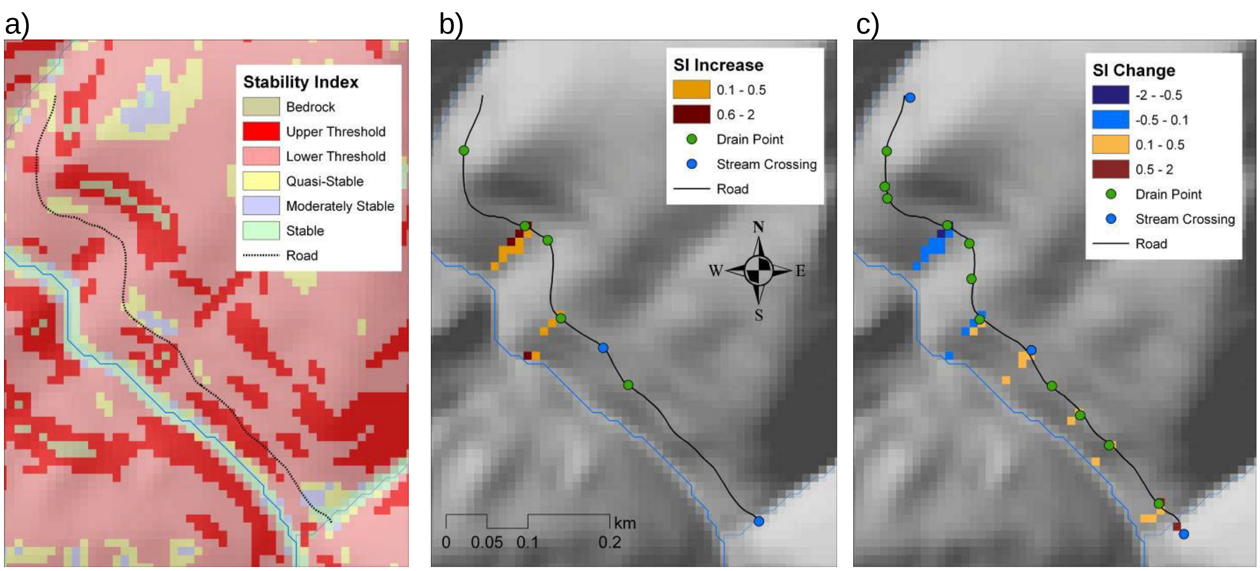

Figure 5. Stability index for hillslopes in the vicinity of road 2354-200.

a) SI values in an un-roaded condition. b) Increases in SI due to the addition of drainage from the original road. c) Difference in SI values between the original and decommissioned road. Orange and red colors indicate increased risk. Blue colors indicate lower risk.

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.

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

L is the road length contributing to the drain point
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. Here, ESI_{crit} = 5, as the risk of gully initiation increases by a factor of 3-4 above that value (Table 6).

Table 6. ESI values for all concentrated drain points at the control and pre-treatment sites. At this site ESI_{crit} = 5, as gully frequency increases significantly above that value.

ESI Value	<1.25	1.25-5	5-23	>23
# of sites with gullies	2	1	8	6
# of sites without gullies	28	17	33	33
% Gullied	7%	6%	24%	18%

The average pre-treatment ESI was 14.2, with an average contributing road length of 82 m. 53% (33 of 62) of the pre-treatment drain points fell into this high risk group (Figure 6). Post-treatment ESI values had a mean of 7.6, due to increased drainage frequency and decreased contributing road length to each drain point. While the average length of road delivering water to these points was reduced to 21 m, 39% of them (32 of 62 total points) still had ESI values in excess of 5. 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 a high risk of gully initiation was calculated to have been reduced by only one as a result of the decommissioning treatments. Thus, the risk of gully initiation may still be high on much of the sampled landscape.

Actual performance of the restoration treatments may exceed these initial predictions, however. The assumption that ESI_{crit} remains the same after treatment is conservative because hydrologic theory suggests that the treated roads may not deliver runoff at the same rate as the pre-existing road, which was gravel-surfaced and compacted. Unfortunately, we do not yet know whether and to what degree this is this case at this site. Post-storm validation monitoring will help address this unresolved question.

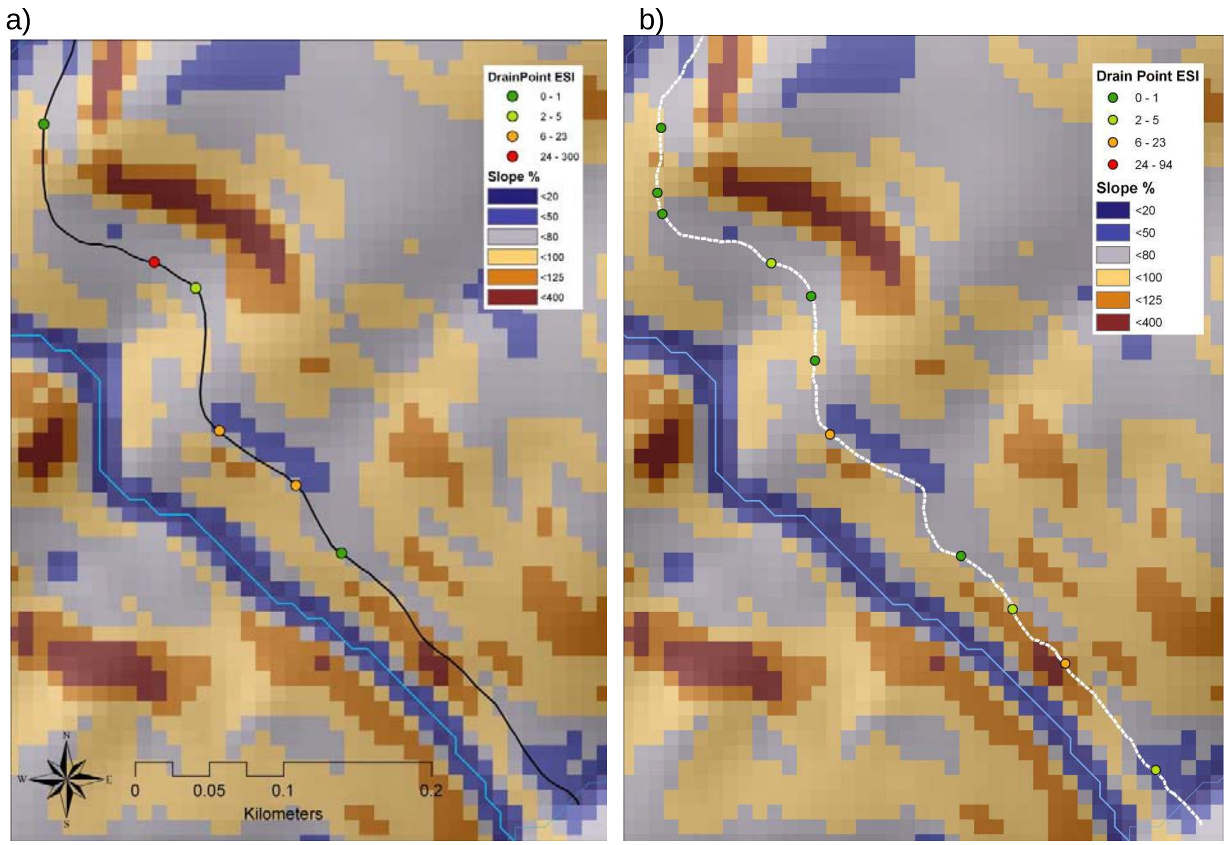

Figure 6. ESI values for drain points concentrating discharge on the 2354-200.

a) pre-treatment and b) post-treatment. Drains with high risk of gullying (ESI >5) are shown in orange and red. The slope map in the background indicates the component of gully risk due to hillslope gradient.

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 relatively high with an average value of 1.7 for the 15 stream crossings (Figure 7). This is out of a range of 0 to 4, where 0 suggests no risk of blockage. The stream crossings with values of 3 and 4 all had culvert to channel width ratios of <1. All 15 stream crossing pipes were removed during decommissioning, which completely eliminated the risk of pipe plugging (Figure 8). Thus the post-treatment SBI score was zero at all crossings.

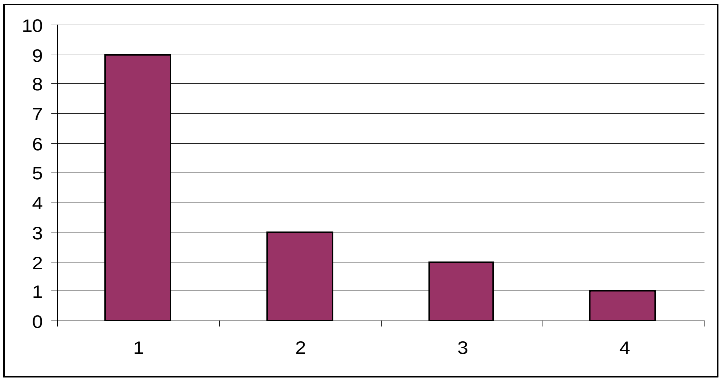

Figure 7. Distribution of Stream Blocking Index values for pre-treatment group. Post-treatment values were zero for all sites.

a) b)

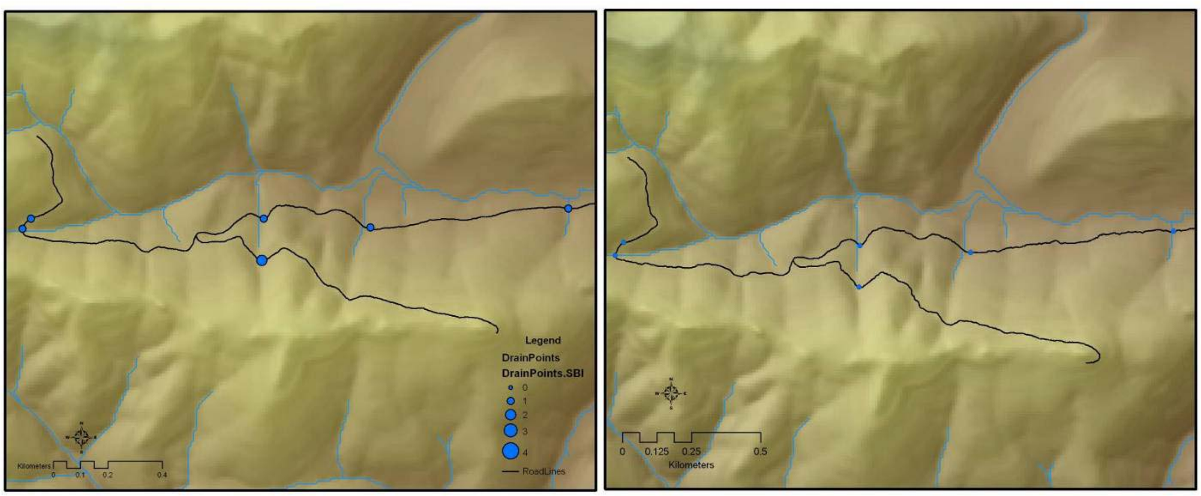

Figure 8. SBI values on the 2300-100 and 2300-130 road stream crossings. a) pre-treatment; b) post-treatment

The risk of a stream crossing failure can also be viewed in the context of the consequences of failure (Flanagan et al. 1998). A consequence of concern at these stream crossings is the erosion of fill material into the stream channel. We calculated the fill material that would likely be excavated in an overtopping type failure. We modeled the prism of fill at risk as bounded at the base by an area 1.2 times the channel width, with side slopes climbing to the road surface at an angle of 33%. The fill volume at risk in the pre-treatment road configuration was approximately 4,098 m^3. All of this material and a great deal more was excavated during the restoration work.

A second, and perhaps greater, consequence of concern at failed stream crossings is the diversion of stream flow onto road surfaces and 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 hillsopes, 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, 60% (9 of 15) of the stream crossings on the original roads had the potential to divert streamflow down the road in at least one direction. The restoration treatments eliminated these risks at all but one site. The sole remaining site with diversion potential was observed on the 2355-100 road to trail conversion, where a 2-foot wide ephemeral channel crosses the travel surface via an un-armored waterbar near the start of the project. Although a stream ford cannot be blocked in a manner similar to a culvert a failure of the drainage structure here is possible

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, non-engineered features and sumps were observed to have the highest rate of problems (74% and 73%, respectively), while diffusely drained roads were least likely to have problems (Table 7). So far, few problems have been observed after the decommissioning treatments. However, there has been little time for such problems to develop as a result of significant storms. Therefore, final conclusions regarding the new drainage system cannot be made until the post-storm validation monitoring is completed.

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

	PRE-TREATMENT			POST- TREATMENT		
Drain Type	Count	Problems	Fill Erosion	Count	Problems	Fill Erosion
Broad Based Dip	1	0%	100%	36	0%	3%
Diffuse Drain	7	0%	14%	84	0%	0%
Ditch Relief	17	41%	35%	1	100%	0%
Lead Off	0			0	0%	
Non-Engineered	23	74%	27%	0	0%	
Stream Crossing	15	33%	0%	23	0%	0%
Sump	11	73%	0%	0		
Waterbar	1	0%	0%	45	0%	0%
Total	**75**	**49%**		**189**	**1%**	

6.0 Summary & Conclusions

The USFS, RMRS and PNW Region initiated a Legacy Roads and Trails Monitoring Project in the summer 2008. As part of the study, field crews inventoried road segments on the Olympic National Forest, before and after decommissioning treatments, as well as a set of control roads. These roads received high-intensity treatments that included removal of culverts and fills at stream crossings, replacement of culverts with armored waterbars or broad-based dips, construction of new waterbars and dips, outsloping of road surfaces, pullback of unstable sidecast material, deep scarification of the roadway and ditches, placement of cleared vegetative material on disturbed areas, revegetation of select sites, and seed and/or mulching of undisturbed areas. At one site, a road was converted to a trail.

The GRAIP model was used to predict the change in level of impact/risk between the pre-existing road and the decommissioned road. The restoration treatments reduced the length of the sampled road that was hydrologically connected to streams by 2,442 m, or 70% from pretreatment conditions. The model predicts that fine sediment delivery was reduced by 81%, from 27.1 tons to 5.2 tons annually. The risks presented by stream crossings becoming plugged by debris and sediment were completely eliminated by the excavation and removal of the culverts and fills. These locations will contribute fine sediment to the channel in the short-term, but this treatment will prevent over 4,000 m^3 of earthen material from eroding into the channel when the stream crossings ultimately become plugged or fail from rusting. The potential for streamflow to be diverted onto roads and unchannelled hillslopes was eliminated at 89% (8 of 9) of crossings.

The slope stability risk below drain point locations on the original road was reduced as water was redistributed across the hillslope to waterbars and diffuse drainage. It is unclear, however, if landslide risk was reduced across the entire treated road length because treatments slightly increased risk in some areas where new concentrated drainage features were added above steep slopes. Similarly, values of a gully index were reduced at many of the original drainage points. Nonetheless, values still exceed conservative initiation thresholds at some 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 reduced by only one (32 vs. 33). Post-storm validation monitoring will determine whether the conservative initiation thresholds used in this analysis are correct, or if gully risk was reduced more than these initial predictions indicate. Existing drain point problems, which were present at 49% (37 of 49) of inventoried sites, were almost entirely eliminated by the restoration efforts. These new drainage features, however, have not yet been evaluated after a large storm event.

As a whole, these initial results indicate that the decommissioning work in the Skokomish River watershed should be effective in greatly reducing many of the hydrogeomorphic impacts and risks that these roads posed to aquatic ecosystems. The final post storm inventory assessment will enable a closer examination of the hydrologic function of the newly decommissioned road system and will answer important questions about runoff generation, gully initiation thresholds, and landslide risk. This report will be updated when these data become available.

Table 8. Summary of GRAIP model risk predictions for the Skokomish decommissioning project.

IMPACT/RISK TYPE	EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION	EFFECT OF TREATMENT: POST-STORM VALIDATION
Road-Stream Hydrologic Connectivity	-70%, -2,442 m of connected road	To be determined.
Fine Sediment Delivery	-81%, -21.8 tons/year	To be determined.
Landslide Risk	uncertain, slight reduction likely	To be determined.
Gully Risk	1 less drain point with elevated gully risk (32 vs. 33), greater reductions possible	To be determined.
Stream Crossing Risk		
- plug potential	-100% (eliminated at 15 sites)	To be determined.
- fill at risk	-100% (- 4098 m^3)	To be determined.
- diversion potential	-89% (eliminated at 8 of 9 sites)	To be determined.
Drain Point Problems	-98% (1% vs. 49% of drain points)	To be determined.

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