Legacy Roads and Trails Monitoring Project

Road Decommissioning in the Bull Run River Watershed
Mt. Hood 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. Based on continued success, the program was allocated $90 million in FY2010. This program is intended to reduce road and trail impacts to watersheds and aquatic ecosystems by decommissioning unneeded roads, removing fish passage barriers, and addressing critical repair and maintenance needs.

The USFS, Rocky Mountain Research Station and 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. 18 post-treatment inventories were executed, as well as two post-storm validation evaluations. This status report focuses only on decommissioning work implemented by the Mt. Hood National Forest (MHNF) in the Bull Run River watershed. At the MHNF sites, treatments included removal of culverts and fills at stream crossings, replacement of culverts with waterbars or broad-based dips, construction of new waterbars and dips, tilling and potholing of road surfaces, pullback of unstable sidecast material, placement of vegetative material on disturbed areas, and revegetation of select sites.

Soon after the treatments for this site were completed in the fall of 2008, a significant rainfall event (>25 yr recurrence interval) occurred over the Bull Run basin, causing damage on the treated roads at excavated stream crossings. Control roads do not show any change post-storm event.

Before-after comparisons using GRAIP indicate that decommissioning treatments resulted in a reduction of some impact-risk metrics, while other risks experienced an increase. Road-stream connectivity was reduced by 16%, from 2729 m of connected road to 2294 m. Delivery of fine sediment was conservatively estimated to have increased by 84%, from a relatively low 3.8 tonnes/year to 7.1 tonnes/year, due to the decompaction and removal of asphalt from the road surfaces. These metrics appear to remain accurate following the post-storm event evaluation.

Values of a stream blocking index were reduced from an average of 2.5 before treatment to zero after treatment (n=36), indicating the risk of stream crossings becoming plugged was completely eliminated by excavation and removal of culverts and associated fills. However, the post-storm

event evaluation revealed that there was one stream crossing where a secondary culvert had not been removed, and was at risk of further fill failure if it were to become plugged. The restoration treatments removed over 13,000 yd^3 of earthen material from areas with a high potential for failure and delivery to stream channels. However, the high stream flows during the storm event resulted in an additional 1080 yd^3 (about 1300 tonnes) of fill erosion in the channel bottoms and side slopes of the stream crossings. Diversion potential was eliminated at 100% of crossing sites.

The modeled slope stability risk below drain point locations on the original road was increased as water was redistributed across the hillslope to new waterbars. It is unclear, however, if landslide risk was increased across the entire treated road length because the treatments decreased risk in some areas where concentrated drainage features were removed above steep slopes. Additionally, there were no landslides observed during the survey, suggesting that the model does not fit this area, or the storm event was not large enough to trigger landslides.

Gully risk, as determined by a gully initiation index (ESI), indicated an increase in risk across the treatment sites, from an average ESI of 4.4 before treatment, to an average of 7.9 after treatment (an increase of 79%). Most of this increase can be attributed to longer contributing road lengths at drain points. Post-storm event, there were no new gullies observed along the treatment roads, suggesting that differences in the runoff rate on these tilled and potholed road surfaces may lower gully risk, or the triggering storm event was not large enough. It was also observed that most of the gullies on the original untreated roads were related to seeps and springs in the cutslopes, suggesting that the gully initiation index based on road length and hillslope slope may not be the best measure here. The seeps and spring features were still present on the treated roads.

Before treatment, inventoried road segments had problems at 32% of 129 inventoried drainage points. Fill erosion greater than 5 ft^3 was observed at 2% of drainage points. Post-treatment monitoring indicated that these problems were almost entirely eliminated by the decommissioning treatment, with only 1% of 111 drain points having problems. However, post-storm event monitoring indicated that 7% of 111 drain points had problems, and 22%, mostly stream crossings, had fill erosion.

Taken collectively, monitoring results indicate that the decommissioning treatments were effective in reducing some hydrogeomorphic impacts and risks to aquatic ecosystems. Increases in risks and other negative impacts can partially be attributed to failure to fully follow design criteria at some sites during implementation. Although risk was significantly reduced at stream crossings by removing culverts and fill material, risks of stream crossing fill erosion were still high, though this is expected to decrease over time as stream crossings adjust to a more natural state. The estimated mass of sediment eroded from the stream crossings was 8% of that which could be expected from failure of all of the culverts and delivery of the associated fill. This equates to about 340 years-worth of delivered sediment from the pre-treatment road surfaces. Additionally, risk of gullying likely remains, though it may be over-predicted by the model. The fine sediment delivery is expected to become smaller over time, as roads become further vegetated. Control roads did not exhibit any significant changes due to the storm event. In the short term, it is likely that there were more negative impacts from the decommissioning treatment than if the roads had been left intact. Assessment of the tradeoffs between more thorough stream crossing treatments that may result in substantial short-term sediment impacts and the long-term risk of catastrophic untreated stream crossing failure is warranted. GRAIP can be used to address these needs in the design phase of future projects.

Summary of GRAIP road risk predictions for the Bull Run River watershed decommissioning project.

Impact/Risk Type	**Effect of Treatment: Initial GRAIP Prediction**	**Effect of Treatment: Post-Storm Validation**	**Control Roads: Pre-Storm Prediction**	**Control Roads: Effect of Storm**
Road-Stream Hydrologic Connectivity	-16%, -435 m	No change from post-treatment	41%, 2457 m	No change post-storm
Fine Sediment Delivery	+84%, +3.2 tonnes/year	No change from post-treatment	40%, 1.8 tonnes/yr	No change post-storm
Landslide Risk	Overall modeled increase, none observed	No change, no new landslides; risk likely not increased	Slight, none observed	No change post-storm
Gully Risk	Increase in average ESI risk (7.9 vs. 4.4), 11 existing observed	No change, no new gullies; risk likely not increased	Average ESI 2.5, 13 gullies observed	No change post-storm
Stream Crossing Risk				
- plug potential	-100% (eliminated at all sites)	1 site with culvert remaining	Average SBI 2.3, 1 overtopped crossing observed	No change post-storm
- fill at risk	-100% (13,010 yd^3)	1078 yd^3 further erosion (about 1300 tonnes)	4430 yd^3	No change post-storm
-diversion potential	-100% (eliminated at all 36 sites)	no change	No diversion risk	No change post-storm
Drain Point Problems	-97%, (1% vs 32% of drainpoints)	-80% from pre-treatment (7% vs 32% of drain points), 28 yd^3 further fill erosion (about 30 tonnes)	23% with problems, 2% with fill erosion	No change post-storm

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 decommissioning work completed by the Mt. Hood National Forest (MHNF) in the Bull Run 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, 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 2007 and 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 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 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, FY2009, and FY2010, pre-treatment evaluations were completed at 21 sites[1] 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)[2] (Figure 1, Table 1). Eighteen post-treatment inventories and two post-storm validation evaluations were also completed in FY2008, FY2009, and FY2010. Post-

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

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

treatment and, to the degree possible, post-storm evaluations will be completed at the remaining sites in FY2011 and FY2012. In 2009, a similar study was begun in Regions 1, 4, and 5.

Figure 1. Location of monitored sites, FY2008 through 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

Bull Run Basin Sites

During the summer and fall of 2008, field crews inventoried decommissioning sites in the Bull Run watershed (Table 2, Figure 2). This watershed is principally underlain by Columbia River basalts, but much of the lower basalt layer, particularly in the western half of the watershed, is itself overlain by a combination of other volcanic units including tuffs, lavas, and lahars. Many hillslopes in the watershed are susceptible to sediment production from runoff. The average precipitation for the entire basin is on the order of 135 inches per year, ranging from as low as 80 inches per year up to 170 inches on the northern boundary of the watershed. The average elevation of the watershed is 2600 feet, whereas the inventoried sites are located between 1,300 and 3,500 feet above sea level on the western slope of the Cascade mountain range (Portland Water Bureau, 2010).

The 102 square-mile Bull Run watershed is located within the 147 square-mile Bull Run Watershed Management Unit (BRWMU) which is managed jointly by the USDA Forest Service (Mt. Hood National Forest) and the City of Portland (Portland Water Bureau). Ninety-six percent of the Bull Run watershed is federally-owned with four percent owned by the city of Portland. The basin lies 26 miles east of the city of Portland and is the city's primary source of water. The BRWMU is closed to the public and highly secure to protect water quality and critical infrastructure. Numerous species of plants and animals thrive in the watershed including Chinook and coho salmon, steelhead, black bear, northern spotted owl, and many others (Portland Water Bureau, 2010).

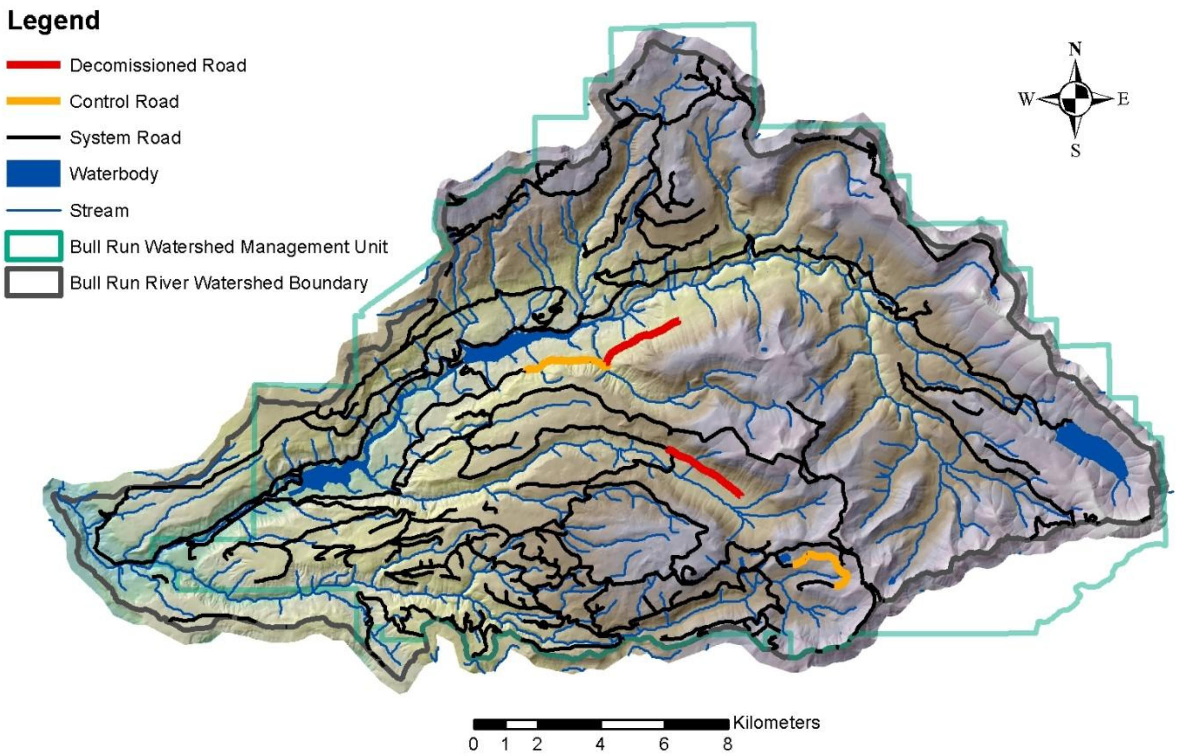

Figure 2. Location of monitored sites in the Bull Run River watershed, Mt. Hood National Forest.

The roads monitored in the Bull Run watershed and analyzed in this report were decommissioned in 2008 (Figure 2). Pre-treatment roads had an inboard ditch. National Forest System Road (NFSR) 1210428 was crowned and surfaced with gravel whereas NFSR 1211000 was paved. Both pre-treatment roads were constructed with periodic drainage features including ditch relief culverts. Both treatment and control sites were typically located on a mid-slope hillslope position and included very frequent live stream crossings. The watershed topography varies, so stream crossing fills, cutslopes and fillslopes range from being small to large. The roads monitored for this study were situated on moderately steep hillslopes or bench-type areas. Aside from the typical concentration of surface water occurring within the prism of these roads, sub-surface groundwater was often intercepted by the treatment roads. This shallow, sub-surface flow appeared to change the hydrology of the roads substantially in some cases. Control roads were largely outside these zones.

Decommissioning treatments included removal of culverts and fills at stream crossings, replacement of culverts with armored waterbars or broad-based dips, and construction of new waterbars and dips. NFSR 121100, which was originally surfaced with asphalt, was tilled and partially recontoured in certain areas. NFSR 1210428 was potholed—meaning the surface was tilled up in an alternating checkerboard pattern—in order to expose soil to increase infiltration capacity and allow for revegetation of the obliterated surface. On both roads, unstable material was pulled back at stream crossings. Placement of cleared vegetative material, revegetation, seed, and/or mulching took place on certain disturbed areas.

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

DECOMMISSIONED ROAD		**CONTROL ROAD**	
Road #	**Treatment**	**Road #**	**Treatment**
1211000 (upper)	Tilling, local partial-recontouring, stream crossing excavation, drainage improvement (removal of culverts and installation of frequent waterbars) , placement of vegetative material on disturbed areas, revegetation of select sites	1211000 (lower)	None
1210428	Potholing, stream crossing excavation, drainage improvement (removal of culverts and installation of frequent waterbars) , placement of vegetative material on disturbed areas, revegetation of select sites	1200222	None

Storm Event in Bull Run Basin

On November 12-13, 2008, the Bull Run Basin experienced a significant rainfall event of between five and seven inches over the basin. Six-hour precipitation totals at the North Fork SNOTEL site ending at 8:00 pm on November 12 exceeded the 100 year six-hour RI amounts from the NOAA Atlas, and five- to 25-year RI stream flows were recorded within the basin (T. Parker, personal communication 2008). Crews re-surveyed the study sites on December 1-3, 2008 and August 18, 2009. Observations made along the treatment roads show that most changes due to the storms occurred at excavated stream crossings. There were no changes observed along control roads. Control roads may have experienced a lesser rainfall intensity during these storms (T. Parker, personal communication, 2011).

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 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 Bull Run, the decommissioning treatments increased the total number of drain points other than diffuse drain points (which represent linear road features with no concentrated flow or definitive point of discharge from the road prism), and redistributed water back onto the hillslope. This reduced the length of road surface connected to the channel. Prior to the treatments, 2,729 m out of the 5,565 m of inventoried road (49%) were hydrologically connected to a stream. After the treatments, 2,294 m of the 5,546 m of monitored road (41%) were connected. Thus, the treatments resulted in a net reduction of 435 m of hydrologically-connected road, which is 16% less than the pre-treatment condition.

There were no observed changes to road-stream hydrologic connectivity due to the storm event, because there were no new drain points or changes in the routing of road surface water since the completion of treatment.

On the control roads, 2,457 m out of 5,705 m of inventoried road (43%) were connected to the channel. There were no observed changes post-storm event.

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 (m/m) of the road segment
V is the vegetation cover factor for the flow path
R is the road surfacing factor

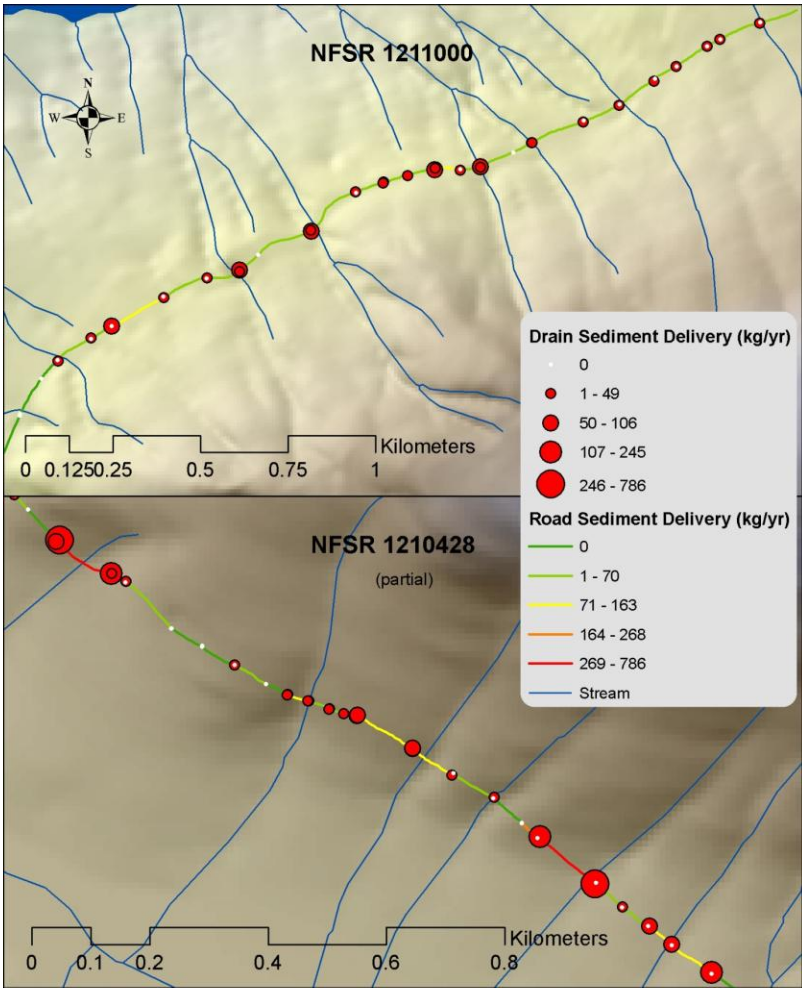

Figure 3. Fine sediment delivery to channels by road segment and drain point, pre-treatment roads. The road line is colored to indicate the mass of fine sediment that is generated on the road and delivered to the channel (kg/yr). The size of the circle indicates the accumulated mass of sediment delivered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

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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.

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 1211000 and 1210428 roads in the pre-treatment condition (Figure 3).

Pre-treatment

Delivery of fine sediment occurs through a mix of road drainage features including ditch relief culverts and stream crossings. 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. 129 drain points were documented, 50% of which were hydrologically connected to stream channels. There were 68 non-diffuse drain points (diffuse drain points represent a linear length of usually outsloped road that does not concentrate water or discharge it at a single discrete point), 75% of which were stream connected. These points deliver 3.8 tonnes of sediment per year, or 56% 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/yr)	Σ Sediment Delivery (kg/yr)	% Sediment Delivery	% Length Connected
Broad Based Dip	0	-	-	-	-
Diffuse Drain	61	3,440	910	27%	26%
Ditch Relief Culvert	19	520	120	23%	30%
Lead Off Ditch	0	-	-	-	-
Non-Engineered	0	-	-	-	-
Stream Crossing	45	2,820	2,820	100%	100%
Sump	4	100	0	0%	0%
Waterbar	0	-	-	-	-
All Drains	**129**	**6,880**	**3,850**	**56%**	**49%**

Post-treatment

Compact gravel and paved road surfaces were tilled and decompacted, which had the effect of increasing sediment production to 12.1 tonnes/year, due to the increased availability of loose sediment (Table 4). However, due to the hummocky nature of the treated surface, it is unlikely that most of this available sediment will make it off of the road. Additionally, as the treated surfaces settle and become more vegetated over time, the amount of available loose sediment is expected to decrease significantly. Post-treatment, most sediment delivery occurs through stream crossings. The removal of all culverts and installation of frequent water bars decreased the total number of drain points to 111, 44% of which deliver sediment to streams.

However, the number of non-diffuse drain points increased from 68 to 88, 52% of which deliver. Due to the increase in sediment production, sediment delivery to streams also increased to 7.1 tonnes/year, which is 59% of sediment generated on the road.

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

Drain Type	Count	Σ Sediment Production (kg/yr)	Σ Sediment Delivery (kg/yr)	% Sediment Delivery	% Length Connected
Broad Based Dip	2	0	0	0%	0%
Diffuse Drain	23	1,430	140	9%	16%
Ditch Relief Culvert	0	-	-	-	-
Lead Off Ditch	1	10	10	100%	100%
Non-Engineered	0	-	-	-	-
Stream Crossing	36	6,520	6,520	100%	100%
Sump	7	1,230	0	0%	0%
Waterbar	42	2,910	420	14%	22%
All Drains	**111**	**12,100**	**7,090**	**59%**	**41%**

The modeled change in sediment production was an increase of 5.2 tonnes/year (76%). Sediment delivery following the treatments shows an increase of 3.2 tonnes/year, which is an increase of 84% (Table 5). Reductions occurred at ditch relief culverts, through the removal of all of the features, and diffuse drains. Diffuse drains on the treated road were in different locations than on the pre-treatment road, because of the disturbance of the road surface. Increases occurred at waterbars, through the installation of new features near to streams, and stream crossings, through the increase sediment production on contributing road segments.

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

Drain Type	Count	Δ Sediment Production (kg/yr)	Δ Sediment Delivery (kg/yr)	Δ Sediment Production (%)	Δ Sediment Delivery (%)	Δ Length Connected (%)
Broad Based Dip	2	0	0	0%	0%	0%
Diffuse Drain	-38	-2,010	-780	-58%	-85%	-83%
Ditch Relief Culvert	-19	-520	-120	-100%	-100%	-100%
Lead Off Ditch	1	10	10	+inf%	+inf%	+inf%
Non-Engineered	0	-	-	-	-	-
Stream Crossing	-9	3,700	3,700	131%	131%	-12%
Sump	3	1,130	0	1,091%	0%	0%
Waterbar	42	2,910	420	+inf%	+inf%	+inf%
All Drains	**-18**	**5,230**	**3,240**	**76%**	**84%**	**-16%**

There were no observed changes to sediment production or delivery due to the storm event, because there were no new drain points since the completion of treatment, no changes in the routing of road surface water, and no changes in surface type or vegetation cover.

Similar to the pre-treatment condition on the treatment roads, the control roads were about half paved and half crushed rock. Sediment production on the control roads was 4.5 tonnes/year (Table 6). Of this, 1.8 tonnes/year (40%) was delivered to the channel. There were 123 drain points observed, 80 of which were non-diffuse points. There were no observed changes to sediment production or delivery on the control roads post-storm event.

Table 6. *Summary of sediment production and delivery at drain points, control road.*

Drain Type	Count	∑ Sediment Production (kg/yr)	∑ Sediment Delivery (kg/yr)	% Sediment Delivery	% Length Connected
Diffuse Drain	43	2970	690	23%	14%
Ditch Relief Culvert	18	340	50	15%	26%
Non-Engineered	2	100	0	0%	0%
Stream Crossing	29	890	890	100%	100%
Waterbar	31	210	180	84%	78%
All Drains	**123**	**4510**	**1800**	**40%**	**43%**

5.3 Landslide Risk

Inherent landslide risk in the Bull Run watershed is low, with 2% of the area of the watershed at high risk (Schulz, 1980). There were no landslides observed from the roads by field crews. This may suggest that mass wasting and hillslope scale failures in this roaded environment are more prone to present as gullies (which were observed; see section 5.4). This is consistent with the observation that there were many springs and seeps in the cutslopes of the treated roads, which intercepted shallow groundwater, and routed it through the ditch in some cases, causing perennial flow to the hillslope below. Similar behavior was observed in the central Oregon Cascades by Wemple and Jones (2003).

The risk of shallow landslide initiation is predicted using SINMAP 2.0 (Pack et al., 2008, http://hydrology.neng.usu.edu/sinmap2/), modified to account for contributions of road runoff. SINMAP has its basis in the infinite plane slope stability model and produces raster grids that illustrate slope stability based on hillslope and specific catchment area at each DEM grid cell. 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.

Data necessary to calibrate SINMAP were not available; therefore this analysis uses SINMAP's default values and likely over-predicts unstable areas. Additionally, mass-wasting distribution in the Bull Run River drainage is highly variable and depending on the local geology, which contributes more or less groundwater to the road. A given catchment area in this watershed may contain more or less water, depending on the geologically dependant availability of groundwater.

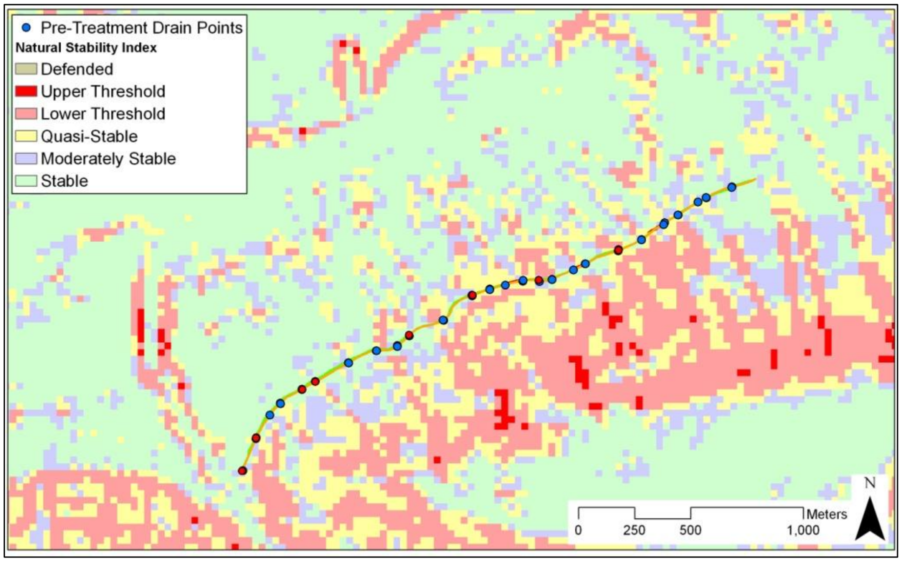

Figure 4. Natural slope stability risk in the area of NFSR 1211000. The yellow, blue, and green cells are generally predicted to be stable, while the pink, red, and tan cells are generally predicted to be unstable.

Figures 4 and 5 illustrate the risk and change in risk in the area. SINMAP was run initially to determine the intrinsic stability of the slopes over which the road traverses and to identify locations that are at high risk of failure without the road. The modeled inherent landslide risk is generally moderate in the area of the treated roads (Figure 4). This is contrary to the low risk that was observed during this inventory and by forest personnel, as well as described by Shulz (1980) and confirmed during the 1995/1996 large storm events (T. Parker, personal communication, 2008). A second stability index run was performed to address the effects of road water contribution to drain points on the original, pre-treatment road network. A third model run was performed to illustrate the risk of shallow landsliding with the modified road drainage system resulting from the restoration treatments.

In Figure 5, the areas along NFSR 1211000 where the treatment increased modeled risk (red and orange cells) or decreased risk (green and blue cells) is shown. Increased risk is due to the addition of new drainage (e.g. waterbars) or more water at existing drain points over steep slopes. The areas where risk was decreased are due to the removal of water from those features, usually due to the removal of that drain point (such as a ditch relief culvert). Cross-hatch areas are places where the terrain was modeled as unstable without road drainage. These areas cannot be made to be stable by road treatments.

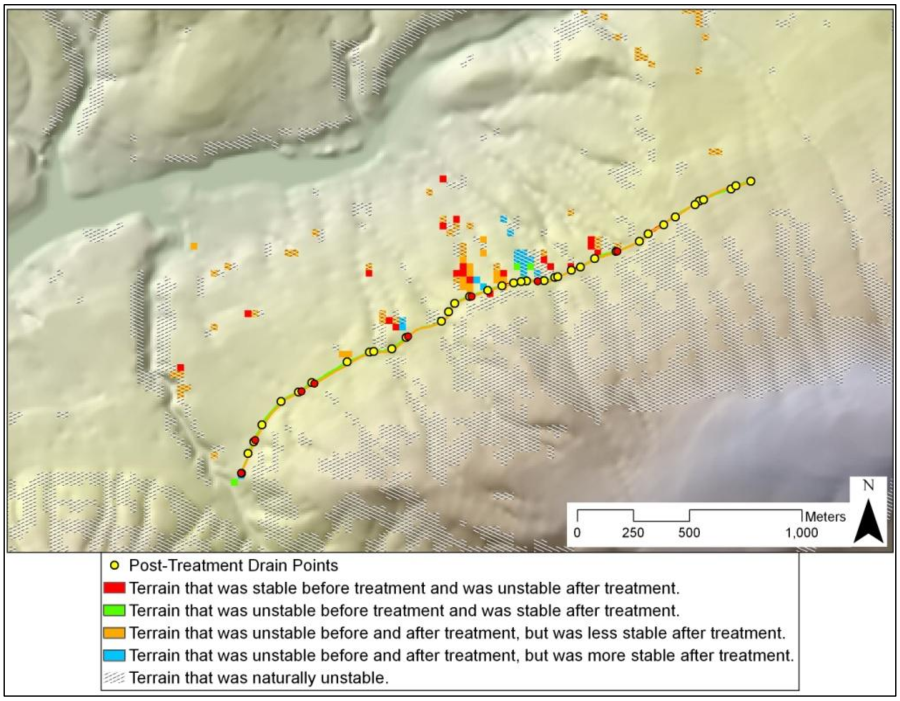

Figure 5. The changes in slope stability due to treatment. Red and orange cells far downslope of the road are model artifacts, and are unlikely to be real risk increases.

The net effect of the decommissioning treatments, which replaced old drainage features and added new features, achieved the goal of reducing risk at only a few of the modeled high risk locations in the sample area. However, modeled 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.

There were no new landslides observed on the treatment roads after the storm event, suggesting that the uncalibrated SINMAP analysis may have overestimated the increase in stability risks. This further suggests that these road surfaces treated in this manner (tilling and potholing) may deliver runoff at a reduced rate than the compact pre-treatment road. Additionally, the storm event may not have been large and/or intense enough to trigger landslides along high-risk areas. Landslide risk appears to be low before and after the treatment and before and after the storm event.

The control roads did not have any observed landslides either before or after the storm-event. Modeled risk increases due to the presence of the roads were very low. This suggests little risk of landsliding due to the control roads.

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

When calibration data for a watershed site fits the expected pattern of longer contributing length and higher hillslope at a drain point resulting in more frequent gullies, ESI is calculated for each drain point and compared to a critical ESI threshold to identify areas with a high risk of gully formation The critical threshold is empirically-derived for each study area using inventoried gullies. However, at this site, the inventoried gullies did not fit the expected pattern, which means that contributing road length and hillslope at drain points are not the primary drivers of gully formation. As such, a reasonable threshold cannot be determined for these roads.

The pattern exhibited by the observed gullies weighted their distribution to shorter contributing road length and lower hillslope below the drain point. Sub-surface flow interception was prevalent at the sites where springs and seeps were discharging abundantly from the cutslopes. This phenomenon was often the source of additional flow in the ditch, which, when discharged through a culvert, would create a gully with nearly year-round flow. Hence, gullies observed at these sites were not always solely a result of storm water runoff captured by and concentrated within the road prism. Rather, they were likely created, at least in part, by shallow groundwater intercepted by the cutslope of the road. The locations of these shallow groundwater interception areas were not recorded in detail during the survey.

The average pre-treatment ESI was 4.4, with an average contributing road length of 45 m. Eleven gullies were observed below drain points with a total estimated volume of 263 yd^3. Post-treatment ESI values had a mean of 7.9, due to increased contributing length of 71 m. This is an increase in average ESI risk of 3.5 (79%). No changes to the location or condition of seeps and springs along the treatment roads were observed, which suggests that gully risk may not have changed.

There were no new gullies observed on the treatment roads after the storm event, even though the average post-treatment ESI was higher than the average pre-treatment ESI, suggesting that the treated roads may not deliver runoff at the same rate as the pre-existing roads, which were gravel-surfaced and compacted or paved. The increase in ESI risk may not be significant, though this is difficult to quantify without a valid threshold. This supports the conclusion that the ESI model does not apply well to this area. Additionally, the storm event may have been too small or not intense enough to trigger new gully formation. There were no changes to the ESI due to the storm event, because the road surface water routing and contributing length at drain points did not change.

Control roads had an average ESI of 1.4. Thirteen gullies were observed, with a total estimated volume of 218 yd^3. Similar to the treatment roads, no good critical threshold can be applied. There were no observed changes to number or size of gullies on control roads post-storm event.

5.5 Stream Crossing Failure Risk

Besides contributing fine sediment to streams through road 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 to high with an average value of 2.5 for the 45 stream crossings (Figure 6). This is out of a range of 1 to 4, where 1 suggests no risk of blockage. Of the 21 stream crossings with SBI values of 3 and 4, all had culvert to channel width ratios of 0.7 or less. The angle at which the stream enters the pipe was greater than 75 degrees on 10 of them, generally due to an intermittent or ephemeral channel running down the cutslope and ditch slightly up-road from the pipe. All 45 stream crossing pipes were removed during decommissioning, which completely eliminated the risk of pipe plugging (Figure 7). Thus the post-treatment SBI score was zero at all crossings.

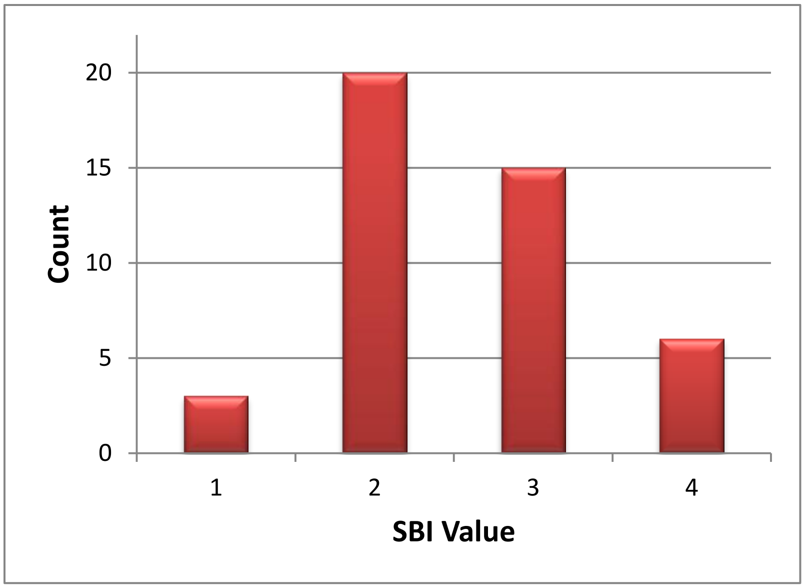

Figure 6. Distribution of Stream Blocking Index values for pre-treatment group.

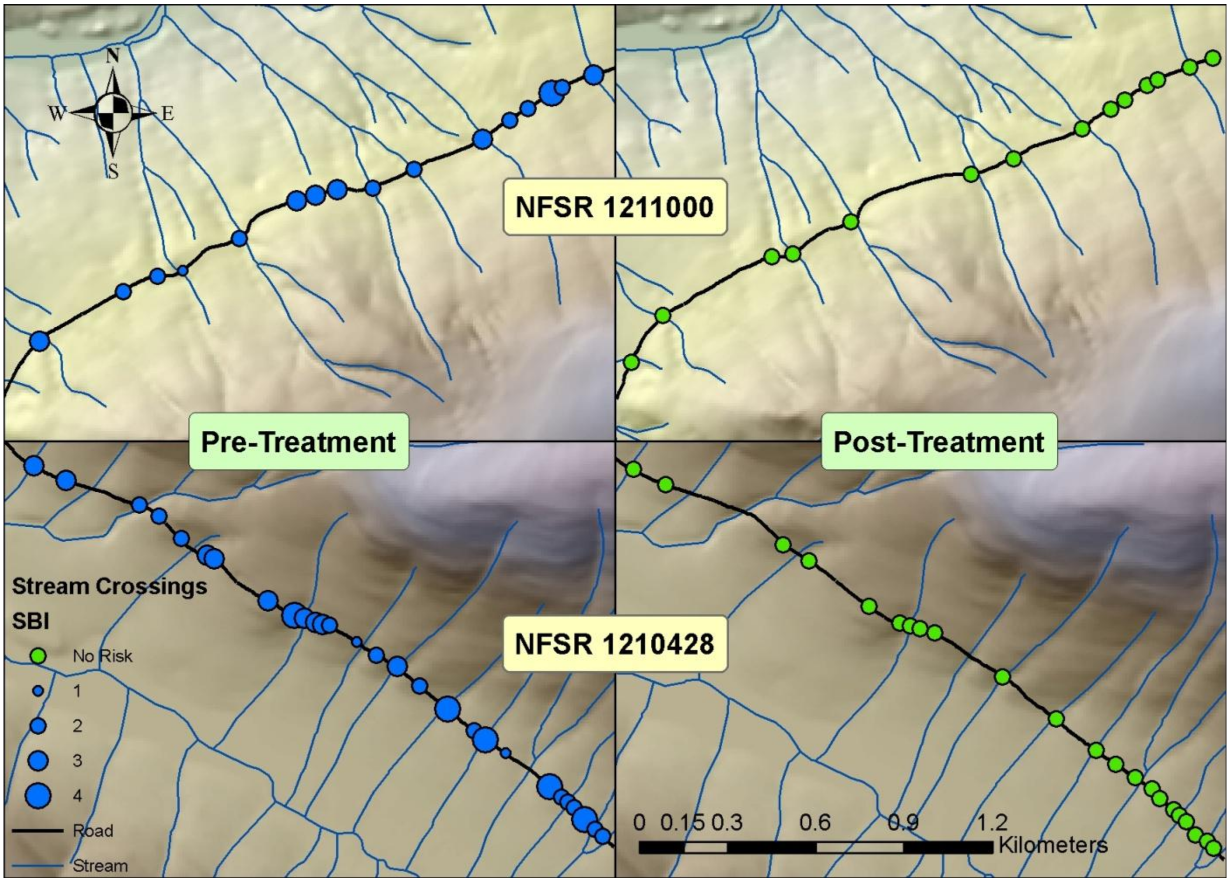

Figure 7. SBI values of stream crossings.

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 on pre-treatment roads. 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 13,010 yd^3. Most of this material was excavated during the restoration work.

A second, and perhaps greater, consequence of concern at failed stream crossings is the diversion of stream flow onto road surfaces and unchanneled hillslopes. Once a crossing becomes occluded and begins to act as a dam, failure can occur in several ways. If the road grade dips into and rises out of the crossing, the failure is likely to be limited to a localized overtopping of the stream crossing. However, if the road grades away from the stream crossing in one or more directions, the flow may be diverted down the road and ditch and onto adjacent hillslopes, where it can cause gullying and/or landsliding (Furniss et al. 1998, Best et al. 1995). In these situations, volumes of sediment far exceeding those at the crossing can be at risk.

GRAIP addresses this issue by classifying the potential for stream crossings to divert streamflow down the adjacent road as: no potential, potential to divert in one direction, or potential to divert in two directions. At this site, 100% of the stream crossings on the original roads had the potential to divert streamflow down the road in one direction. The restoration treatments eliminated this risk entirely by re-establishing the channel across the former road bed and pulling back fill material to create high side slopes on either side of the channel.

At 21 of 36 (58%) observed post-treatment stream crossings, high flows due to the storm-event resulted in the crossings becoming scoured and eroding large amounts of sediment from the channel bottoms (Figures 8-10). This sometimes led to failures along the side slopes, which were undercut. Further side slope failures can be expected due to this undercutting. A tape was used to estimate the volume of sediment eroded from the stream crossings to the nearest cubic yard. 956 yd^3 of sediment was eroded from the channel bottoms, and 122 yd^3 was eroded from the side slopes in this manner, for a total of 1,078 yd^3 and an average of 30 yd^3 per crossing (Table 7). This is consistent with Cook and Dresser (2010), who found an average of 28 yd^3 of erosion in similar environments. This volume is 8% of the fill volume that could be expected to eventually fail, had the crossings remained intact and untreated (13,010 yd^3, above). The mass of the eroded sediment was about 1,300 tonnes (calculated using a bulk density of the fill of 1.6 tonnes/m^3; Madej, 2001).

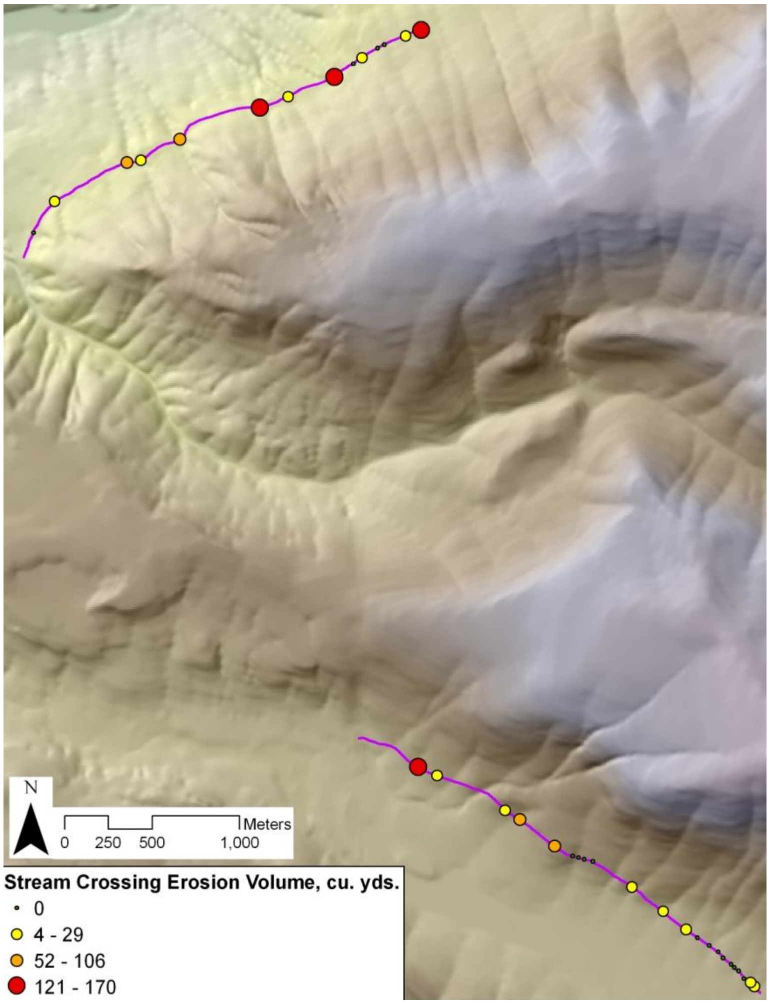

Figure 8. Locations and quantities of stream crossing channel erosion along both decommissioned roads.

Table 7. *Type and amount of stream crossing erosion by road number and mile post.*

Road Number	Mile Post	Erosion Type	Erosion Volume (yds^3)
1210-428	0.25	Channel	158
	0.32	Channel	4
	0.60	Channel	29
	0.67	Channel	58
	0.81	Channel	52
	0.88	None	0
	0.91	None	0
	0.93	None	0
	0.96	None	0
	1.13	Channel	23
	1.27	Channel	26
	1.37	Channel	12
	1.42	None	0
	1.47	None	0
	1.51	None	0
	1.54	None	0
	1.57	None	0
	1.59	None	0
	1.61	None	0
	1.64	None	0
	1.67	Channel	4
	1.69	Channel	8

Road Number	Mile Post	Erosion Type	Erosion Volume (yds^3)
1211	0.09	None	0
	0.22	Channel	9
	0.52	Channel, Side	106
	0.57	Channel	15
	0.73	Channel, Side	82
	1.05	Channel	121
	1.15	Channel	14
	1.34	Channel	149
	1.44	None	0
	1.48	Channel	16
	1.54	None	0
	1.57	None	0
	1.65	Channel	19
	1.71	Channel	170

Figure 9. Excavated stream crossing on NFSR 1210428. Condition before the storm (top), with some scour already present; view from same location after the storm (middle); and view in the channel after the storm (bottom). 178 yd^3 of sediment was eroded from this crossing during the storm. This crossing was located on an unstable stream channel that runs through an historic landslide (T. Parker, personal communication, 2011)

Figure 10. Excavated stream crossing on NFSR 1211000. Condition before storm (top) and after storm (bottom). 121 yd^3 of sediment was eroded from this crossing by the storm.

During the field survey, it was visually observed that failures of this nature most commonly occurred at crossings with channel bottoms that were too narrow relative to the stream width and had a longitudinal slope that was shallower than the natural channel. Erosion depth was typically limited to the level of the buried natural soil surface and crossing sediment sizes became coarser after the storm, as finer sediments were washed away. Project design criteria generally called for crossing channel widths to be 1.1 bank full stream widths, for side slopes to not exceed 50% slope, and for longitudinal crossing slopes to match the natural contours of the uphill stream. These criteria were not met in some places, which may have led to increased crossing erosion. For example, ten crossings had at least one side slope in excess of 50% slope. This suggests that had design criteria been met during the implementation phase, many of these problems may not have occurred.

At one stream crossing, a previously unnoticed buried pipe was located after the treatment was complete. The pipe opening became scoured out and was routing water through it, allowing for possible further fill failure. A spider-type excavator was brought in to pinch the uphill end of the culvert closed and re-bury the opening, so that it would no longer be able to divert water from the intended excavated channel bottom (Figure 12). This reduced or eliminated the risk of further failure due to the culvert. Additionally, the crossing was slightly re-shaped to reduce the risk of side slope failure. This illustrates the importance and difficulty of finding and removing old and potentially buried culverts.

Figure 11. Excavated crossing on NFSR 1211000 that had a second buried pipe. The spider excavator dug down to the pipe opening (top), and exposed the inlet (bottom, with arrow) before it was pinched closed and re-buried.

At another stream crossing on NFSR 1210428, a buried pipe was scoured out and was flowing water at the time of the post-storm event survey (Figure 11). There were no plans to treat this pipe as above (this crossing is about 1 km from the start of the road, as opposed to 300 m for the above crossing).

Figure 12. Second pipe that was left in after the crossing excavation and was flowing water at the time of the survey.

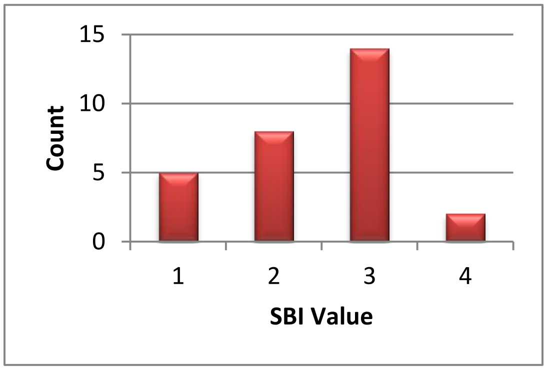

Figure 14. Distribution of Stream Blocking Index values for control group.

Control roads had an average SBI of 2.3 (Figure 14), and none of the 29 observed crossings had diversion potential. There was 4430 yd^3 of fill at risk. One crossing on road 1200-222 was observed to have plugged and overtopped before the storm-event (Figure 13). This crossing had an SBI of 3. There were no changes to the stream crossings due to the storm event.

Figure 13. Stream diversion of the Little Sandy River on the 1200-222 control road. This was present during the pre-storm survey.

After another 25 year recurrence interval stream flow event in 2011 and 2012, further field reconnaissance was conducted by forest personnel. Though the side slopes of the stream crossings were still eroding to a stable angle, there was limited additional erosion observed overall (Figure 15). Stream crossing erosion may represent a one-time impact in this case, as the channels adjust to a stable slope and width.

Figure 15. Stream crossing in road 1211 in 2008 after the initial 25 year recurrence interval storm (top) and in 2012 after the more recent 25 year recurrence interval storms (bottom). There may be some side slope erosion, but no new major erosion was observed.

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 or in the ditch, or when they saturate the fill material. 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, or when they divert stream flow. Lead off ditches are considered problematic if they are dysfunctional, are gullied, or have excess deposition. Non-engineered features are almost always a problem due to a blocked ditch, a gully, a diverted wheel track, or a broken outside berm. Stream crossings are considered a problem if they are blocked by sediment or wood, crushed or rusted significantly, incising, scouring, or losing much water from flow around the pipe, or when they have a high SBI and diversion potential. Sumps are a problem if they pond water on the road surface or cause fill saturation. Water bars 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. Excavated stream crossings are considered to be in poor condition if their fill pile blocks down-road flow, if secondary culverts remain in the crossing, if the stream flows under the fill, or if there is a landslide in the side slope. Fill erosion is defined as at least 5 ft^3.

Figure 16. Pool behind a fill pile from a stream excavation on NFSR 1210428 that was placed on the uphill side of the crossing, preventing the water running down the ditch from draining.

At this site, stream crossings and sumps were observed to have the highest rate of problems (53% and 75%, respectively) during the pre-treatment survey, while diffusely drained roads were least likely to have problems (Table 8). The sumps recorded during the surveys were not engineered, but occurred where standing water could not exit the road prism as a result of a blocked ditch. Following the decommissioning treatments, one ditch flowed under the spoils pile from the excavation fill, and no other problems were observed. However, at that point there had been little time for such problems to develop as a result of storms.

The post-storm monitoring revealed problems that were the result of poorly placed stream crossing excavation debris and fill, which became saturated in some places where it was placed on the uphill side of the crossing (6 of 36 crossing sites), which caused water to pool behind the fill pile and saturate (Figure 16). In one location, the fill pile was placed over top of a natural spring, which resulted in the fill becoming saturated and failing as small gullies and landslides into the crossing (Figure 17).

Figure 17. Spring that emits from a fill pile on NFSR 1211000. Upper part of pile (left), and channel from pile into the stream crossing (right).

Additionally, there were three new waterbars that were observed to have fill erosion at their outlets post-storm. The total volume of this new fill erosion was 750 ft^3 (28 yd^3). The mass of the new fill erosion was about 30 tonnes (calculated using a bulk density of the fill of 1.6 tonnes/m^3; Madej, 2001).

Table 8. *Drain point condition problems and fill erosion below drain points, pre- and post-treatment and post-storm event.*

	PRE-TREATMENT			**POST- TREATMENT**			**POST-STORM EVENT**		
Drain Type	Count	Problems	Fill Erosion	Count	Problems	Fill Erosion	Count	Problems	Fill Erosion
Broad Based Dip	0	-	-	2	0%	0%	2	0%	0%
Diffuse Drain	61	0%	0%	23	0%	0%	23	0%	0%
Ditch Relief	19	53%	5%	0	-	-	0	-	-
Lead Off	0	-	-	1	0%	0%	1	0%	0%
Non-Engineered	0	-	-	0	-	-	0	-	-
Stream Crossing	45	2%	0%	36	3%	0%	36	28%	58%
Sump	4	75%	0%	7	0%	0%	7	0%	0%
Waterbar	0	-	-	42	0%	0%	42	0%	7%
Total	**129**	**32%**	**2%**	**111**	**1%**	**0%**	**111**	**7%**	**22%**

Control roads had problems at 23% of all recorded drain points (Table 9), largely at ditch relief culverts (rust through and occlusion) and stream crossings (blockage and high SBI). Fill erosion was observed at 2% of drain points. There was no change to these conditions observed after the storm event.

Table 9. *Drain point condition problems and fill erosion below drain points, control roads.*

	CONTROL, PRE- AND POST-STORM EVENT		
Drain Type	Count	Problems	Fill Erosion
Diffuse Drain	43	0%	0%
Ditch Relief	18	33%	0%
Non-Engineered	2	100%	50%
Stream Crossing	29	69%	7%
Waterbar	31	0%	0%
Total	**123**	**23%**	**2%**

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 Mt. Hood 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 waterbars or broad-based dips, construction of new waterbars and dips, tilling and potholing of road surfaces, placement of vegetative material on disturbed areas, and revegetation of select sites.

Soon after the treatments for this site were completed in the fall of 2008, a significant rainfall event occurred over the Bull Run basin, causing damage on the treated roads at excavated stream crossings. Control roads do not show any change post-storm event.

The GRAIP model was used to predict the change in level of impact/risk between the pre-existing road and the decommissioned road (Table 10). The restoration treatments reduced the length of the sampled road that was hydrologically connected to streams by 435 m, or 16% from pre-treatment conditions. The model predicts that fine sediment delivery was increased by 84%, from 3.8 tonnes to 7.1 tonnes annually. These metrics appear to remain accurate following the post-storm event evaluation.

The risks presented by stream crossings becoming plugged by debris and sediment were eliminated by the excavation and removal of the culverts and fills at all but one site, where a secondary culvert remained buried in the crossing after treatment. The treatments will prevent 13,010 yd^3 of earthen material from eroding into the channel when the stream crossings would have ultimately become plugged or fail from rusting. However, the high stream flows during the storm event resulted in an additional 1,080 yd^3 of fill erosion in the channel bottoms and side slopes of the stream crossings. The potential for streamflow to be diverted onto roads and unchanneled hillslopes was eliminated at 100% of crossings.

The modeled slope stability risk below drain point locations on the original road was increased as water was redistributed across the hillslope to new waterbars. It is unclear, however, if landslide risk was increased across the entire treated road length because the treatments decreased risk in some areas where concentrated drainage features were removed above steep slopes. Additionally, there were no landslides observed during the survey, suggesting that the model does not fit this area, or the storm event was not large enough to trigger landslides.

Gully risk, as determined by a gully initiation index (ESI), indicated an increase in risk across the treatment sites, from an average ESI of 4.4 before treatment, to an average of 7.9 after treatment (an increase of 79%). Most of this increase can be attributed to longer contributing road lengths at drain points. Post-storm event, there were no new gullies observed along the treatment roads, suggesting that differences in the runoff rate on these tilled and potholed road surfaces may lower gully risk, or the triggering storm event was not large enough. It was also observed that most of the gullies on the original untreated roads were related to seeps and springs in the cutslopes, suggesting that the gully initiation index based on road length and hillslope slope may not be the best measure here. The seeps and spring features were still present on the treated roads.

Before treatment, inventoried road segments had problems at 32% of 129 inventoried drainage points. Fill erosion greater than 5 ft^3 was observed at 2% of drainage points. Post-treatment monitoring indicated that these problems were almost entirely eliminated by the decommissioning treatment, with only 1% of 111 drain points having problems. However, post-storm event monitoring indicated that 7% of 111 drain points had problems, and 22%, mostly stream crossings, had fill erosion.

Table 10. *Summary of GRAIP road risk predictions for the Bull Run River watershed decommissioning project.*

Impact/Risk Type	Effect of Treatment: Initial GRAIP Prediction	Effect of Treatment: Post-Storm Validation	Control Roads: Pre-Storm Prediction	Control Roads: Effect of Storm
Road-Stream Hydrologic Connectivity	-16%, -435 m	No change from post-treatment	41%, 2457 m	No change post-storm
Fine Sediment Delivery	+84%, +3.2 tonnes/year	No change from post-treatment	40%, 1.8 tonnes/yr	No change post-storm
Landslide Risk	Overall modeled increase, none observed	No change, no new landslides; risk likely not increased	Slight, none observed	No change post-storm
Gully Risk	Increase in average ESI risk (7.9 vs. 4.4), 11 existing observed	No change, no new gullies; risk likely not increased	Average ESI 2.5, 13 gullies observed	No change post-storm
Stream Crossing Risk				
- plug potential	-100% (eliminated at all sites)	1 site with culvert remaining	Average SBI 2.3, 1 overtopped crossing observed	No change post-storm
- fill at risk	-100% (13,010 yd^3)	1078 yd^3 further erosion (about 1300 tonnes)	4430 yd^3	No change post-storm
-diversion potential	-100% (eliminated at all 36 sites)	no change	No diversion risk	No change post-storm
Drain Point Problems	-97%, (1% vs 32% of drainpoints)	-80% from pre-treatment (7% vs 32% of drain points), 28 yd^3 further fill erosion (about 30 tonnes)	23% with problems, 2% with fill erosion	No change post-storm

As a whole, these results indicate that the decommissioning work in the Bull Run River watershed should be effective in reducing some of the hydrogeomorphic impacts and risks that these roads posed to aquatic ecosystems. Increases in risks and other negative impacts can partially be attributed to failure to follow design criteria. Risk was reduced at stream crossings significantly by removing culverts and fill material. However, the post-storm event assessment indicated that risk of stream crossing fill erosion was still high, though this is expected to decrease over time as stream crossings adjust to a more natural state. The estimated mass of sediment eroded from the stream crossings was 8% of that which could be expected to eventually fail had the crossings not been removed, however it was still 340 years-worth of delivered sediment from the pre-treatment road surfaces. Additionally, risk of gullying likely remains, though it may be over-predicted by the model. Increases in fine sediment delivery risks are expected to become smaller over time, as road surfaces adjust and become vegetated. Control roads did not exhibit any changes due to the storm event. In the short term, it is likely that there were more negative impacts from the decommissioning treatment than if the roads had been left intact. Assessment of the tradeoffs between more thorough stream crossing treatments that may result in substantial short-term sediment impacts and the long-term risk of catastrophic untreated stream crossing failure is warranted.

Further field reconnaissance was conducted by forest personnel in 2011 and 2012 after another 25 year recurrence interval stream flow event. Though the side slopes of the stream crossings were still eroding to a stable angle, there was limited additional erosion observed overall. Stream crossing erosion may represent a one-time impact in this case, as the channels adjust to their natural slope and width.

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.

References

Best, D. W., Kelsey, H. M., Hagans, D.K. and M. Alpert. 1995. Role of fluvial hillslope erosion and road construction in the sediment budget of Garret Creek, Humboldt County, California. In Geomorphic Process and Aquatic Habitat in the Redwood Creek Basin, Northwestern California. Nolan, K. M., Kelsey, H. M., and Marron, D. C. editors. USGS professional paper #1454. pp m1-m9.

Black, T. A., Cissel, R. and Luce, C. H. 2009. The Geomorphic Road Analysis and Inventory Package (GRAIP) Data Collection Method. USDA Forest Service Rocky Mountain Research Station, Boise Aquatic Science Lab.

Cook, C., and Dresser, A. 2010. Erosion and Channel Adjustments Following Forest Road Decommissioning, Six Rivers National Forest. In M Furniss, C Clifton, and K Ronnenberg, eds., 2007. Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004, PNW-GTR-689, Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Flanagan, S. A., Furniss, M. J., Theisen, S., Love, M., Moore, K., and J. Ory. 1998. Methods for Inventory and Environmental Risk Assessment of Road Drainage Crossings. USDA Forest Service Technology and Development Program 9877-1809-SDTDC 45pp.

Furniss, M. J., Love, M., and S. A. Flanagan. 1997 Diversion Potential at Road Stream Crossings. USDA Forest Service Technology and Development Program 9777-1814-SDTDC 12pp.

Istanbulluoglu, E., Tarboton, D.G., Pack, R.T., Luce, C.H. 2003. A sediment transport model for incision of gullies on steep topography. Water Resources Research. 39(4): 1103-1117.

Jones, J. A., and G. E. Grant, 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon, Water Resour. Res., 32, 959-974.

Luce, C.H., and T. Black. 1999. Sediment production from forest roads in western Oregon. Water Resources Research. 35(8): 2561-2570.

Madej, Mary A. 2001. Erosion and Sediment Delivery Following Removal of Forest Roads, Earth Surface Landforms and Processes, 26(2) pp.175-190.

Pack, R. T., Tarboton, D.G., Goodwin, C.N. and A. Prasad, 2005. SINMAP 2. A Stability Index Approach to Terrain Stability Hazard Mapping, technical description and users guide for version 2.0, Utah State University.

Portland Water Bureau, 2010. The Bull Run Watershed. Website, accessed online on April, 22 2010 at http://www.portlandonline.com/water/index.cfm?c=29784.

Prasad, A. 2007. A tool to analyze environmental impacts of road on forest watersheds. MS Thesis. Utah State University, USA.

Prasad, A,, Tarboton, D. G., Schreuders, K. A., Luce, C.H., and T.A. Black. 2007. GRAIP1.0 Geomorphic Road Analysis and Inventory Package: A tool to analyze the environmental impact of roads on forested watersheds. Tutorial and Reference Manual. http://WWW.engineering.usu.edu/dtarb/graip.

Schulz, M.G. 1980. The quantification of soil mass movements and their relationship to bedrock geology in the Bull Run Watershed, Multnomah and Clackamas Counties, Oregon. M.S. Thesis, Oregon State University, USA.

Wemple, B. C., Jones, J. A., and Grant, G. E. 1996. Channel network extension by logging roads in two basins, western Cascades, Oregon. Water Resources Bulletin, 32, 1195-1207.

Wemple, B.C., Jones, J. A. 2003. Runoff production on forest roads in steep mountain catchement. Water Resources Research, 39(8).