Wall Creek Watershed
GRAIP Roads Assessment
North Fork John Day Subbasin
Umatilla National Forest

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Nathan Nelson[1], Caty Clifton[2], Tom Black[1], Charlie Luce[3], and Sara McCune[4]

	[1]Hydrologist [3]Research Hydrologist US Forest Service Rocky Mountain Research Station 322 East Front Street, Suite 401 Boise, ID 83702 USA	[2]Forest Hydrologist US Forest Service Umatilla National Forest 2517 S.W. Hailey Ave. Pendleton, OR 97801 USA	[4]Student Whitman College 345 Boyer Ave. Walla Walla, WA 99362, USA	Produced with funding from: EPA United States Environmental Protection Agency U.S. Department of the Interior Bureau of Land Management

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Contents

List of Tables

List of Figures

Executive Summary

BACKGROUND AND OBJECTIVES

This report presents results from a watershed-wide inventory and assessment of roads in the Wall Creek watershed in northeast Oregon using the "Geomorphic Roads Inventory and Analysis Package", or GRAIP, a field-based model developed by the Rocky Mountain Research Station and Utah State University. The primary objectives of the project were to:

- evaluate the types and sources of road-related hydrologic risk in the watershed
- locate and quantify sediment sources and contributions to streams
- identify and prioritize future restoration actions to improve watershed conditions and move towards an ecologically (and economically) sustainable road system.

Field inventory, modeling and analysis were completed on 726 km (450 miles) of Forest Service and BLM roads, approximately 90 percent of federally managed roads in this 518 km^2 (200 mi^2) watershed. A small group of roads decommissioned in the watershed in 2008 were also included in a Pacific Northwest study of treatment effectiveness using GRAIP. Results from this study (forthcoming) will help managers quantify benefits from future treatments and develop options for road management (maintenance and decommissioning priorities).

Roads were identified as a major factor affecting watershed condition in a 1995 watershed analysis. Six streams were listed as impaired for sedimentation (narrative criteria) on the 1994/1996 303(d) list. The basis for listing was stream survey data (embeddedness and red counts) reported in the watershed analysis. Wall Creek watershed was identified in 2002 as a Forest priority and in 2005 as a Regional focus watershed for restoration.

This watershed-scale road assessment was motivated by land management agency commitment to address 303(d) listed streams and support development of Total Maximum Daily Loads (TMDL) in the John Day Basin (lead agency: Oregon Department of Environmental Quality). Funding was provided by grants from the EPA and BLM, and by Forest Service project managers (RMRS and UNF).

Quantifying sediment sources from roads and focusing future treatments on high risk sites will help fulfill agency obligations for meeting water quality objectives. As part of TMDL development, a parallel project to inventory and analyze in-channel conditions for the TMDL was commissioned by DEQ and BLM using the Relative Bed Stability (RBS) method (Kauffman et al, 2008). Results from the GRAIP analysis were compared with RBS data in an effort to link sediment source areas with potential impairment.

Table 1. Watershed "At-a-glance"

Drainage area	518 km^2 (200 mi^2)
Land Ownership	74% Forest Service 10% BLM 16% Private & County
Elevation range	1739 m (5707') at Madison Butte 629 m (2060') at confluence with NFJD River
Major geologic units	Columbia River basalts, Picture Gorge basalts, John Day formation (tuffs), exotic terrains (metamorphic and sedimentary), Mazama ash
Precipitation	23" Annual average from 13" at the confluence, to 30" at Madison Butte Intensity (10-Yr-6 Hour) = 1.2"
Air temperatures	Maximum = 32ºC (90 ºF) July Minimum = -6 ºC (21º F) January
Stream discharge at mouth[1]	Low flow from 0 to 0.14 cms (0-5 cfs) Average ~ 2.2 cms (80 cfs or 0.4 cfsm) 2-YR flood ~ 24 cms (865 cfs or 4.3 cfsm) 50-Yr flood ~ 69 cms (2453 cfs or 12.3 cfsm)
Streams[2]	Total = 1175 km (730 mi) Perennial = 296 km (184 mi) Fish-bearing = 172 km (107 mi) Mid Columbia River steelhead = 154 km (96 mi) 303(d) streams (6) listed for sedimentation = 96.7 km (60.1 mi)
Forest vegetation types	Mixed dry pine plant communities in lower elevations Cool-moist Grand Fir/Douglas-Fir in higher elevations (watershed about 70% forested)
Roads[3]	Total = 1030 km (640 mi)* FS and BLM = 837 km (520 mi) Miles of closed road = 446 km (277 mi) *FS data only* Average road density > 3.2 mi/mi^2

NOTES

1-Wall Creek is ungaged, stream discharge values are approximate. Low flows from observation and measurement, Average stream discharge estimated from unit runoff from nearby gages, flood discharges (2-year and 50-year recurrence) estimated from regional equations (cfsm is unit runoff in cubic feet per square mile).

2 – Miles of stream were determined from Forest stream layer, original from 1:24000 topographic maps, "blue lines" were manually "densified " to add intermittent streams. Mapping was field-verified (1995). Miles represent an approximation of the extent of the active channel network.

3-Total miles of road are estimated due to variable data quality and unmapped roads

SUMMARY OF RESULTS

Road-Stream Hydrologic Connectivity

A total of 199 km (123 mi) of 726 km (451 mi) of inventoried road in the Wall Creek study area (27%) are hydrologically connected to a stream. Connected roads increase the overall drainage density by 15 percent, also called channel network extension (Wemple et al, 1996). Roads are connected to streams either directly at crossings or indirectly by flow paths below drain points. While not all connected, 320 km (199 mi) of road drains within 50 m of a stream channel and 459 km (285 mi) of road drain within 100 meters of a stream channel.

Connectivity affects volume and timing of runoff and sediment delivery to streams and is highest during spring snowmelt (annual event) and occasional winter rain-on-snow floods. Summer convective storms are common but more localized and less predictable, driving runoff and erosion in smaller catchments. Connectivity is variable in low relief areas with roads acting as dams or diversions. Connectivity also occurs in numerous locations where roads intercept groundwater.

Sediment Production and Delivery

Inventoried roads produce about 81,445 kg of sediment per year with about 20,976 kg (26%) delivered to the stream network (from 199 km, or 27% of the road system). Twelve percent of the inventoried road length (93 km) delivers 90 percent of the sediment to streams (Figure 1).

Native surface roads make up about a third of the total miles inventoried but produce (81%) and deliver (77%) the majority of road sediment. Compared to other surface types, native surface roads produce and deliver four to six times more than graveled roads, and >200 times more than paved roads. A total of 66,256 kg/year of sediment is produced and 16,228 kg/year delivered to streams from inventoried native surface roads.

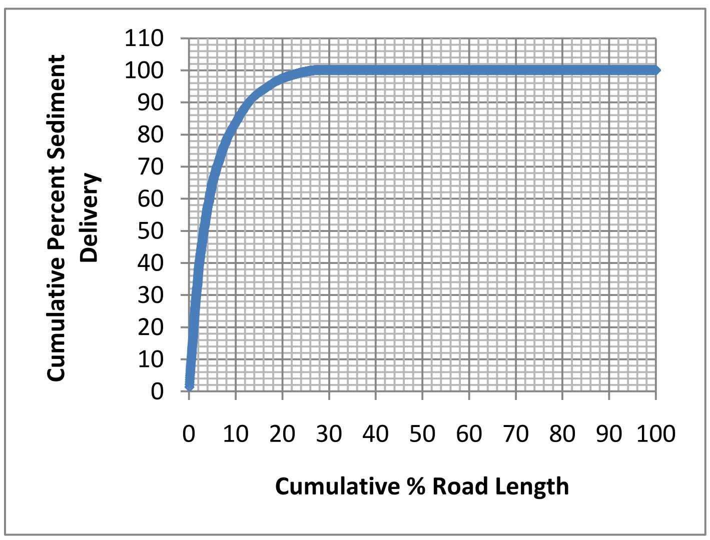

Figure 1. Percent of total sediment delivery to streams by road length

Sediment delivery initiates at road drainage features or “drain points”. Drain point types include broad-based dips, ditch relief culverts, non-engineered drains, and stream crossings. Drain type is important to identify the origin of road-related runoff and sediment delivery to the stream network, and to determine treatment options. Over 6000 drain points were surveyed, with about 1500 (23%) connected to a stream (connectivity is determined by identifying and mapping flow paths and sediment evidence). Broad-based dips have relatively low connectivity (14%) but have the highest sediment delivery per unit (25 kg/yr). Ditch relief culverts have higher connectivity (26%) but lower delivery per unit (5 kg/yr). More stream crossings are connected (by definition, with exceptions for "orphaned" crossings) than any other drain type, and crossings have relatively high unit sediment delivery (10.3 kg/yr).

Sediment sources from roads occur throughout the watershed, with localized "hot spots" in Little Wall and Middle Big Wall subwatersheds. High sediment production and delivery occur on segments of roads: 2107-010 (Little Wall-Skookum), 2110 (Lower Wall-BLM), 2128-065 and 070 (Wilson Creek), 2200-019 and 027 (Little Wall-Lovlett Creek), 2202 (Little Wall and Lower Wall), and 2300 (follows Big Wall Creek and has a high density of drain points delivering sediment).

Gullies and Landslides

A total of 59 gullies were identified, of these 14 receive direct discharge from a drain point and most are located at slope breaks below drain points. Landslides are uncommon in the watershed because of relatively low precipitation and stable landforms. Of the 19 landslides recorded, 16 were considered road-related (cut-slope or fill-slope failures). Three of these slides are associated with drain points that deliver water and sediment to the slide.

Downstream sediment accumulation

Sediment from the road system enters the stream network at connected drain points. The model accumulates sediment from stream segments to sum the total annual road sediment for the watershed. Sediment at the mouth of Wall Creek from the inventoried road system totals 20,822 kg/yr, or 40 $kg/km^2/yr$, averaged over the watershed. Stream sediment loads vary between subwatersheds with Middle Big Wall Creek and Little Wall Creek having the highest unit area sediment delivery, 67 and 77 $kg/km^2/yr$, respectively. For the 303(d) listed streams, Big Wall Creek has the highest and Porter Creek the lowest unit area sediment loads, 40 and 17 $kg/km^2/yr$, each.

Estimating the proportion that road sediment contributes to the total sediment load for the watershed requires establishing a base sediment yield (and identifying other sources) which presents numerous technical challenges. Sediment yields in forested watersheds are highly variable from year to year, with annual loads largely driven by climatic events and watershed disturbances. Published regional and local data sources, and WEPP model estimates were considered in estimating background sediment. Sediment yield data from 10 years of monitoring in upper Skookum Creek (Harris et al, 2005 and Wondzell et al, 2007), and WEPP FuME model runs give annual values in the range of 1000 to 4000 kg/km2/yr. Using the lower value, a base estimate for the watershed is 518,000 kg/yr, with road sediment making a small (<5%) contribution above background sediment loads. Other "above-base" sources include historic grazing and logging, but these are largely legacy effects with sediment either already mobilized in the channel network or exported from the watershed. Current practices (grazing, logging, recreation) produce small amounts of sediment, but BMPs control delivery to channels so effects are minor and localized. Perennial streams on the National Forest, for example, have been fenced from livestock grazing access since the mid 1990s. The BLM has not permitted grazing on most of their land in lower Wall Creek since 2000. Over one million dollars in watershed improvement projects have been implemented over the last two decades in the Wall Creek watershed, including repairs to stream crossings and about 15 miles of road decommissioning in the last 2 years (Wall Creek Watershed Action Plan, 2009). The road system remains the single largest controllable source of hydrologic impairment, including sediment delivery, in the watershed.

TMDL development and options for delisting 303(d) streams

Results from the Relative Bed Stability survey (LRBS and %SAFN) were compared with GRAIP data (road sediment accumulation in streams) to identify possible linkages between source and channel conditions. The general intent of RBS, collected at 49 locations in the watershed, is to provide an overall indication of bed stability and sedimentation. We found no apparent relationship in the expected direction of higher streambed fine sediment with higher road sediment contribution. While roads may contribute a small portion of the overall sediment budget on an annual basis, this source is a chronic contribution. RBS may also not be sensitive to this source of sediment. More precise field measurements would be necessary to conduct site or reach-scale assessments using RBS (Kaufmann et al, 2009).

Options include:
Delisting based on data since both RBS and GRAIP indicate minor “excess sedimentation”.

Update Watershed Action Plan (2009) with road treatment analysis and plan, and submit to DEQ as a “Water Quality Implementation Plan” for TMDL sufficiency. Road-derived sediment delivered to streams has now been quantified so load reduction “targets” can be derived.

Recommendations for Restoration Priorities (preliminary)

The GRAIP process produced a ranked list of hydrologically connected and high sediment delivery road segments. These data and the resulting maps will provide the basis for an effective road restoration prioritization strategy for Wall Creek.

Short term (this year):

- Review high risk road segments and drain points prior to scheduled maintenance and project level activities.
- Identify opportunities for treatments to correct drainage or erosion problems.
- Begin field assessment and prioritization of high risk sites for future treatment and develop targets for reducing connectivity and sediment delivery, and stabilizing crossings.
- Incorporate results from Regional decommissioning effectiveness study in evaluation of treatment cost-effectiveness.

Long term (2-3 years):

- Incorporate results in out-year project plans that focus on connected and high sediment-producing road segments and drain points.
- Pending Legacy funding requests, complete inventory and “minimum road system” analysis, with costs to repair or decommission high risk roads and crossings.

- Develop plans and schedules to complete treatments, including monitoring, and begin implementation.

Costs and Lessons Learned

Overall, the project was successful in completing a watershed-wide, high quality inventory and assessment of over 450 miles of roads in a multi-ownership watershed. Project success can be attributed to several factors including funding support from EPA and BLM, RMRS oversight on training, a full time field manager, and local Ranger District support (crews were stationed in a local guard station with access to the District office). Costs averaged about $240/mile, with field inventory, data processing, modeling and analysis. These unit costs may be relatively high compared to other similar projects for several reasons including limited access; over half of the roads were inaccessible by vehicle (closed), technical challenges of operating and maintaining high tech field equipment (i.e. high grade GPS satellite requirements and periodic breakdown of field recorders), and QAPP requirements to evaluate data quality.

Recommendations for similar projects of this magnitude include assigning a full-time project field manager to oversee logistics, providing comprehensive training for field crews and ensuring support from the local District manager and staff (safety and logistics). A quality assurance plan in place is also critical to evaluate between-crew field interpretations. The Forest recommended that GRAIP developers add attributes for NFS/BLM road system numbers to the data dictionary. Road files were updated to include this information to streamline road identification for treatment using common number systems, and to link GRAIP data to Forest corporate databases (GIS and INFRA).

Table 2. Summary of GRAIP road risk factors for Wall Creek watershed sediment assessment

Impact/Risk type	GRAIP results	Management options*
Road-stream hydrologic connectivity	27% of inventoried roads 199 km (123 mi) out of 726 km (451 mi) are connected to the stream network effectively increasing stream density by 15%	Disconnect …connected roads: Maintenance (ditches, water bars, Reconstruction (grade alignment), Storm-proofing (install drainage and spot gravel) and Decommissioning critical sections (remove connected elements)
Fine sediment production and delivery	Total Sediment Production = 81,445 kg/yr Total Sediment Delivery = 20,976 kg/yr (26% of produced) 12% of inventoried roads, 93 km (58 miles) deliver 90% of sediment to streams Little Wall and Middle Wall subwatersheds have the highest delivery per unit area	Focus treatments on high sediment producing road segments and drain points, spot gravel open native surface roads and crossings, decommission high risk roads no longer needed
Drain point condition	29% of drain points (1861) were identified as problems, including: broadbased dips not properly outsloped and/or ponding water (582); non engineered drains with blocked ditch, gully, or broken berm (363); and blocked or incised stream crossings (348).	Various practices to repair or eliminate problems include: maintenance to improve drainage, realigning grade, spot gravel, outsloping, ditch maintenance, repair and stabilize crossings
Stream crossing risk: Plug and diversion potential at culverts, and eroded or blocked fords	281 crossings with culverts, majority with relatively low blocking index, 55 with potential to plug (high skew angle, low channel ratio). 96 crossings with diversion potential in one direction, 1 crossing with diversion potential in both directions (headwaters of Indian Cr). 24 of 217 fords are incised or blocked	Replace or remove culverts, armor and bridge or low-water fords Apply critical dips to reduce diversion potential at high-risk stream crossings Prioritize crossing repairs based on road management objectives and resource values at risk and develop appropriate treatments
Existing gullies and gully potential	59 recorded, 14 gullies receive water from a drain point Gully potential at drain points not strongly related to slope-length index	Treat drain point flow source Evaluate other gullies (source, active or legacy)
Existing landslides and landslide risk	Landslides uncommon in the watershed, 19 observed, 16 road-related, 3 with drain points delivering water to the feature	Evaluate landslides associated with drain points for stability, resource values at risk

* Management options suggest possible treatments or need for further assessment, examples not intended as comprehensive list of all practices or needs.

1.0 Background

The National Forest Transportation System represents a major public investment and provides many benefits to forest managers and the public. Roads, however, also have negative effects on water quality, aquatic ecosystems, and other resources. There is currently a large backlog of unfunded maintenance, improvement, and decommissioning work needed on the National Forest and BLM roads. Critical components of the infrastructure (e.g., culverts) are also nearing or have exceeded their life-expectancy, adding further risk and impacts to watershed and aquatic resources.

Six streams within the Wall Creek watershed were 303 (d) listed for sediment by the Oregon Department of Environmental Quality (1994/1996, ODEQ). These streams (Table 3) may be impacted by sediment from roads in the watershed. In order to quantify the amount and location of sediment contributions from roads to streams, the Forest Service with funding support from EPA and BLM, designed a site-specific road-sediment inventory using the Geomorphic Road Analysis and Inventory Package (GRAIP, Prasad et al. 2007, http://www.fs.fed.us/GRAIP).

The GRAIP data collection and analysis procedure provides land managers with field-based data that captures the extent to which roads influence hydrologic function and stream channel conditions. GRAIP identifies precise locations where sediment delivery is occurring, where drainage features are compromised, and where road maintenance or decommissioning is required. Detailed information can then be used to prioritize actions to minimize adverse watershed and aquatic impacts from roads.

Table 3. 303 (d) listed streams in the Wall Creek watershed (ODEQ, 2006).

Water Body	River Mile	Criteria	Season/Use	Uses
Alder Creek	0 to 5.5	Sedimentation*	Undefined	see definition
Big Wall Creek	0 to 21.3	Sedimentation*	Undefined	Rearing, spawning, aquatic life
Big Wall Creek	0 to 21.3	Temperature	Year Around	Rearing, migration, 18 C
Hog Creek	0 to 4.1	Sedimentation*	Undefined	see definition
Indian Creek	0 to 5.4	Temperature	Year Around	Rearing, migration, 18 C
Porter Creek	0 to 7.4	Sedimentation*	Undefined	Rearing, spawning, aquatic life
Skookum Creek	0 to 12.4	Temperature	Summer	Rearing: 17.8 C
Swale Creek	0 to 11.1	Sedimentation*	Undefined	see definition
Swale Creek	0 to 11.1	Temperature	Summer	Rearing: 17.8 C
Wilson Creek	0 to 10.7	Sedimentation*	Undefined	Rearing, spawning, aquatic life
Wilson Creek	0 to 10.7	Temperature	Summer	Rearing: 17.8 C

*****The formation of appreciable bottom or sludge deposits or the formation of any organic or inorganic deposits deleterious to fish or other aquatic life or injurious to public health, recreation, or industry may not be allowed. (www. DEQ.oregon.or.us, accessed 7/1/2007).

All roads in the Wall Creek watershed were targeted for inventory, however, due to time, access, and resource constraints, priority areas were identified to complete. Of the six subwatersheds within the Wall Creek watershed; four were initially targeted: Lower Big Wall, Middle Big Wall, Wilson, and Little Wall. Field work began in the lower elevations (Lower Big

Wall, on BLM) and continued into Middle Big Wall, Wilson, Little Wall and Skookum. Additional mid-season funding from EPA supported completion of targeted areas and a partial inventory of Skookum Creek so that the majority of roads in five of six subwatersheds were covered. Roads on existing GIS layers were targeted for inventory though some mapped roads did not exist (not present or decommissioned), were not accessible (private land), or were determined to have no stream connections and omitted from inventory. Unmapped roads found during field surveys were also inventoried, which include "user-defined" or unclassified roads, temporary roads, and skid trails. A total of 451 miles of road were inventoried (roads that continued outside of the watershed were completed rather than end a survey at the watershed boundary). Table 4 and Figure 3 summarize mapped and inventoried miles for each subwatershed. Field work began May 20, 2009, and was completed October 4, 2009.

Table 4. Summary of total road miles in GIS databases and miles inventoried by subwatershed

as of 4 December 2009 (After road straightening and preprocessing)					
Subwatershed	Road Length (m)	Road Length (mi)	Road Comp (m)	Road Comp (mi)	Percent Done
Middle Big Wall	139,577	87	144,931	90	104
Swale Creek	103,888	65	2,514	2	2
Wilson Creek	214,485	133	168,501	105	79
Lower Big Wall	85,690	60	130,873	81	136
Little Wall	167,353	104	159,166	99	95
Skookum Creek	114,823	71	98,685	61	86
Total	**825,816**	**520**	**704,671**	**438**	**84**
All Roads			725,616	451	

2.0 Objectives and Methods

GRAIP is formulated to assess the geomorphic and hydrologic impacts of roads, their physical condition and associated stream connections. It is a relatively intensive field-based method that provides detailed information designed to improve understanding of the overall effect of roads on key watershed processes. Specifically, the project was designed to address the following in Wall Creek:

- identify the current level of fine sediment delivery from roads to streams in Wall Creek compared to background
- identify the types and sources of road-related hydrologic risk in the watershed
- locate and quantify sediment sources and contributions to 303(d) streams
- select and prioritize future restoration actions to improve watershed conditions and move towards an ecologically (and economically) sustainable road system.
- compare GRAIP results with Relative Bed Stability (Kauffman et al, 2007) data available for the watershed (2007 BLM contracted analysis) to verify stream impairment and sediment source

GRAIP is used to inventory and model the risk profile of each of the road segments and drain features 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 with Geographic Positioning System (GPS) technology and automated data forms (Black et al., 2009). The GIS applications couple field data with GIS terrain analysis tools to analyze road-stream hydrologic connectivity, fine sediment production and delivery, downstream sediment accumulation, stream sediment input, 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.

Relative bed stability is defined as the ratio of bed surface mean particle diameter divided by the estimated critical diameter at bankfull flow (Kauffman et al, 2007). The RBS concept was developed by EPA and others based on EMAP (Kaufman et al, 1999) protocols as a tool to evaluate regional patterns of channel stability and sedimentation. RBS surveys in John Day Basin watersheds with 303(d) listed streams were completed by Demeter Designs Inc. under contract with BLM in 2007 and 2008. The project was intended to help verify sediment listings and inform TMDL development. The GRAIP and RBS data available in Wall Creek presented an opportunity to link sediment sources with instream impairment as potentially signaled by two different methods.

3.0 Study Area

Wall Creek Watershed

Wall Creek is located in the John Day River Basin on the western edge of the Blue Mountains and comprises a drainage area of just over 200 square miles. Most of the watershed is underlain by two geologic units of layered basalt flows with interbedded sediments. Higher elevations in the northeastern portion of the watershed are underlain by basalt/andesite or mudstone/clastics/volcanics (Figure 2). Terrain within the watershed consists primarily of mid-elevation, basalt-capped plateaus with deeply incised canyons. Annual precipitation varies with elevation from 12 to 32 inches per year, with most of the watershed receiving between 14 and 20 inches per year. Wall Creek is a tributary to the North Fork John Day River (HUC 170702).

The watershed is comprised of 95,190 acres on the Umatilla National Forest (UNF), 12,243 acres of Prineville BLM, and 20,768 of county and private land. The watershed contains approximately 8 percent of the land base of the John Day River system. The confluence of Wall Creek is 22.5 stream miles upstream from the confluence of the North Fork with the main John Day River.

From the headwaters, Wall Creek flows east to its confluence with Little Wall Creek, and south to the NFJD. Major tributaries include Wilson Creek, Little Wall Creek, Skookum Creek, and Swale Creek. The landscape is characterized by uplifted, moderately dissected plateaus with gently sloping uplands, steep escarpments, canyons, and depositional areas consisting of alluvial landforms in the valley bottoms and along stream terraces. Annual runoff and streamflow are controlled by spring snowmelt with peaks occurring in April and May in the higher elevations, and by rain dominated runoff in the lower elevations. Low flows occur in late summer and fall. During mid to late summer when stream flows are at their lowest and cumulative heating of surface water is at maximum, water temperatures in Wall Creek at the mouth often reach 80º F.

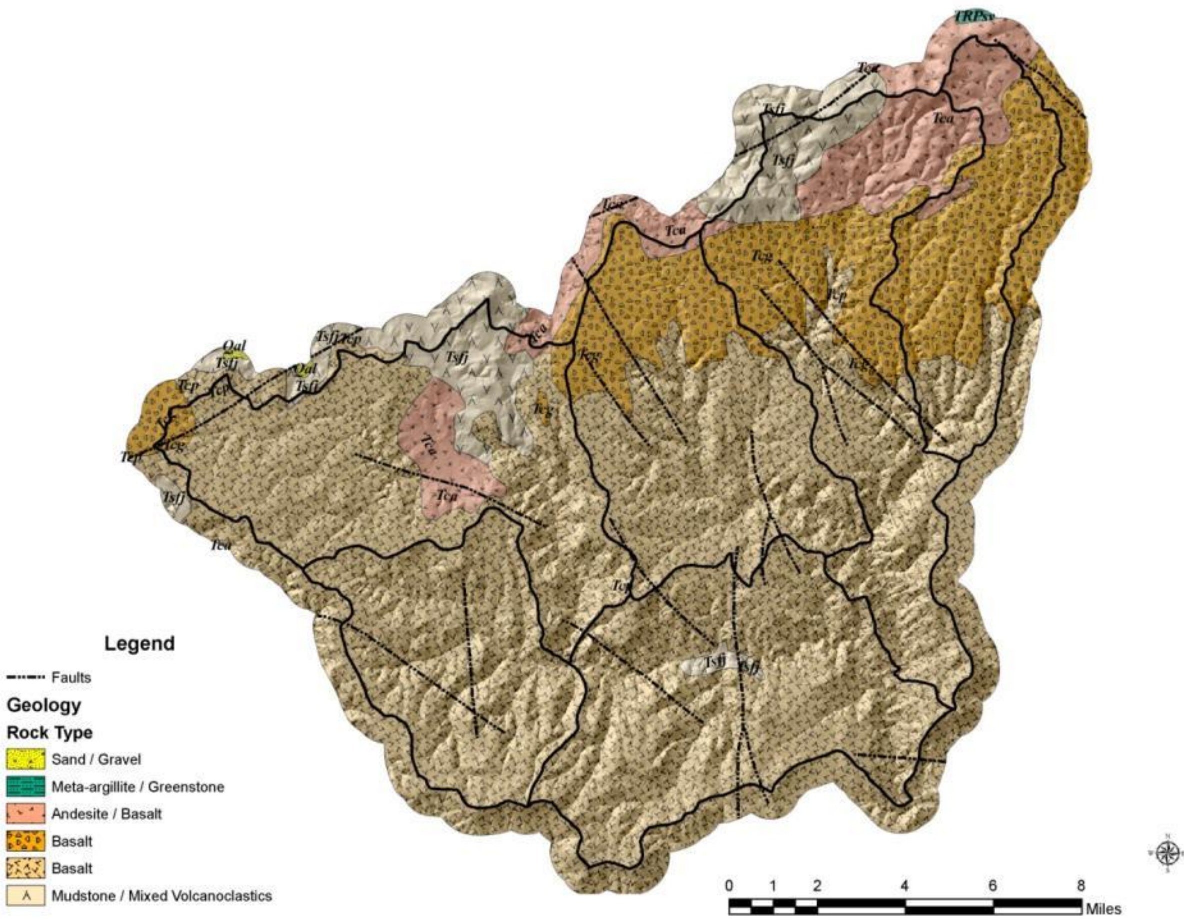

Figure 2. Geologic map of the Wall Creek watershed showing subwatershed boundaries. (Source: 1:100K USGS)

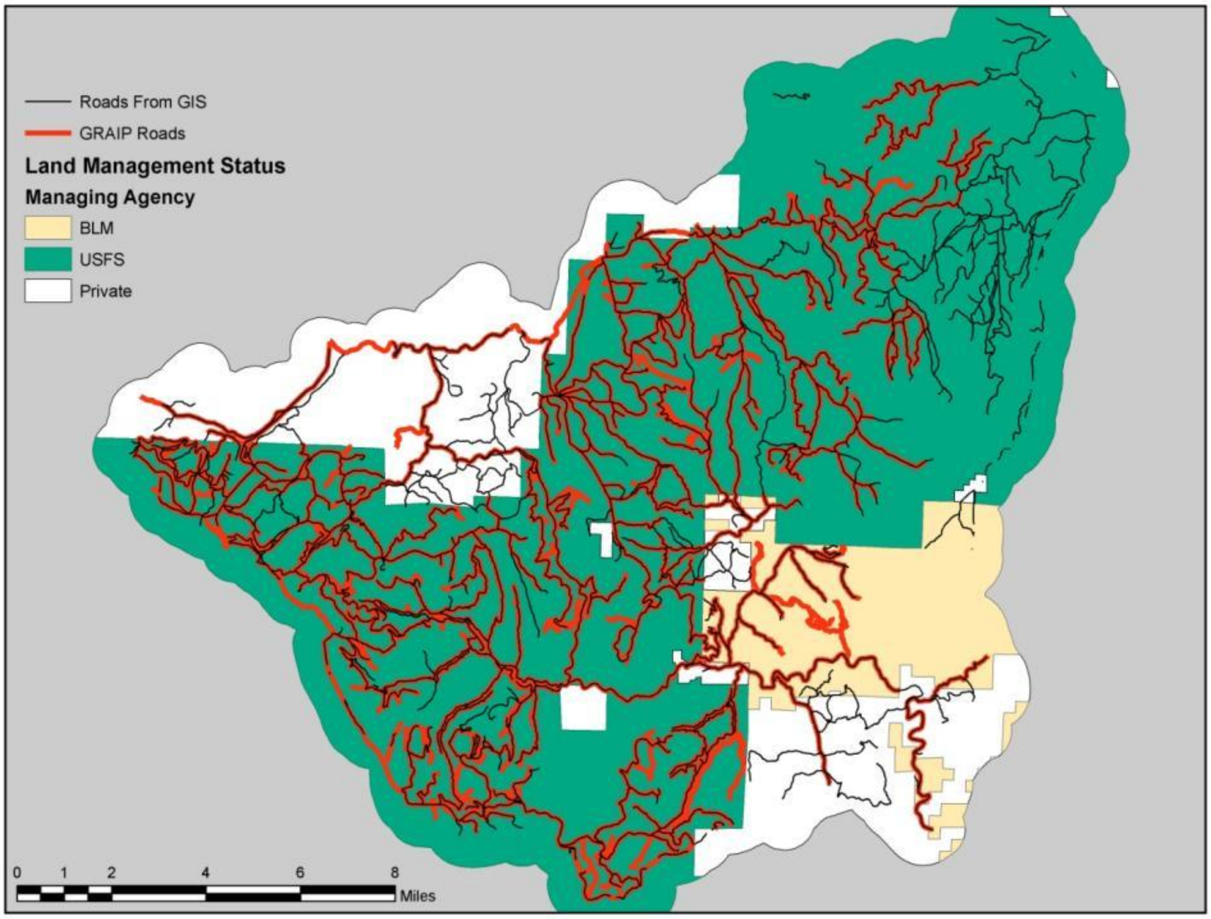

Figure 3. Wall Creek watershed mapped roads (GRAIP survey in RED) and land management status.

4.0 Results

A total of 8414 road segments, 6563 drain points, and 892 other associated features were surveyed in 4 months of field work. Data analysis provides specific information on the condition and function of 451 miles of roads, 438 of which are within the Wall Creek watershed (Figure 3). GRAIP inventory data and modeling tools were used to characterize the following types of impacts and risks:

- Road-stream hydrologic connectivity
- Fine sediment production and delivery
- Drain point condition
- Downstream sediment accumulation
- Stream crossing failure risk
- Gully initiation risk
- Landslide risk

4.1 Road-Stream Hydrologic Connectivity

Roads often intercept shallow groundwater converting subsurface flow to surface runoff, resulting in local hydrologic impacts when water is discharged directly to channels (Wemple et al., 1996). Additional runoff is also produced from compacted road surfaces. Basin-scale studies in the Oregon Cascades suggest that a high degree of integration between the road drainage system and the channel network can increase some peak flows (Jones and Grant 1996).

The hydrologically-connected portion of the road is calculated in GRAIP 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. A total of 199 km (123 mi) out of the 726 km (451 mi) of inventoried road in the Wall Creek study area (27.4%) were hydrologically connected to a stream. While not all connected, 320 km (199 mi) of road drains within 50 m of a stream channel and 459 km (285 mi) of road drains within 100 meters of a stream channel.

Connected roads increase the overall stream density by about 17 percent (using base forest stream layers). Stream miles were estimated in Wall Creek from original 1:24000 ortho-photo maps that were extended, or “densified”, to include intermittent channels. Mapped intermittent streams were field verified to verify spatial accuracy and stream type (Wall Creek Ecosystem Analysis, 1995). Stream network systems are not static and may expand or contract in response to weather conditions (wetter vs drier years), disturbance events (fires, floods) and land uses (roads, grazing, logging).

Road-stream hydrologic connectivity represents the maximum extent roads are integrated with streams and is controlled by the pattern and distribution of runoff, slope length, vegetation, and delivery paths, among other factors (Bracken and Crocke, 2007). Maximum connectivity in Wall Creek occurs during spring snowmelt and widespread persistent frontal storms, when the connection between saturated hillslopes and streams is greatest. Isolated convective storms (common in summer) increase local connectivity at the catchment scale (short duration).

A"peak flow effect" from road hydrologic connectivity is most likely during snowmelt and storm events at least on a localized basis if not at the watershed scale, but the magnitude of effect is difficult to quantify without direct measurement and/or more detailed modeling. High stream flows from all sources, hillslopes and roads, transport sediment and scour channels during events. Scour observed at road-stream crossings provides physical evidence of localized road connectivity effects.

Broad-based dips and water bars are the most common types of drainage features (1,964 and 1,595 features, respectively), and also drain the largest portion of the road network (Figure 4, Table 5). However, the bulk of the hydrologic connectivity between the road and stream networks, takes place at stream crossings and broad-based dips (543 and 271 connected features, respectively). Broad-based dips (167 m) and ditch relief culverts (124 m) have the longest average connected road lengths, while water bars (84 m) and stream crossings (87 m) had the shortest averages.

Table 5. Summary of Effective Road Lengths by Drain Point Type. Sumps cannot be stream connected, and stream crossings are stream connected by definition.

Drain Type	All			Connected			Non-Connected		
	Count	***Average***	***Sum***	***Count***	***Average***	***Sum***	***Count***	***Average***	***Sum***
Broad Based Dip	1,964	151	297,092	271	167	45,308	1,693	149	251,784
Diffuse Drains	521	112	58,389	60	103	6,201	461	113	52,187
Ditch Relief	808	114	92,426	212	124	26,243	596	111	66,183
Lead Off Ditch	152	88	13,447	22	94	2,070	130	88	11,377
Non-Engineered Drains	567	105	59,403	238	105	25,058	329	104	34,345
Stream Crossings	543	87	47,345	543	87	47,345	0	0	0
Sump	323	103	33,197	0	0	0	323	103	33,197
Water Bars	1,595	77	123,396	317	84	26,584	1,278	76	96,812

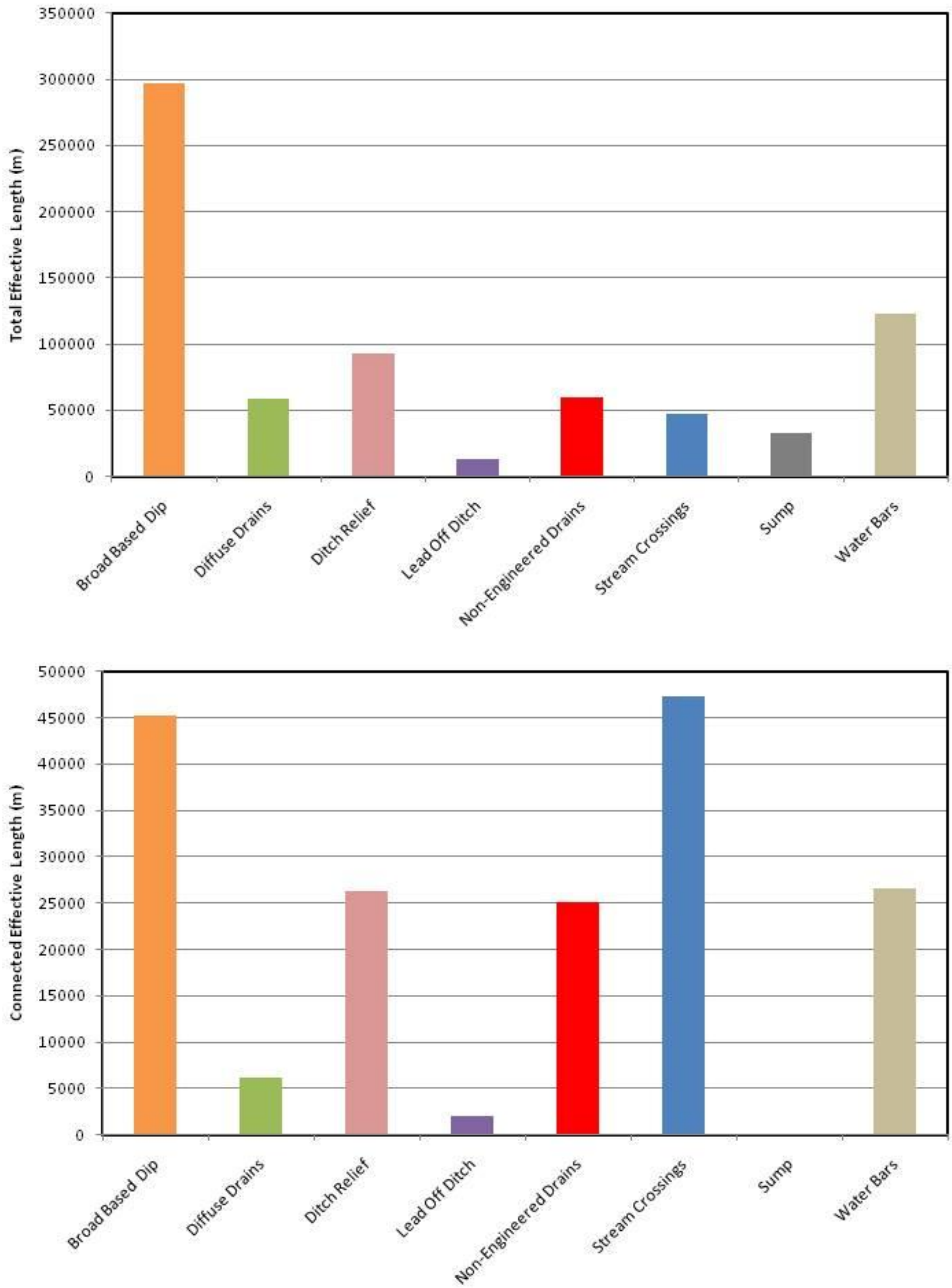

Figure 4. Hydrologic connections; effective lengths and drain types. Top: Total effective road lengths associated with each drain type. Bottom: Stream connected effective lengths associated with each drain type.

The GRAIP inventory also collects information on the types and conditions of drainage features beyond the eight basic types. This information can be used to determine if certain sub-types or conditions are more likely to connect longer portions of roads (Figure 5, Table 6).

Bridges (309 m), fabricated-material water bars (cattleguards; 274 m), and 12" (201 m) or smaller (196 m) ditch relief culverts were found to, on average, connect the longest road sections. Cattleguards act as water bars by draining water from the road surface. These are often used where gates would be impractical due to higher traffic volumes, and are, by necessity, placed at intersections of roads and range fences. While placement options are thereby limited, effort should be made to reduce the contributing road length and stream connection at these points. The same also applies to bridges.

In terms of total road length connected, grade reversals (42,829 m), road-material water bars (24,938 m), natural fords (24,265 m), round steel culverts (18,157 m), and 18" ditch relief culverts (13,535 m) make up the top five sub-types. Grade reversals are the most common drainage feature on the road network with over 1,900 distributed throughout the watershed. These features are simply the point where two road grades meet, most often in small swales. Road-material water bars are constructed using a dozer blade or other implement to raise a small berm across the road; over 1,500 are present in the Wall Creek watershed. Natural fords are the second most common type of stream crossing, but they are rarely orphaned. Round steel culverts are the most common type of stream crossing, but nearly half (127 of 275) are orphaned and thereby do not connect the road to the stream. The 18" ditch relief culvert is the most common size, with 417 present in the watershed and 114 providing stream connections.

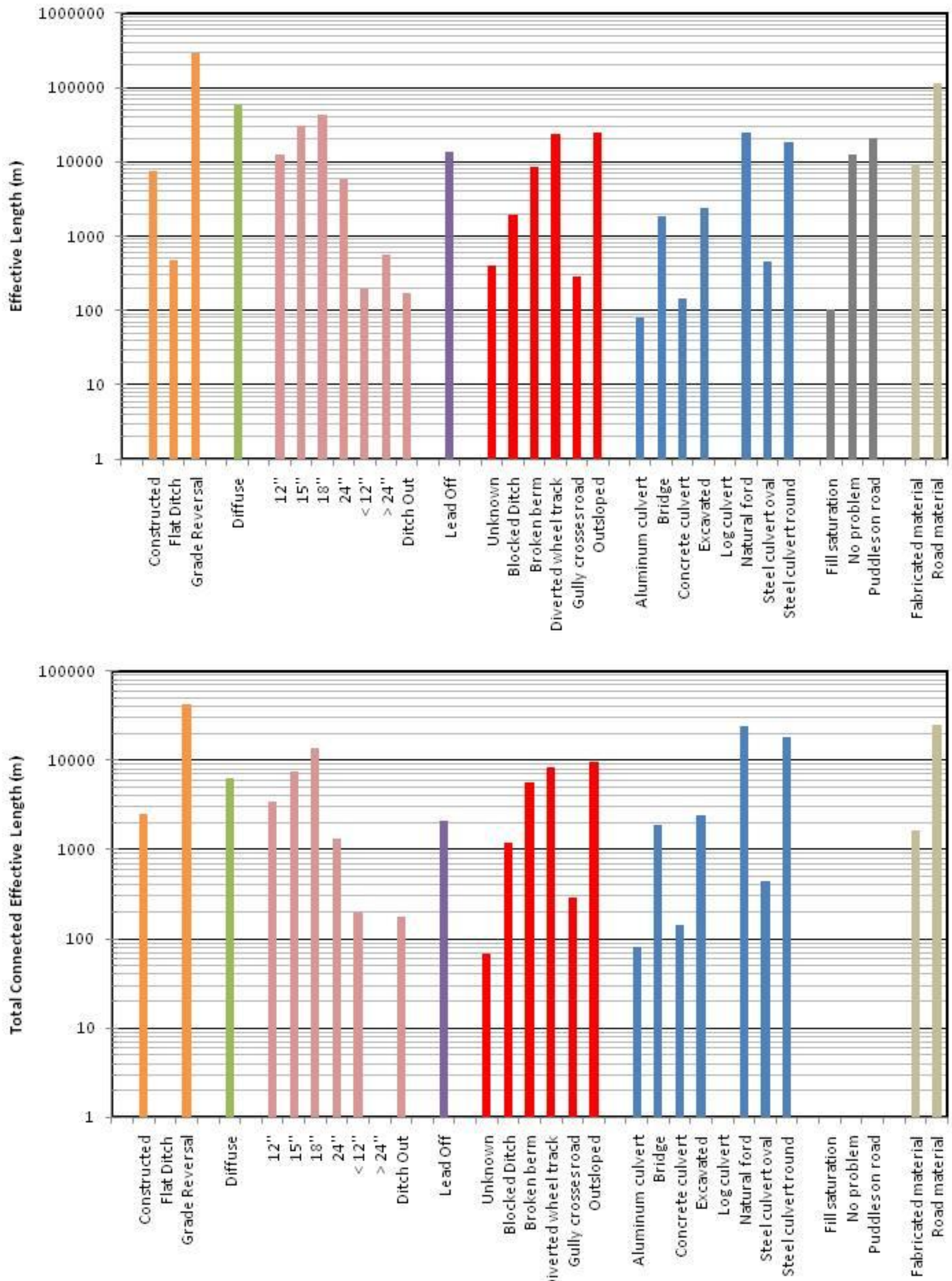

Figure 5. Hydrologic connections; effective lengths and drain sub-types. Top: Total effective road length by drain sub-type. Bottom: Stream connected effective road length by drain sub-type. Axis is logarithmic.

Table 6. Summary of Effective Lengths by Drain Point Type and Sub-type. Sumps cannot be stream connected, and stream crossings are stream connected by definition. Stream crossings listed as non-connected are orphans and thereby do not connect the road and the stream.

Drain Type and Sub-type	All			Connected			Non-Connected & Orphaned Stream Crossings		
	Count	*Average*	*Sum*	*Count*	*Average*	*Sum*	*Count*	*Average*	*Sum*
Broad Based Dip									
Constructed	53	143	7,559	16	155	2,479	37	137	5,079
Flat Ditch	4	121	483	0	0	0	4	121	483
Grade Reversal	1,907	152	289,050	255	168	42,829	1,652	149	246,222
Diffuse Drains									
Diffuse	521	112	58,389	60	103	6,201	461	113	52,187
Ditch Relief									
12''	78	163	12,725	17	201	3,410	61	153	9,315
15''	264	114	30,046	64	119	7,620	200	112	22,426
18''	417	103	42,843	114	119	13,535	303	97	29,309
24''	40	147	5,883	13	101	1,310	27	169	4,573
< 12''	4	49	196	1	196	196	3	0	0
> 24''	2	280	560	0	0	0	2	280	560
Ditch Out	3	58	174	3	58	174	0	0	0
Lead Off Ditch									
Lead Off	152	88	13,447	22	94	2,070	130	88	11,377
Non-Engineered Drains									
Unknown	7	58	405	1	69	69	6	56	336
Blocked Ditch	20	96	1,913	11	110	1,209	9	78	704
Broken berm	79	108	8,505	42	134	5,624	37	78	2,882
Diverted wheel track	245	95	23,292	92	91	8,348	153	98	14,944
Gully crosses road	3	97	291	3	97	291	0	0	0
Outsloped	213	117	24,997	89	107	9,517	124	125	15,480
Stream Crossings									
Aluminum culvert	2	40	81	2	40	81	0	0	0
Bridge	7	265	1,857	6	309	1,857	1	0	0
Concrete culvert	2	72	144	2	72	144	0	0	0
Excavated	33	73	2,393	27	89	2,393	6	0	0
Log culvert	2	0	0	0	0	0	2	0	0
Natural ford	217	112	24,265	214	113	24,265	3	0	0
Steel culvert oval	5	90	448	3	149	448	2	0	0
Steel culvert round	275	66	18,157	148	123	18,157	127	0	0
Sump									
Fill saturation	2	52	103	0	0	0	2	52	103
No problem	127	99	12,542	0	0	0	127	99	12,542
Puddles on road	194	106	20,552	0	0	0	194	106	20,552
Water Bars									
Fabricated material	41	225	9,228	6	274	1,646	35	217	7,582
Road material	1,554	73	114,168	311	80	24,938	1,243	72	89,230

4.2 Fine sediment production and delivery

Fine sediment production for a road segment (E) is estimated with a base erosion rate and the properties of the road (Luce and Black ,1999; Cissel et al., 2009; Prasad, 2007), as shown below.

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

B is the base erosion rate[1] (kg/m)
L is the road length (m) contributing to the drain point
S is the slope of the road (m/m) contributing to 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. GRAIP tracks sediment production from road surfaces, delivery through drain points, and accumulation in the stream network (Figure 6).

[1] For this analysis, a base erosion rate of 1.5 kg/m of road length was assumed, based on three years of data from nine native and aggregate surfaced roads in a dry volcanic forested landscape in the Spencer Creek watershed near Klamath Falls, Oregon (Turaski 2004, USFS unpublished data)). Further work could determine if this rate is appropriate for this climate, geology and road system.

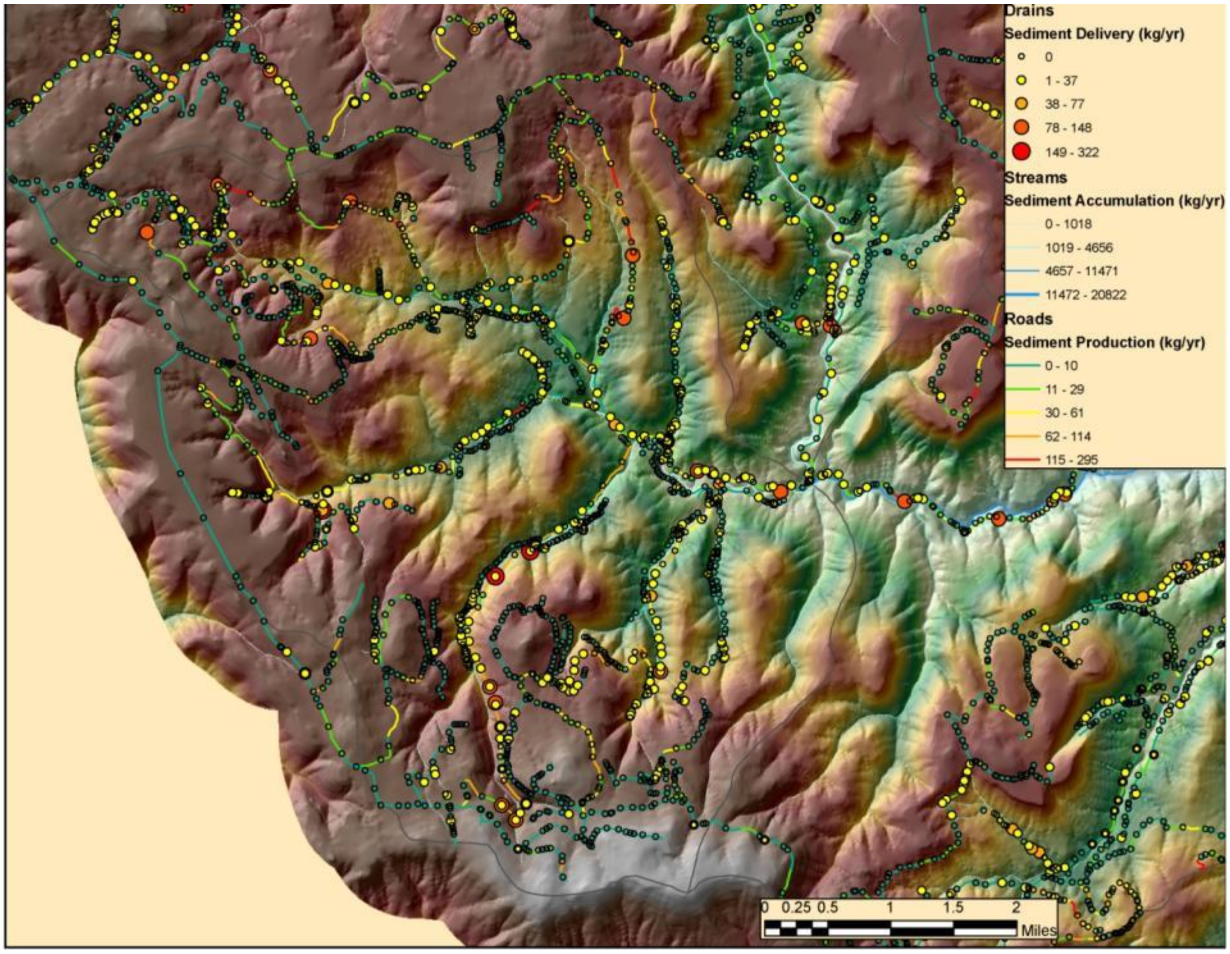

Figure 6. Fine sediment delivery to channels by road segments and drain points in the Middle Big Wall subwatershed. Road lines colored to indicate the mass of sediment produced and delivered to the channel. Size and color of the circle indicate the accumulated mass of sediment delivered at each drain point. Other subwatersheds are shown in Appendix 2.

Road Segment Analysis and Surface Type

The fraction of sediment produced and delivered from the road system can also be evaluated in terms of road length. Figure 1 (see Executive Summary) displays sediment delivery by cumulative road length. Of the 725.6 km of total road length, 22.7 km (~3%) are generating 50 percent of the sediment delivered to streams. Approximately 7 percent (51.8 km) of the road generates 75 percent of the delivered sediment, and approximately 12 percent (92.9 km) of the road generates 90 percent of the delivered sediment.

KEY FINDING: A relatively small percent of the road system generates and delivers the majority of sediment and the location of these roads is now known.

Road surface type is widely recognized as an important factor influencing sediment production and delivery and represents one management option for sediment reduction, for example by paving or graveling native surface roads. The majority of roads in the Wall Creek watershed are crushed rock (35%), native (35%), or covered by herbaceous vegetation (26 percent). Paved roads make up 3 percent of the roads in the watershed (Figure 7). GRAIP model results show native surface roads produce 25 times more sediment than paved roads, and 5 times more than any other surface type. Native surface roads produce about 66,000 kg of sediment per year, and deliver about 16,000 kg per year (about 24%). Roads covered with brush, trees, or organic debris (about 1% of the road network) are often close to stream channels; these roads only produce about 148 kg of sediment per year, and deliver 62 kg of that sediment to the streams (or 42%) due proximity to the stream. By total length of road, native and crushed rock roads produce and deliver the greatest amount of sediment, while paved and herbaceous vegetation types produce and deliver a much smaller amount of sediment per year (Figure 10).

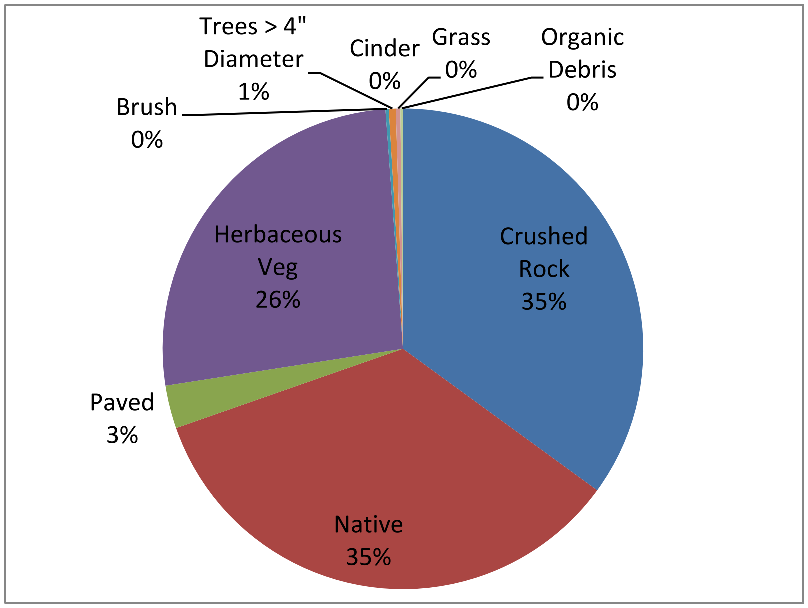

Figure 7. Distribution of road surface types by road length in Wall Creek watershed.

Vegetation in the road flow path increases the overall roughness of the road. Increased roughness decreases flow velocity and erosion and transport of sediment on the road surface. Where vegetation in either flow path on the road surface is greater than 25 percent, GRAIP predicts a 7-fold decrease in sediment production. Of the 726 km of roads inventoried, 293 km (40%) did not have flow path vegetation exceeding 25 percent in either flow path, 170 km (23%) had vegetation exceeding 25 percent in one flow path, and 263 km (36%) had vegetation exceeding 25 percent in both flow paths.

The relationship of surface type to sediment production and delivery was evaluated in several ways, first by percent of produced sediment that is delivered (Figure 8). Results were not immediately intuitive and required consideration of road surface type and proximity to streams. In Wall Creek, native surface roads were more common on ridges distant from streams, while brushy roads closed to traffic were more common near streams.

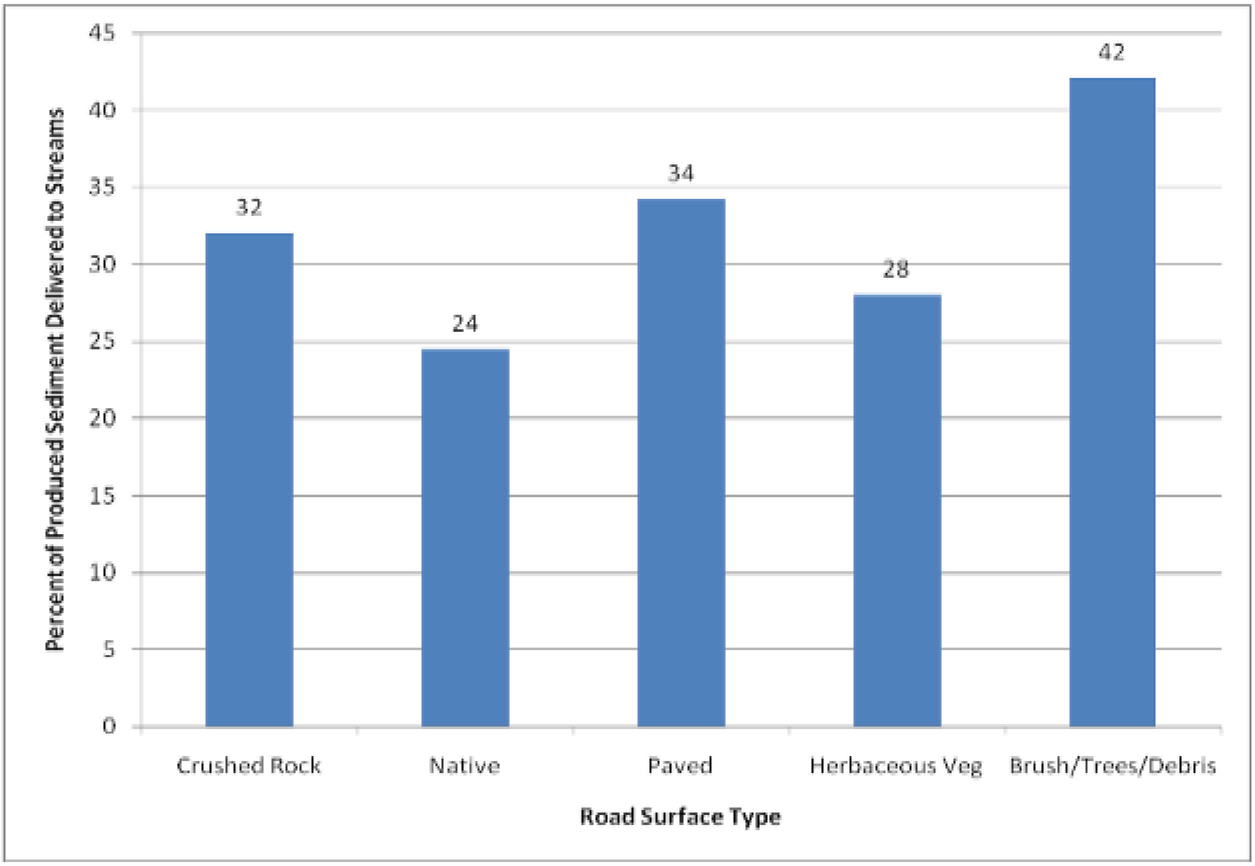

Figure 8. Percent of the total sediment produced that is delivered to the stream network, by road surface type. Note that proximity to the stream channel influences delivery (many streamside roads are closed and brushed in but have high delivery because of proximity).

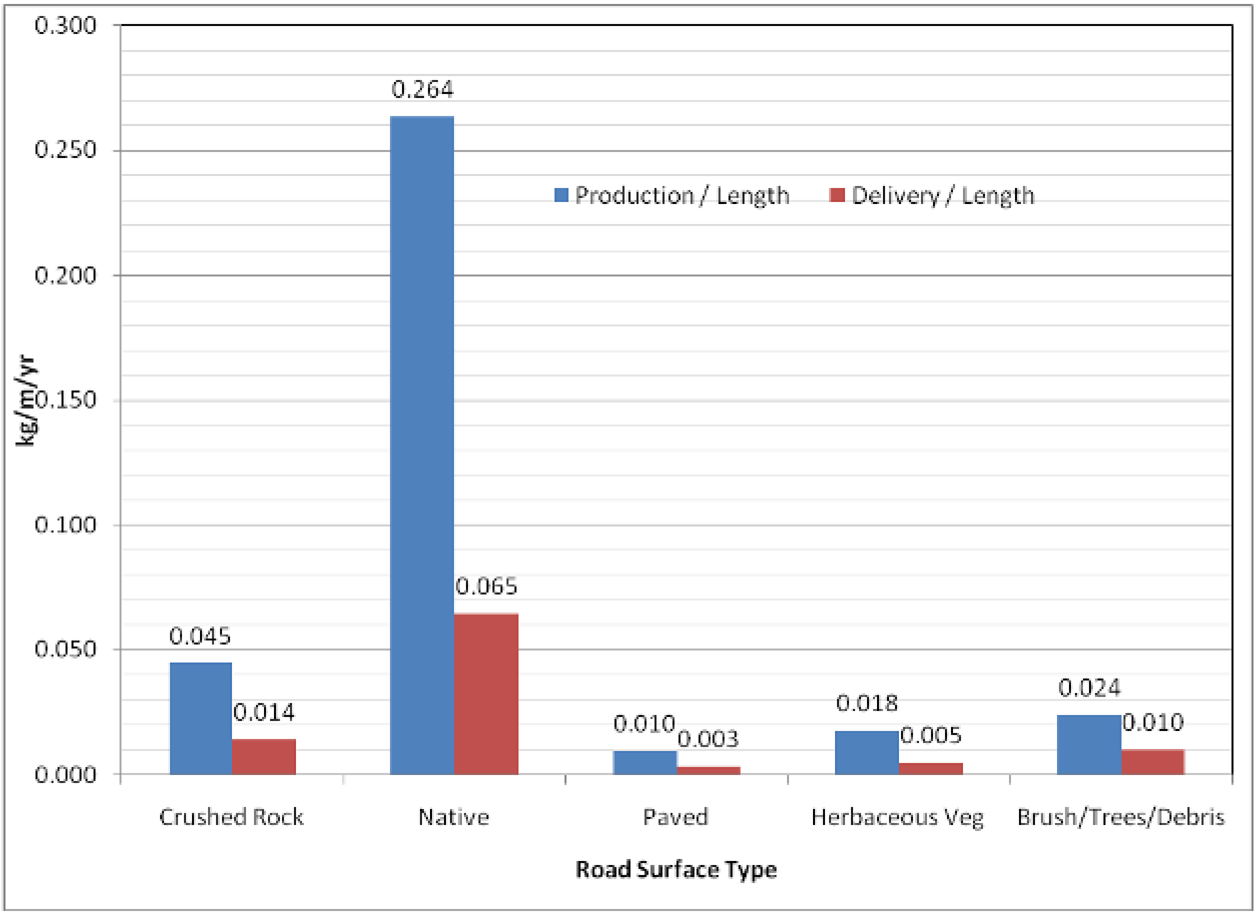

Figure 9. Unit sediment production and delivery for each surface type.

Overall, on a unit area basis, native roads produce and deliver the most sediment, with crushed rock second, and vegetated roads third highest. Paved roads produce and deliver the least sediment per unit of road (Figure 9). Based on total sediment produced and delivered, native roads are highest, rocked roads second highest, and herbaceous covered roads third highest (Figure 10).

These data and results will allow identification of the specific location and type of road segments delivering sediment. Various kinds of treatments made on these segments would decrease or eliminate sediment delivery, such as constructing additional drainage features, surfacing or decommissioning.

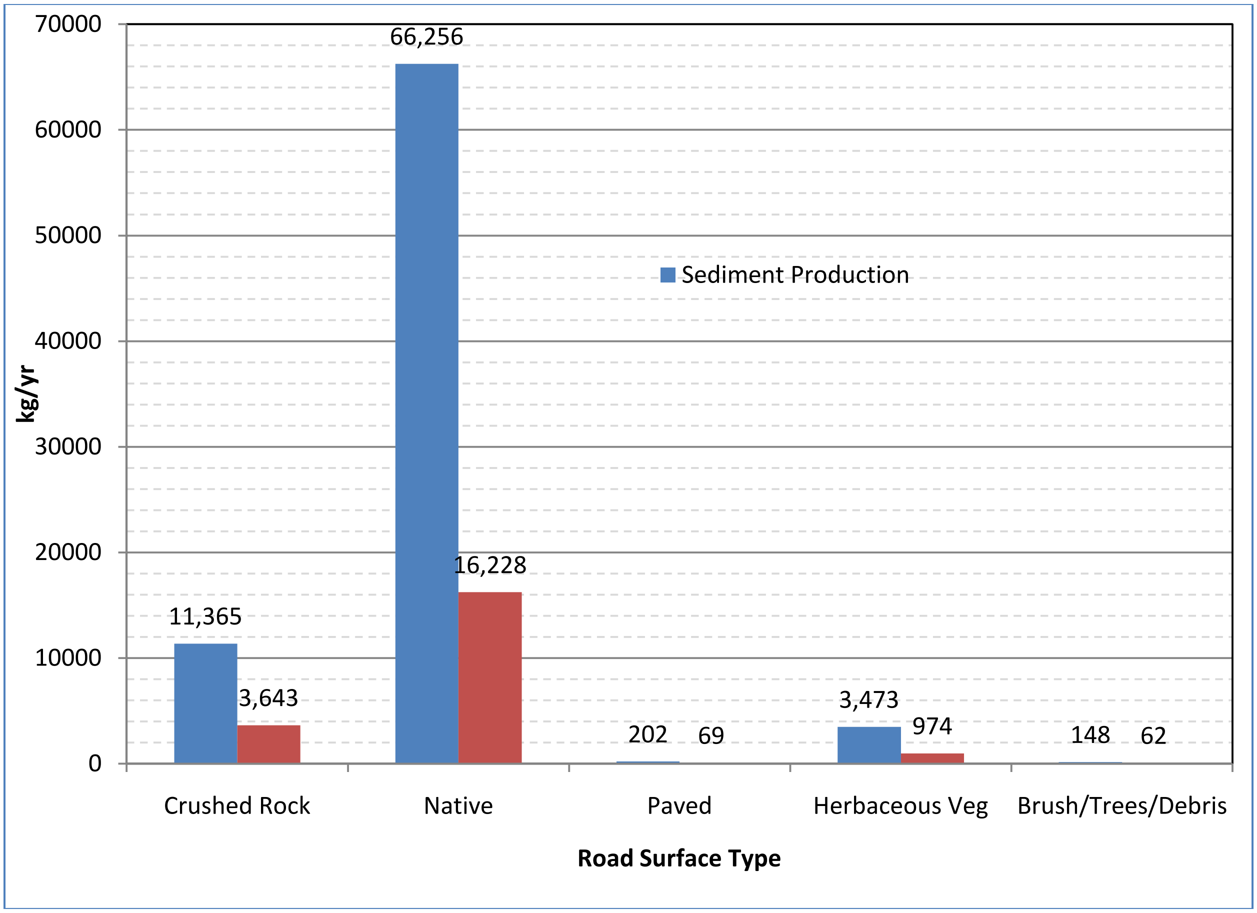

Figure 10. Total sediment production and delivery for each surface type.

4.3 Drain Point Analysis

There are eight types of drain points defined in the GRAIP system: broad based dips, diffuse drainage, ditch relief culverts, lead off ditches, non-engineered drainage features, stream crossings, sumps, and water bars (Table 7). Delivery of fine sediment to the stream network occurs by road drainage features including: ditch relief culverts, non-engineered drain points, stream crossings and others. In Table 8, sediment delivery is broken out by drain point type to compare differences in sediment delivered to the channel. All drain points were recorded but field crews also identified drain points not actively receiving runoff from the road based on field evidence. In these cases, the drain point is noted to be an “orphan” and no flow is routed to these points in the model. A total of 6,473 drain points were documented; 1,663 of which (25.7%) were hydrologically connected to stream channels. A small number (176, or 2.7%) of drain points were classified as orphans (Table 9). Connected drain points deliver 21,000 kg of sediment per year, or 26 percent of the sediment generated by the road surfaces and ditches. Fewer than 2 percent of drain points (104 sites) deliver half of this sediment (Figure 11).

Broad-based dips, stream crossings, water bars, and non-engineered drains delivered the most sediment, with a combined total of 19,000 Kg per year, or about 91 percent of the annual sediment load (Table 8). After stream crossings, which deliver all received sediment to the stream channel, ditch relief culverts and non-engineered drains are the most efficient drain point types, delivering 40 and 36 percent, respectively, of received sediment (Figure 12). Normalizing sediment delivery by the number of connected drain points in each type, it becomes evident that broad based dips tend to deliver the greatest quantity of sediment per stream connection (25.1 kg/yr/connection), and ditch relief culverts deliver the least, 5.3 kg/yr/connection (Table 8, Figure 13).

Table 7. Descriptions of Drain Point Types.

Drain Type	Description
Broad Based Dip	Large grade reversal or dip; can be designed or result from two hillslopes meeting. Often called "dips" or "sags".
Diffuse Drains	Water leaves the road in non-concentrated, minor flow paths.
Ditch Relief	Drains water from inboard ditch under the road and onto the hillslope.
Lead Off Ditch	A ditch that moves flow from a ditch directly onto a hillslope.
Non-Engineered Drains	A place where water leaves a ditch or the road in an unplanned manner.
Stream Crossings	A place where a road crosses a stream using a culvert, ford, or bridge.
Sump	A place where water collects and infiltrates; can be designed features (e.g. cattle pond or road closure trench-and-berm) or natural depressions.
Water Bars	Water diversion feature cut into the road surface. Water bars are smaller than broad- based dips. Often small berms.

Table 8. Sediment production and delivery by drain point type.

Drain Type	Count	Received Sediment (kg/yr)	Delivered Sediment (kg/yr)	Sediment Received per Drain Point (kg/yr)	Sediment Delivered per Drain Point (kg/yr)	Sediment Delivered per Connected Drain Point (kg/yr)	Percent Delivery
Broad Based Dip	1964	39,585	6,799	20.2	3.5	25.1	17.18
Diffuse Drain	521	4,779	368	9.2	0.7	6.1	7.69
Ditch Relief	808	2,836	1,132	3.5	1.4	5.3	39.91
Lead Off Ditch	152	1,640	328	10.8	2.2	14.9	19.99
Non-Engineered	567	9,356	3,363	16.5	5.9	14.1	35.94
Stream Crossing	543	5,581	5,581	10.3	10.3	10.3	100.00
Sump	323	2,442	-	7.6	-	-	0.00
Water Bar	1595	15,119	3,406	9.5	2.1	10.7	22.53
All Drains	**6,473**	**81,336**	**20,976**	**12.6**	**3.2**	**12.6**	**25.79**

Table 9. Drain point connectivity to streams and orphan drain points. Orphan drain points do not receive sediment.

Drain Type	Total	Stream Connected	% Connected	Connected Orphans	Not Connected	% Not Connected	Unconnected Orphans
Broad Based Dip	1,964	271	13.80	-	1,693	86.20	5
Diffuse Drain	521	60	11.52	-	461	88.48	3
Ditch Relief	808	212	26.24	28	593	73.39	90
Lead Off Ditch	152	22	14.47	-	130	85.53	7
Non-Engineered	567	238	41.98	2	329	58.02	3
Stream Crossing	543	543	100.00	141	-	0.00	-
Sump	323	-	0.00	-	323	100.00	11
Water Bar	1,595	317	19.87	5	1,278	80.13	42

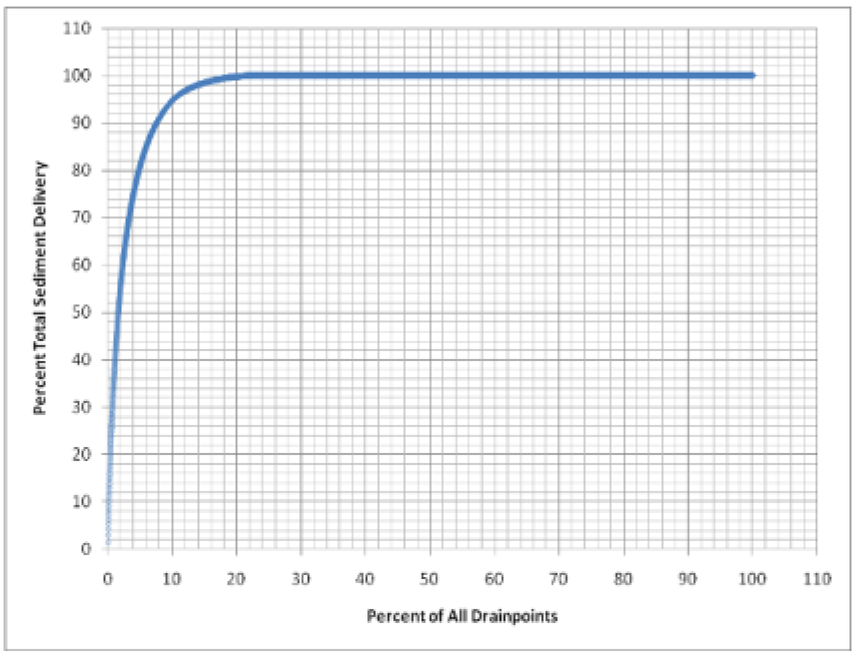

Figure 11. Percent total sediment delivered to streams by percent of drain points. Treating 1.6 percent of the drainpoints (104 sites) could reduce sediment delivery by as much as 50 percent (10506 kg/yr). Treating 9 percent (585 sites) could reduce sediment by as much as 90 percent.

The drain types with the highest percentage of features that actively deliver sediment to a stream channel are stream crossings (100%), non-engineered drains (42%), and ditch relief culverts (26%). Stream crossings, by definition, are connected and deliver sediment unless they are orphaned from the road. Non-engineered drains often have shorter connection distances than other drains such as water bars, broad based dips, and ditch reliefs. Ditch relief pipes concentrate flow and efficiently pass sediment from the road to the stream.

We examined the drain point data to consider which variables were significant in predicting the observed connection between the road and the channel. Using non-parametric statistics in the program Hyper-Niche, we analyzed 5,064 non-stream crossing drain points (McCune et al., 2010). Of the 16 candidate variables, the three most significant were found to be distance to channel, drain point type, and elevation. The elevation variable is most likely a proxy variable that contains information about geomorphic position and available water. It was observed that higher elevation sites included broad uplands and that lower elevation sites included many confined valleys; because of the confined valleys and resulting shorter distances from channels, connection rates are higher at low elevations. After these three variables, improvements to fit (log likelihood ratio) were too small to be useful. Additionally, non-engineered drain points showed the highest probability of stream connectivity out of the six drain point types analyzed.

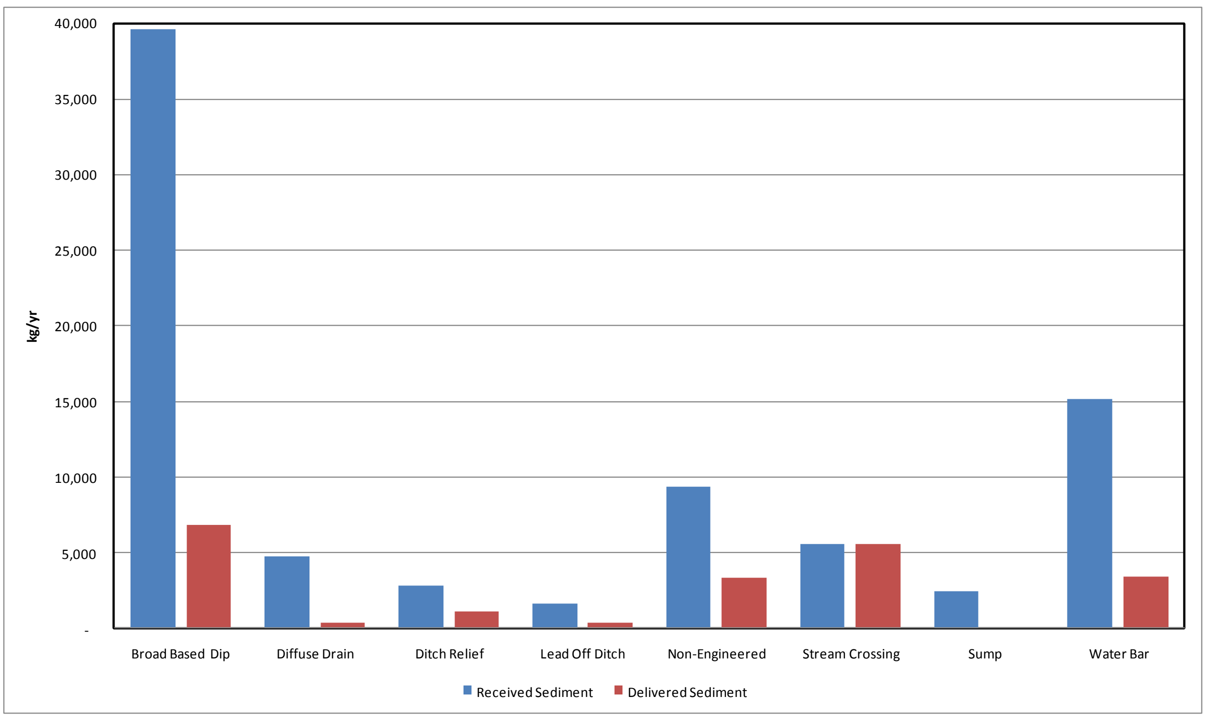

Figure 12. Distribution of total sediment received and delivered (kg/yr) for each drain type.

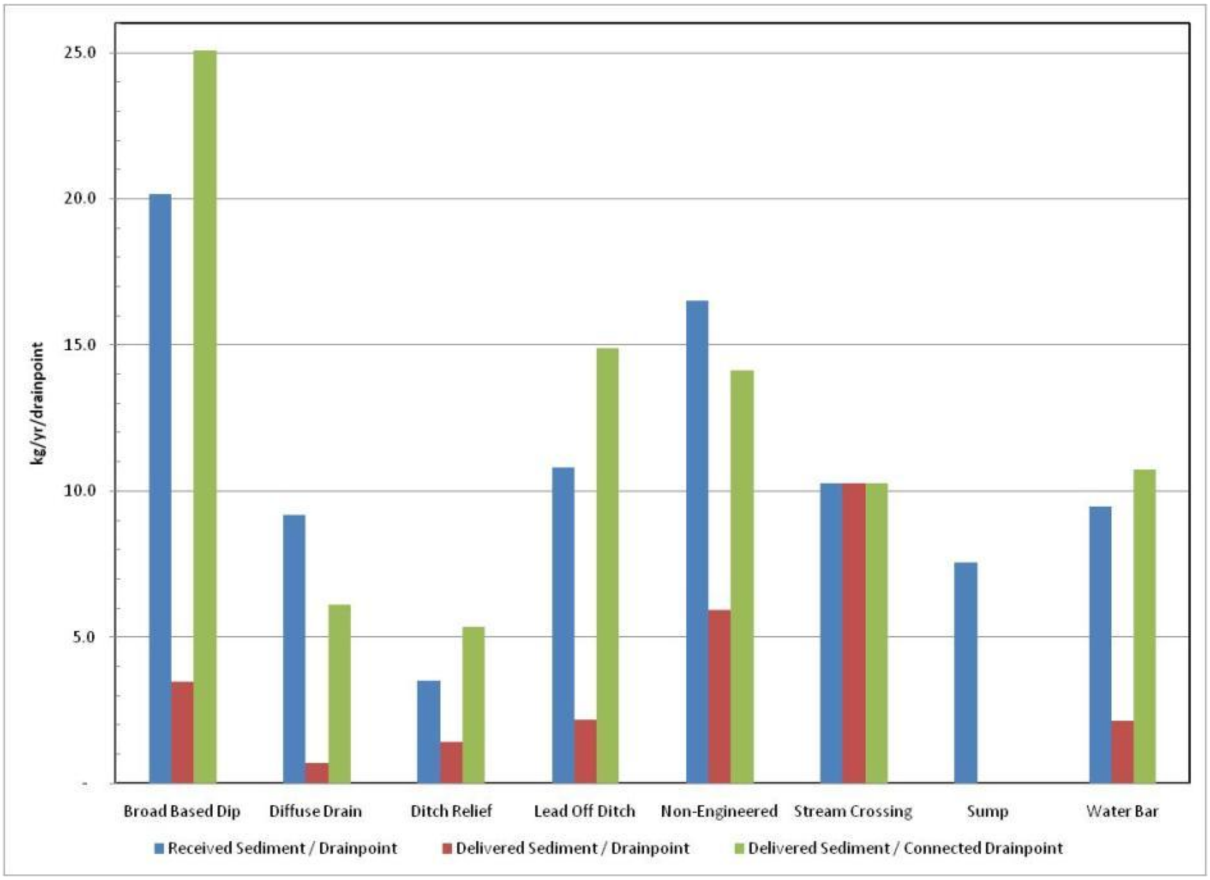

Figure 13. Sediment received and delivered normalized by number of drain points of each type.

While sediment delivery from road to stream occurs throughout the Wall Creek watershed, the Little Wall Creek subwatershed appears as a hot spot for sediment delivery (Table 10, Figure 14). The Little Wall Creek subwatershed has the greatest quantity of delivered sediment (6,846 kg/yr), the highest (39) percent delivery, the greatest average sediment delivery per drainpoint (5.2 kg/yr), and the greatest sediment delivery by area (76.6 $kg/yr/km^2$). Middle Big Wall and Lower Big Wall subwatersheds are next in order. Lower Big Wall ranks second for sediment delivery (4645 kg/yr), percent delivery (25 percent), and average sediment delivery per drainpoint (3.7 kg/yr). Middle Big Wall ranks second for sediment delivery by area (66.6 $kg/yr/km^2$).

Table 10. Sediment Production and Delivery by Subwatershed.

Subwatershed	SedProd (kg/yr)	SedDel (kg/yr)	Count	Area (km^2)	% Delivery	Average Delivery per Drainpoint (kg/yr)	Delivery per Unit Area (kg/yr/km^2)
Lower Big Wall	18,735	4,645	1,270	101	24.8	3.7	45.9
Middle Big Wall	19,421	4,241	1,620	64	21.8	2.6	66.6
Wilson Creek	12,041	2,876	1,320	108	23.9	2.2	26.7
Little Wall	17,620	6,846	1,311	89	38.9	5.2	76.6
Skookum	11,821	2,215	804	104	18.7	2.8	21.3

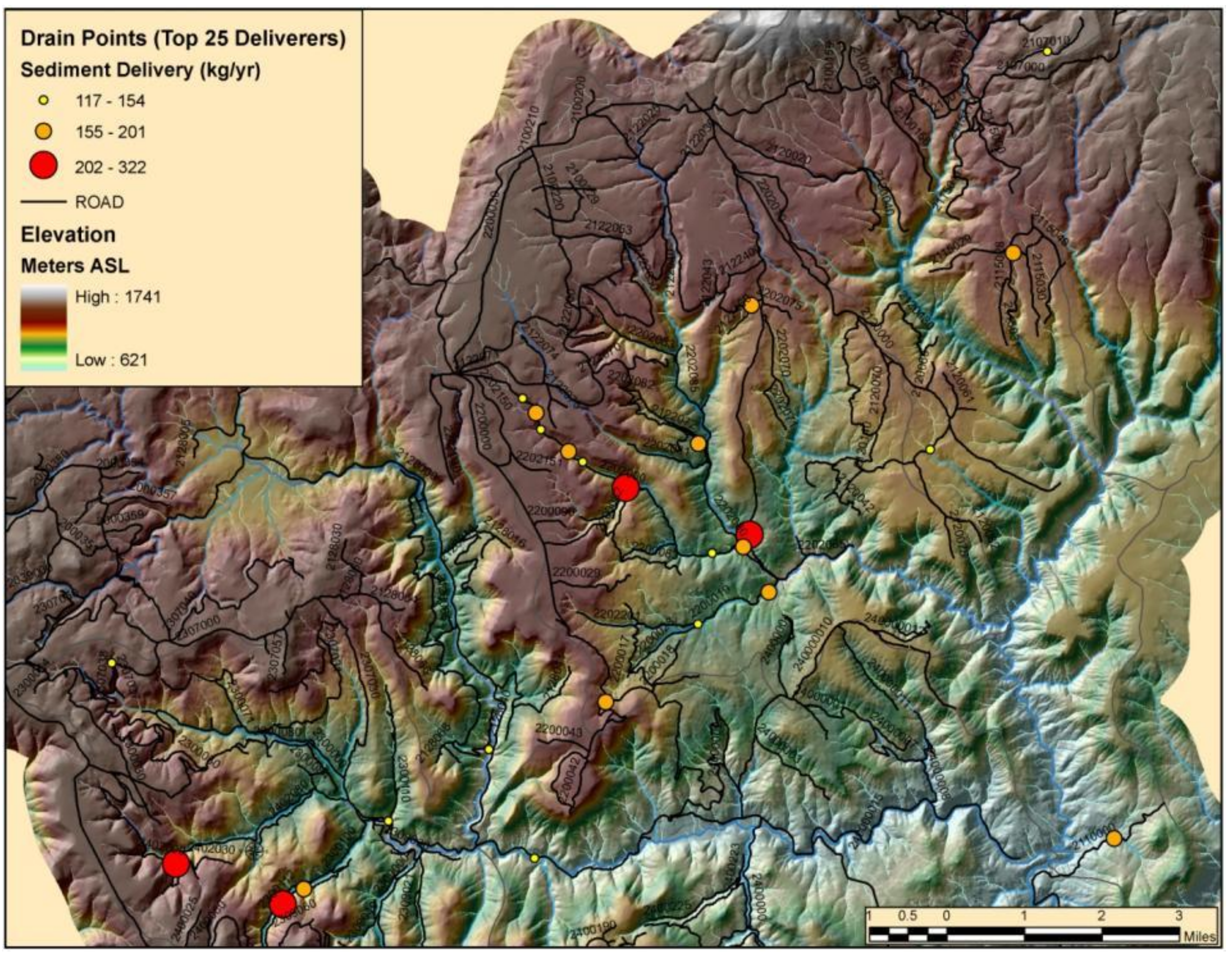

Figure 14. Top 25 drain points by sediment delivery.

Drain Point Condition

The GRAIP inventory includes evaluation 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 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 percent occlusion of the inlet by sediment, substantial inlet crushing, significant rust, or flow around the pipe. Lead-off ditches are considered a problem if they have excess deposition or are gullied. Non-engineered features are generally 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 (Table 11).

Typical drain point problems in the Wall Creek watershed include: puddles on roads, diverted wheel tracks, and partially blocked stream crossing (Figure 15). Non-engineered drains and stream crossings have the highest rate of problems (64% each), followed by sumps (61%). Less than 6 percent of the non-engineered drains and fewer than 5 percent of the stream crossings exhibit fill erosion problems.

Table 11. Drain Point Condition Problems and Fill Erosion Below Drain Points.

Drain Type	Count	Number with Problems	% with Problems	Number with Fill Erosion	% Eroded
Broad Based Dip	1,964	582	29.6	14	0.7
Diffuse Drain	521	0	0.0	0	0.0
Ditch Relief	808	191	23.6	10	1.2
Lead Off Ditch	152	8	5.3	0	0.0
Non-Engineered	567	363	64.0	33	5.8
Stream Crossing	543	348	64.1	24	4.4
Sump	323	196	60.7	0	0.0
Water Bar	1,595	173	10.8	8	0.5
Totals	**6,473**	**1,861**	**28.8**	**89**	**1.4**

Other road related information collected during the field inventory included: gates, ends of roads, gullies, landslides, photo points, road closure features, and road hazards. These additional features will provide further details about erosion and mass wasting features and be useful to managers in assessing the condition of roads and watershed resources.

Figure 15. Examples of drain point condition problems, clockwise from upper left: crushed and occluded ditch relief culvert (road 2200 near Turner Mountain), eroded waterbar (road 2200-027), buried ditch relief culvert (road 2128 near Wilson Prairie), and ditch relief emptying into gully below road crossing (road 2519).

4.4 Downstream Sediment Accumulation

Sediment enters the stream network below connected drain points. Road related sediment accumulates in the streams and is routed through the network. GRAIP calculates two measures of sediment accumulation for each stream segment. The first measure, sediment accumulation (Figure 16), is the mass of road-related sediment that passes through each stream segment per year. The assumption is road-related fine sediment has a residence time of less than one year. The second measure, specific sediment (Figure 17), is the mass of road-related sediment normalized by the contributing area. This measure is useful because larger streams with larger contributing areas can transport a greater mass of sediment, from all sources, and allows comparisons with smaller watersheds that may have fewer roads and smaller sediment loads.

Road-related sediment at the mouth of the Wall Creek watershed totals 20,822 kg/yr or .04 $Mg/km^2/yr$ (Tables 12 and 13, Figure 16 and 17). Specific sediment (sediment per unit area) in some small catchments ranges as high as 3.96 $Mg/km^2/yr$. Specific sediment at the mouth of the watershed is .04 $Mg/km^2/yr$.

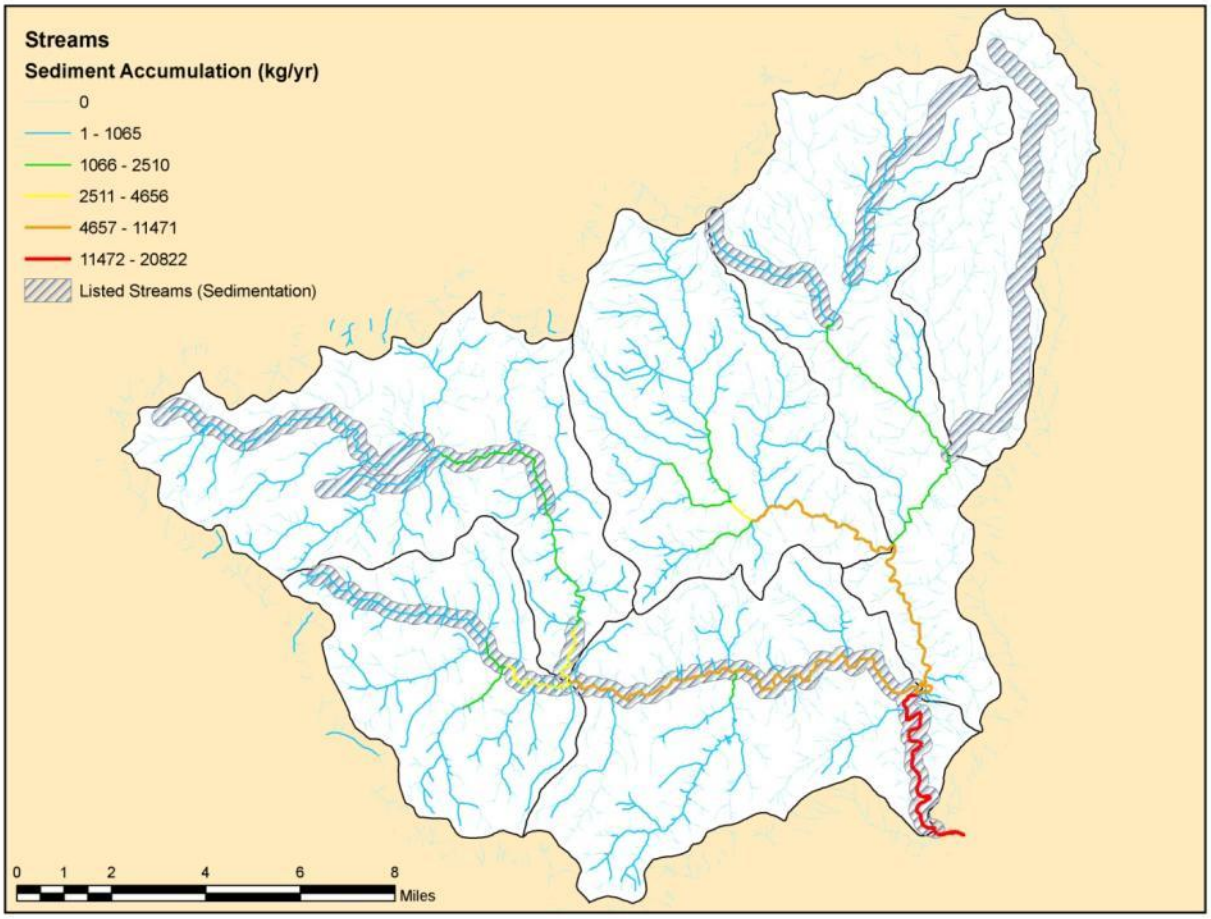

Figure 16. Sediment accumulation from roads in kg/yr and 303(d) streams listed for sediment in the Wall Creek watershed.

Table 12. Road-related sediment accumulation at the mouth of 303(d) streams listed for sedimentation (note roads in Swale Creek were not surveyed).

NAME	MILES	PARAMETER	Road Sediment at Mouth (kg/yr)	Road Sediment at Mouth (Mg/km^2/yr)
Swale Creek	0 to 11.1	Sedimentation	-	-
Big Wall Creek	0 to 21.3	Sedimentation	20,822	0.040
Alder Creek	0 to 5.5	Sedimentation	724	0.028
Hog Creek	0 to 4.1	Sedimentation	315	0.024
Wilson Creek	0 to 10.7	Sedimentation	2,877	0.027
Porter Creek	0 to 7.4	Sedimentation	604	0.017

Table 13. In-stream sediment by subwatershed.

Subwatershed	Including Upstream Subwatersheds		Excluding Upstream Subwatersheds		
	Road Sediment at Mouth (kg/yr)	Road Sediment at Mouth (Mg/km^2/yr)	Area (km^2)	Sediment Delivery (kg/yr)	Sediment Delivery (Mg/km^2/yr)
Lower Big Wall	20822	0.040	101	4645	0.046
Middle Big Wall	4240	0.070	64	4241	0.067
Wilson Creek	2877	0.027	108	2876	0.027
Little Wall	6878	0.077	89	6846	0.077
Skookum	9074	0.037	104	2215	0.021

Comparing road sediment accumulation in surveyed 303(d) streams, Big Wall Creek has the highest specific sediment loads and Porter Creek the lowest (Figure 17, Table 12).

Road sediment at the mouth of each subwatershed was derived from the stream shapefile; these figures include the contributions and area of upstream subwatersheds, hence, Lower Big Wall represents the entire Wall Creek watershed. Sediment delivery is derived from the drain point file and the area of each subwatershed; these figures do not include contributions or area of upstream subwatersheds.

Background sediment yields, roads and other sources

Estimating the proportion that road sediment contributes to the total sediment load for the watershed requires estimating an annual base sediment yield, and identifying other sources, which presents numerous technical challenges. Sediment yields in forested watersheds are highly variable from year to year, with annual loads largely driven by climatic events and watershed disturbances. Published regional and local data sources, and FSWEPP model estimates were considered in estimating background sediment (http://forest.moscowfsl.wsu.edu/fswepp/). Sediment yield data from 10 years of monitoring in upper Skookum Creek (Harris et al, 2005 and Wondzell et al, 2007), and WEPP FuME model runs give annual values in the range of 1000 to 4000 kg/km2/yr. Using the lower value, a base estimate for the watershed is 518,000 kg/yr, with road sediment making a small (<5%) contribution above background sediment loads.

Overall sediment yields using the above estimates are relatively low, and the direct contribution of roads to background sediment yields on an annual basis appears to be low. Roads may be contributing indirectly to watershed sediment yields by increasing channel erosion through hydrologic connectivity (peak flows) during storm events. Sediment produced in the watershed is generally fine grained and readily mobile, with transport occurring during short periods of precipitation and/or snowmelt. Other “above-base” sources include historic grazing and logging but these are largely legacy effects with sediment either already mobilized in the channel network or exported out of the watershed. Current practices (grazing, logging, recreation) produce small amounts sediment but BMPs control delivery to channels so effects are minor and localized. Most perennial streams on the

National Forest, for example, have been fenced from livestock grazing access since in the mid 1990s. The BLM has not permitted grazing on most of their land in lower Wall Creek since 2000. Over one million dollars in watershed improvement projects have been implemented over the last two decades in the watershed, including instream habitat enhancement, riparian planting, repairs to road-stream crossings, and about 15 miles of road decommissioning just in the last 2 years (Wall Creek Watershed Action Plan, 2009). The road system remains the largest contemporary source of hydrologic impact in the watershed.

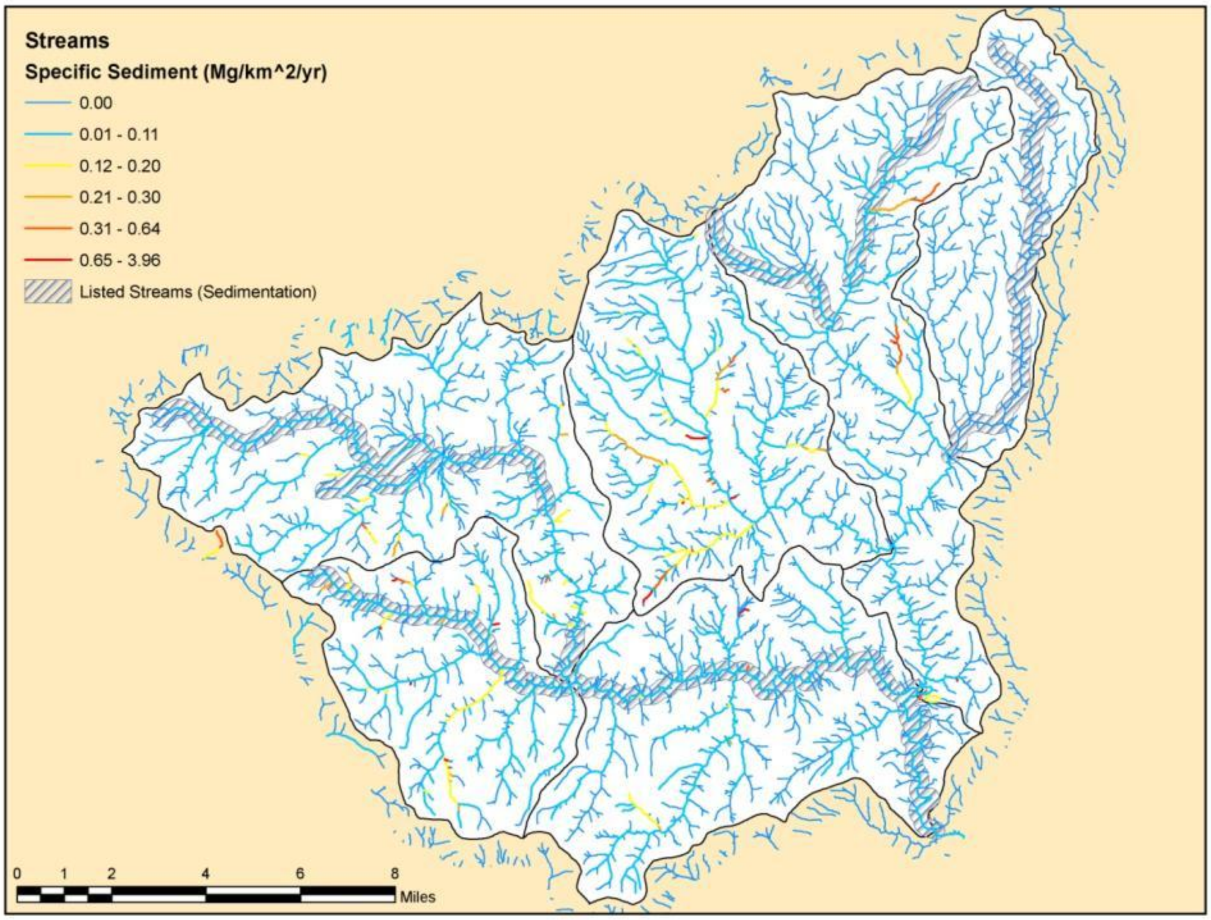

Figure 17. Specific sediment from roads and streams listed for sediment in the Wall Creek watershed.

4.5 Stream Crossing Failure Risk

Besides contributing fine sediment to streams through chronic 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.

Field crews recorded a total of 543 stream crossings in the Wall Creek watershed. Crossings with culverts (281) were included in the analysis; the 262 crossings without culverts were not included in SBI calculations. These crossings included natural fords (217) and excavated crossings (33). Risk of pipe plugging is not a factor at these crossings.

The average SBI value for the Wall Creek watershed is 1.78 for the 281 assessed stream crossings. This in a range of 1 to 4, where 1 indicates minimal risk of blockage (Figure 18). All stream crossings with an SBI of 4 have pipe to channel ratios less than or equal to 0.375 and skew angles greater than 45 degrees. Crossings with an SBI of 3 have pipe to channel ratios between 0.25 and 0.83 and skew angles are considered a problem (>45 degrees) in 19 of 51 cases. Stream crossings with an SBI of 1 all have pipe to channel ratios greater than or equal to 1 and no problems with skew angles. A few of these have pipes are three times the width of the stream. It is recommended that the 56 stream crossings with an SBI value of 3 or 4 be considered high risk and be considered for risk reduction measures.

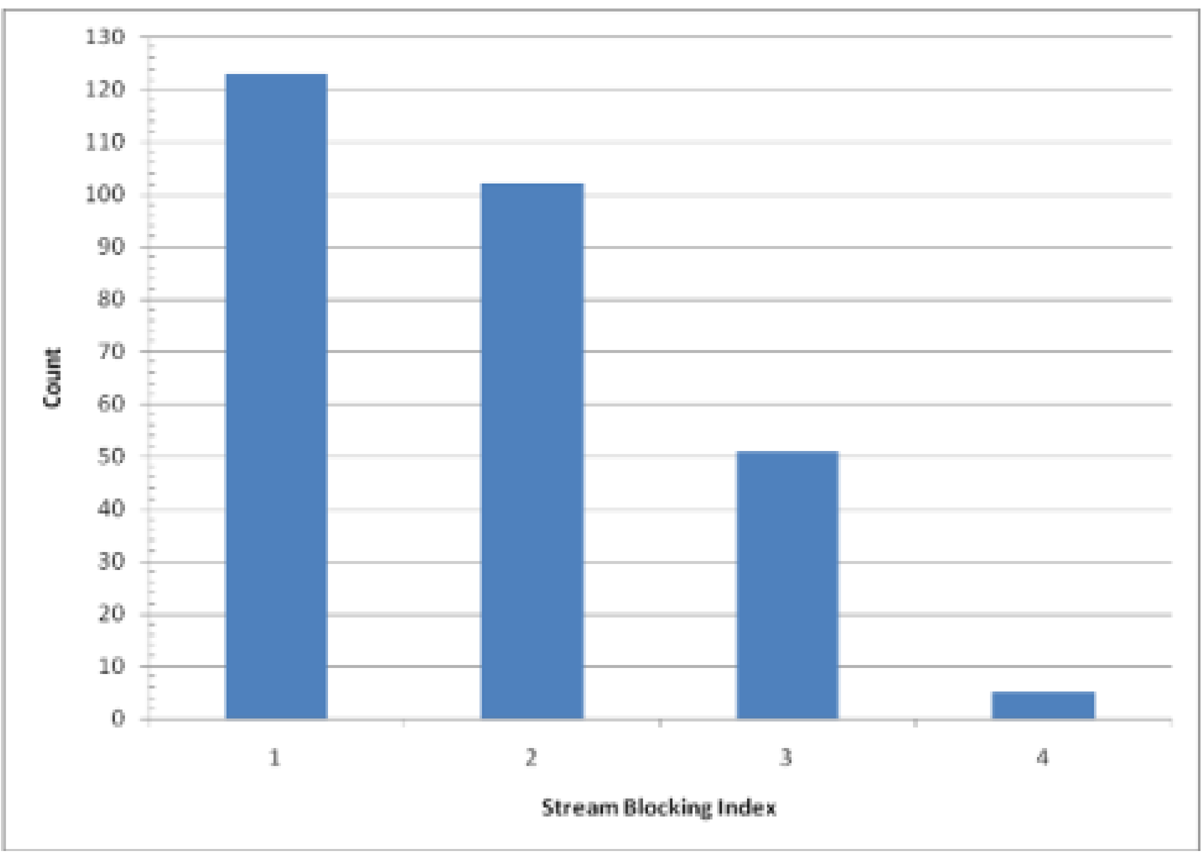

Figure 18. Distribution of Stream Blocking Index values.

Another potential problem at stream crossings is the risk of diversion when crossings are blocked or undersized. Of the 543 stream crossings recorded, 446 have no potential diversion, 96 have the possibility of diversion onto the road in one direction, and only one crossing (headwaters of Indian Creek) could be diverted onto the road in both directions.

When crossings fail and divert water onto roadways, damage to the road and to downslope areas occur by surface erosion, ditch erosion, and mass failure of fill slopes (Furniss et al., 1997, Best et al., 1995). While these types of failures are infrequent, they can be catastrophic. Stream crossings at high risk of blocking (SBI of 3 or 4) and having diversion potential should have the highest priority for risk reduction treatments.

4.6 Gullies and Gully Initiation Risk

Existing Gullies

For inventory purposes, gullies were defined as “V-shaped” erosional features more than 10 feet in length and at least 6 inches in average depth. Non-road-associated gullies were found to be caused by factors other than the road network. Road-associated gullies receive direct or indirect discharge from the road.

Of the 59 located gullies (Figure 19), 18 of them are not associated with the road network and are more likely related to past grazing, logging, fire, or other impact. Only 12 of the 59 gullies receive direct discharge from the road. Most of the 41 road-associated gullies receive contributions from the road and from swales or colluvial hollows and initiate at some break in slope downhill from the road; such gullies most likely not caused by the road drainage, though they are likely significantly impacted by such additional drainage. Direct discharge from the road does result in a slight increase in average gully volume.

Significant volumes of sediment have been removed by gullies recorded in the study (Table 14); however, the locations of these gullies and their volumes seem to be related to local conditions rather than a length of road, contributing area, or slope. Road-associated gullies are responsible for 49% of the eroded material from the gullies; 51% of the estimated gully volume in due to the 18 gullies that are not road-associated. The nearly 4,000 tonnes of sediment removed by road-associated gullies is the equivalent of over 175 years of fine sediment delivery from the road surface. While the road network does provide water to these gullies and is therefore responsible for some fraction of the eroded material, it is unlikely that these gullies would not have existed without the road network’s contribution.

Table 14. Statistics for different populations of gullies located in the Wall Creek watershed.

	Count	Volume (m^3)	Average Volume (m^3)	Mass (kg)
All Gullies	59	6,185	105	8,040,302
Non-road Associated Gullies	18	3,168	176	4,117,927
Road-Associated Gullies	41	3,017	74	3,922,375
Gullies with Direct Discharge from Road	12	1,060	88	1,377,639

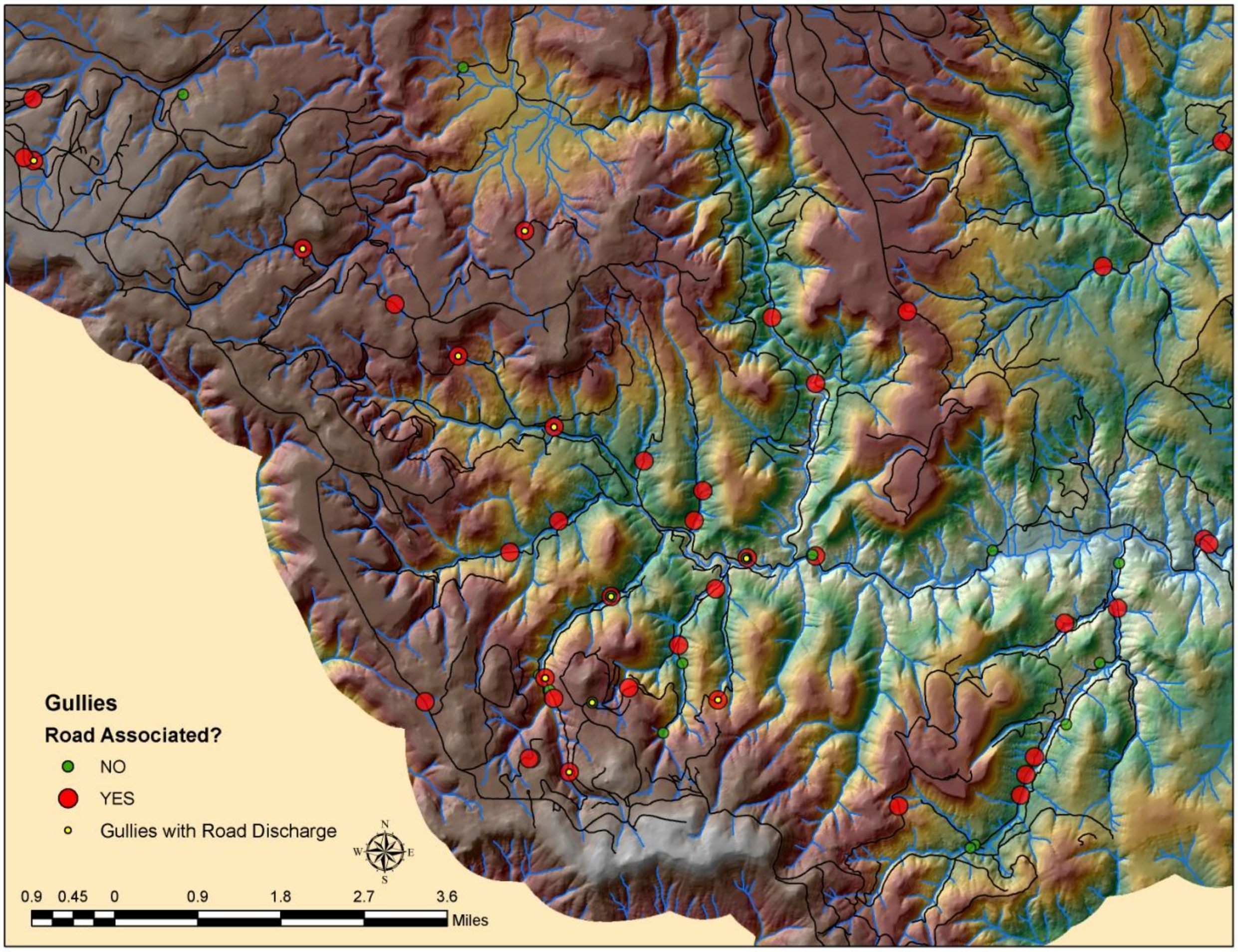

Figure 19. Map of gully types and locations in the Wall Creek watershed.

Gully Initiation Risk

Road-related gully formation can be a substantial source of sediment delivered 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

ESI is a measure of the road-related driving forces responsible for gully initiation. 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. A critical ESI threshold does not appear to apply in this study area (Figure 20, Tables 15 and 16), as other local factors (e.g. soil strength) likely control the location of gullies.

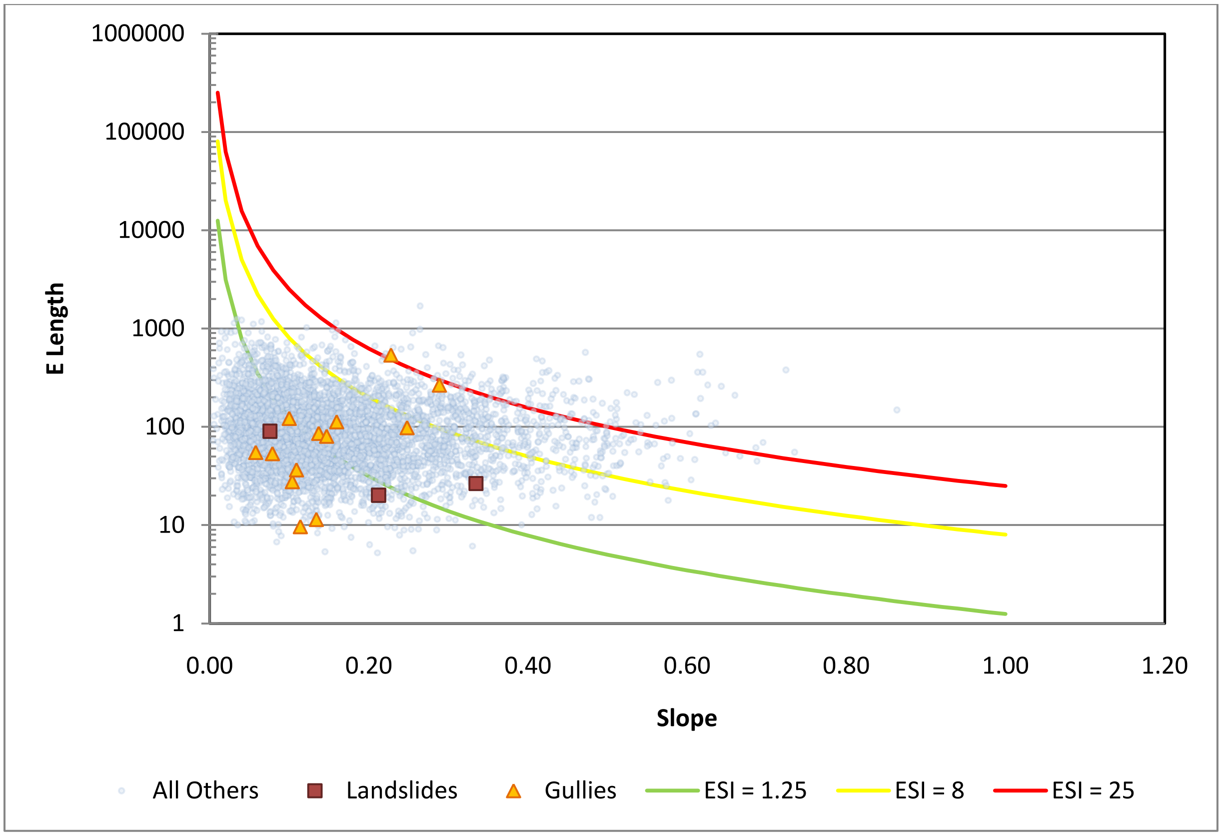

Figure 20. Plot showing length/slope relationships for landslides, gullies, and other drainpoints in the Wall Creek watershed. Note lack of critical ESI relationship. One drainpoint is an orphan (E Length = 0) and is not shown.

Table 15. ESI values for all concentrated drain points in the Wall Creek watershed.

Drainpoint Discharges to:	**ESI < 1.25**	**1.25 <= ESI < 8**	**8 <= ESI < 25**	**ESI > 25**
Gully	8	4	1	1
Landslide	2	1	0	0
Elsewhere	3300	2323	670	163
Gully %	0.24	0.17	0.15	0.61
Landslide %	0.06	0.04	0	0

Table 16. ESI summary statistics.

	Minimum	Maximum	Average	Standard Deviation
All Drains	0.00	208.02	3.98	9.11
All Drains, except diffuse, stream crossings, and orphans	0.00	208.02	4.40	9.67
Drains within 50 m of a recorded gully	0.00	28.62	2.49	5.18
Drains within 50 m of a recorded gully, except diffuse, stream crossings, and orphans	0.07	28.62	3.31	6.29
Drains direct to gully	0.00	27.88	4.65	8.53

4.7 Landslide Risk

Existing Landslides

Landslides are rare within the Wall Creek watershed, with 1 slump mapped on existing Forest GIS layers. This feature is located on the lower east slope of Wall Creek below Big Willow Springs. Several segments of roads bisect the slump (2300-100, 2309-030, and 2309-031). All produce sediment and 1 short section of 2309-030 delivers to a tributary to Wall Creek. Of the 19 landslides recorded in the field inventory, 16 were considered to be road related. Most of these were fill-slope or cut-slope failures. Of the road related landslides, three have drain points that deliver water and sediment to the slides. Though steep canyon walls have higher potential landslide risk and lower threshold stability, most slopes appear stable or subject to slow creep or rock fall rather than mass failure by landslide or slumping. This is characteristic of near-horizontal, resistant basalt flows.

Changes in Landslide Risk

The risk of shallow landslide initiation is predicted using SINMAP 2.0 (Pack et al., 2005, http://hydrology.neng.usu.edu/sinmap2/), modified to account for contributions of road runoff. Landslide risk, evaluated using a stability index, is generally low throughout the watershed whether or not the effects of roads are taken into account. Further, changes due to the effects of roads are generally of low magnitude and localized (Figure 21), most often only slightly decreasing the stability of lower threshold areas (Figures 22 and 23).

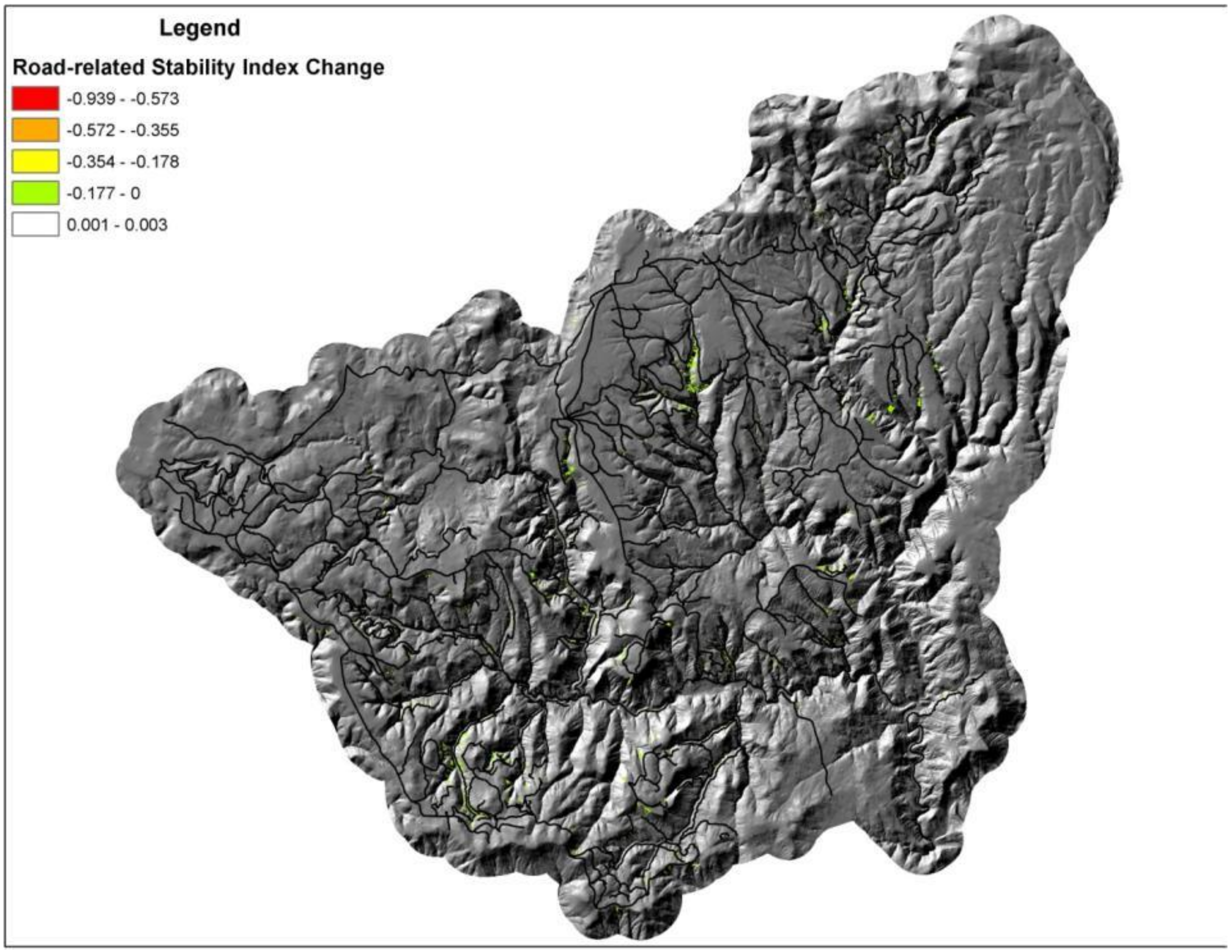

Figure 21. Location of road-related impacts on hillslope stability.

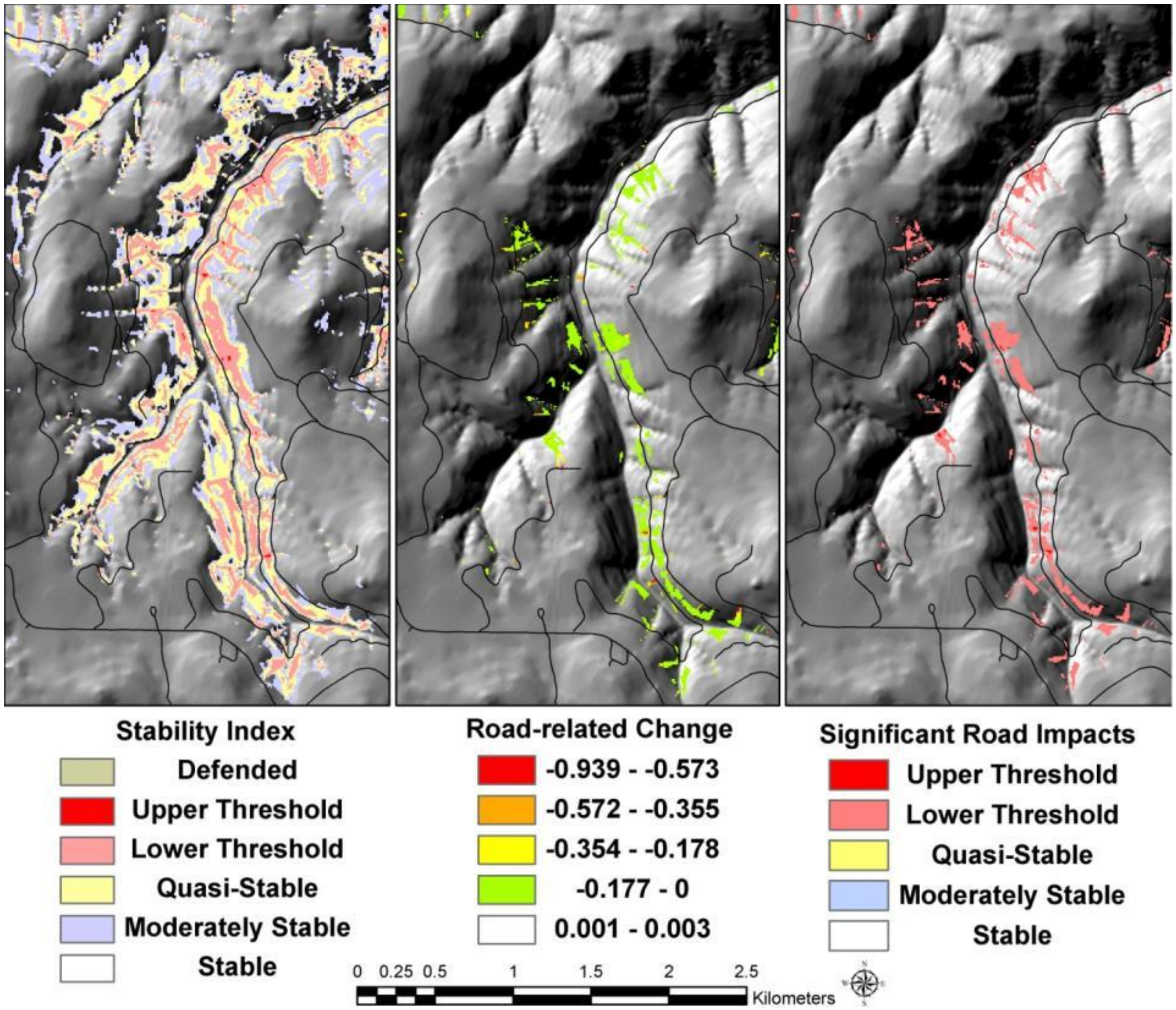

Figure 22. Effects of roads on the Stability Index along the 2300-100 road. Left; map of the stability index without the effect of road-related runoff. Center; effects of road-related runoff expressed as a difference in areas where the road has destabilized or reduced the stability of already unstable slopes. Right; map of the stability index with the effects of road-related runoff in areas altered by the road.

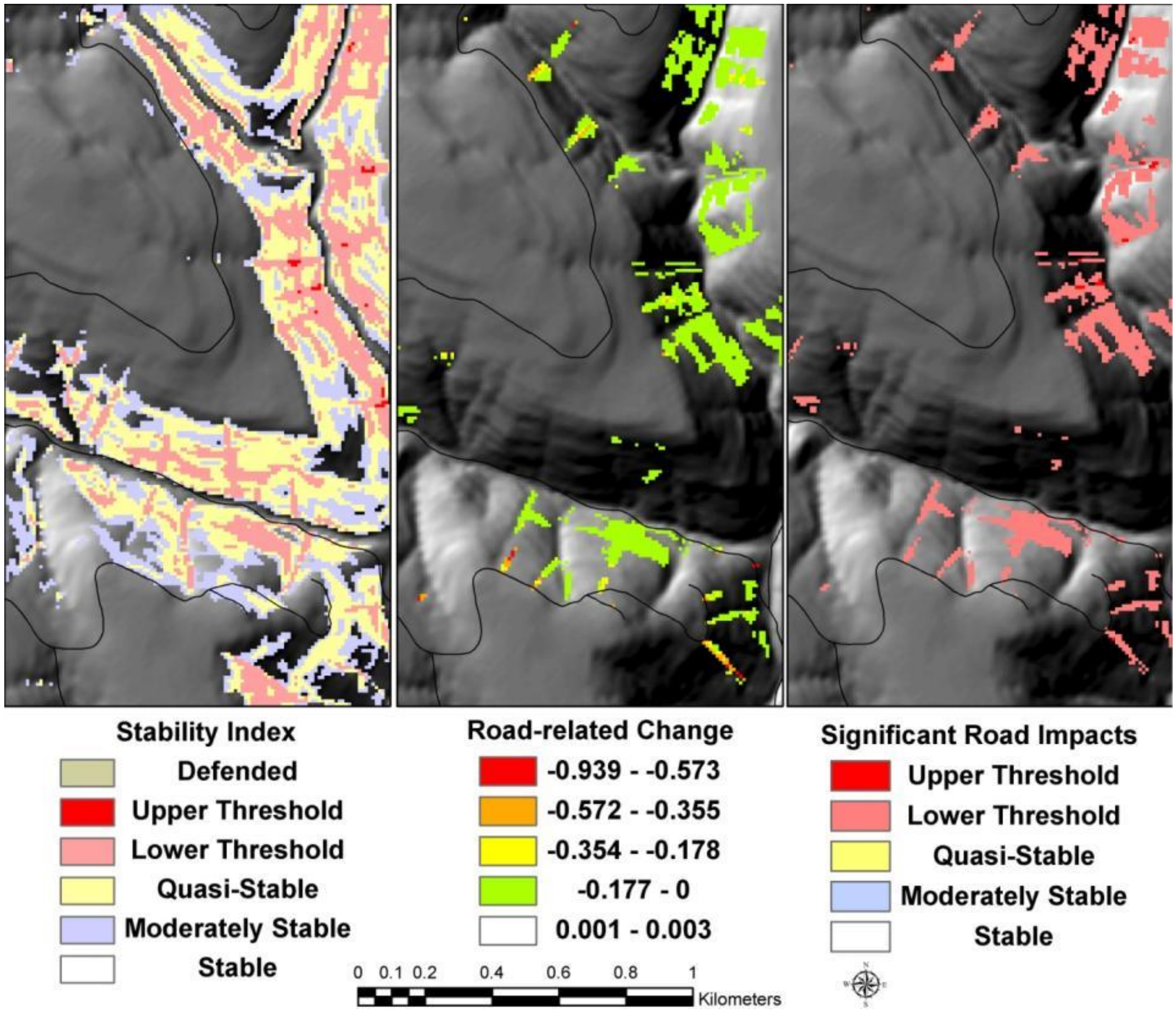

Figure 23. Effects of roads on the Stability Index near the junction of Squaw Creek and Little Wall Creek. Left; stability index without the effect of road-related runoff. Center; effects of road-related runoff expressed as a difference in areas where the road has destabilized or reduced the stability of already unstable slopes. Right; stability index with the effects of road-related runoff in areas altered by the road.

5.0 Inventory Cost Structure

The Wall Creek project was funded by the EPA Region 10 and the BLM Oregon State office, with some additional support from the Umatilla National Forest and the Rocky Mountain Research Station. Six seasonal employees were hired for the summer to carry out the project including four crew people, a crew leader and a GIS analyst. Fifty-two percent of the funding was used to support the field data acquisition, and thirty percent was used to support the data processing, modeling, analysis and report writing (Figure 24). The field crew was in travel status during the work on the Wall Creek project, so per diem was paid. Some personal vehicle mileage was paid as part of travel that should appear in the vehicle category. Vehicle costs were lower than expected at 5% of project costs due to a substantial fuel surcharge rebate issued by GSA. Much of the equipment used in the study was already available to the project and was not purchased with project funds. The total project cost including overhead was $110,000.

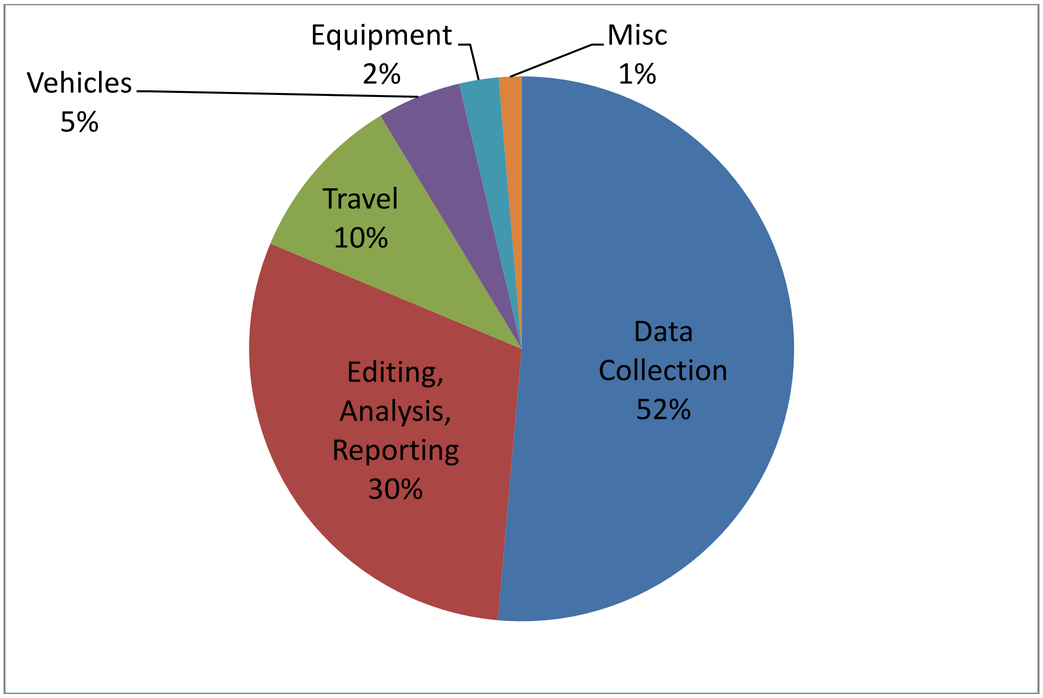

Figure 24. Percentage of project funds used for each cost category. Salary for data collection accounted for more than half the project cost.

6.0 Quality Assurance Project Plan Results

To ensure accuracy and consistency between field crews, each crew received training prior to being dispatched to the study area. Field crews received additional training in the field by the field crew leader on arrival. The field crew leader also visited with the crews in the field at least once per work period (8 days) to evaluate crew performance and to answer any field related questions that came up. The crew leader was a member of an "expert" team for empirical assessment of crew precision and bias.

Three road sections were selected for Quality Assurance and Quality Control (QAQC) analysis (Figure 25). Each road segment was completed independently by each crew and by an expert team. Sediment production and sediment delivery results were compared to measure precision and bias. One section was selected based on having high sediment production and delivery. The 2nd section was specifically chosen to have only a few sediment delivery points (low sediment delivery). The 3rd section was chosen by convenience and is generally representative of average road conditions in the watershed.

Precision is a measure of repeatability and consistency. Since sediment production and delivery values were so low, absolute precision was measured by calculating the standard deviation:

$$s = \sqrt{\frac{\sum_{i-1}^{n}(x_i - \overline{X})^2}{n+1}}$$

where,

x_i = individual estimate of sediment production or delivery (replicate)

$\overline{X}$ = mean of all replicates, including estimates derived from measurements by expert crew

N = number of replicates

Bias is a measure of accuracy. Absolute bias was calculated as:

$$B = \overline{X} - T$$

where,

T = estimated sediment production or delivery based on measurements obtained by expert crew

$\overline{X}$ = mean of all replicates, not including results of expert crew

Data quality objectives were selected as target values for sediment production and delivery for each 2-mile QAQC plot. Absolute values of 2 T/km/yr for sediment production and 1 T/km/yr for sediment delivery were established for plots with production values less than 10 T/km/yr and delivery values less than 5 T/km/yr. Above these values, a relative target of 20% applies.

Precision and bias were calculated for each of the three road segments and for all three in combination. For individual road segments, precision ranged from 0.01 T/km/yr to 0.12 T/km/yr and bias ranged from -0.09 T/km/yr to 0.16 T/km/yr (Table 17). On a watershed basis, precision is 0.05 T/km/yr for both sediment production and delivery; bias is 0.02 T/km/yr for sediment delivery and 0.04 T/km/yr for sediment production. These values are well below the target values of 1 T/km/yr for sediment delivery and 2 T/km/yr for sediment production. Relative precision and bias measures are within 20 percent except for the precision of sediment delivery (25.5%), when analyzed at the watershed scale. Differences between individual crews and the expert crew for individual road sections are greater than the differences for the aggregated road sections. This implies that, while differences between crews measured on individual sections may be large, the data collected across the watershed is consistent, regardless of which crew collected the data.

Table 17. QAQC statistics for Wall Creek using absolute precision and bias measures.

QAQC1					
	Experts	Crew 1	Crew 2	Abs_Prec	Abs_Bias
Sum DP_SedDel	1415	892	1272		
Sum DP_SedProd	1440	1258	1438		
Sum_RD_Length	3598	3592	3617		
SedDel/Length (T/km)	0.39	0.25	0.35	0.07	-0.09
SedProd/Lemgth (T/km)	0.40	0.35	0.40	0.03	-0.03

QAQC2					
	Experts	Crew 1	Crew 2	Abs_Prec	Abs_Bias
Sum DP_SedDel	118	399	712		
Sum DP_SedProd	454	688	1220		
Sum_RD_Length	3163	3161	3157		
SedDel/Length (T/km)	0.04	0.13	0.23	0.09	0.14
SedProd/Lemgth (T/km)	0.14	0.22	0.39	0.12	0.16

QAQC3					
	Experts	Crew 1	Crew 2	Abs_Prec	Abs_Bias
Sum DP_SedDel	306	235	513		
Sum DP_SedProd	540	486	580		
Sum_RD_Length	3185	3172	3173		
SedDel/Length (T/km)	0.10	0.07	0.16	0.05	0.02
SedProd/Length (T/km)	0.17	0.15	0.18	0.01	0.00

All					
	Experts	Crew 1	Crew 2	Abs_Prec	Abs_Bias
Sum DP_SedDel	1839	1525	2496		
Sum DP_SedProd	2434	2432	3237		
Sum_RD_Length	9946	9925	9948		
SedDel/Length (T/km)	0.18	0.15	0.25	0.05	0.02
SedProd/Length (T/km)	0.24	0.25	0.33	0.05	0.04

Because of how the model interprets the field data when calculating the sediment production and delivery, the most important factors for crews to get right are the road surface type, flowpath vegetation, flowpath length (how many road segments drain to each drain point), and drain point stream connection. Further analysis was performed to look at how consistently the crews agreed with the expert crew on these factors (Table 18), and what effect differences might have on the overall model results. Road-related values were analyzed as percents of the total road length that were recorded as native or connected to the stream. Flowpath vegetation was expressed as the percent of the total flowpath length having vegetation cover less than 25 percent. Drain points were analyzed by percent connected. Road surface type and flowpath vegetation are the two major factors related to sediment production on a given road segment. Drain point connectivity and the connected road length are more important for sediment delivery.

In general, crews recorded a greater percentage (19.3% greater) of the roads as having a native surface than the experts, and the overall precision was 14.7 percent. The extreme case occurred on the second QAQC plot. This road has a crushed rock surface for most of its length, but that surface cover is often only intact on about 50 percent of the road surface. This means that, in effect, the road is, at any given point, half crushed rock and half native. The experts recorded 11.5 percent of the road as native, crew 1 recorded 42.8 percent, and crew 2 recorded 92.7 percent. This resulted in prediction of greater quantities of sediment being produced on the road.

On the other hand, crews tended to record more vegetation in the flowpath, resulting in a lower percentage (0.95% lower overall) of the road having flowpath vegetation cover of less than 25 percent. This accounts for most of the difference in sediment production on QAQC plot 1, and would tend to reduce sediment production predictions slightly. Overall precision regarding flowpath vegetation (2.7%) was better than any of the other measured variables.

Drain point connections to the stream provide the link to pass sediment from the road network to the stream network. Drain point connection, as expressed by percent of collected drainpoints that were deemed to be connected, yielded a precision of 11.0 percent. Crews tended to connect drain points more often than the experts (bias of 15.7%). This has a tendency to increase sediment delivery predictions relative to the predictions of the experts.

Another major factor that affects the amount of predicted sediment delivery is the length of road that is hydrologically connected to the stream network. Due to the possibility of orphan drain points and drain points that only drain one flowpath, the connected length is not entirely dependent on the number of connected drain points. Precision was 10.9 percent and bias was 6.5 percent. A bias toward having more of the road network connected also increases the sediment delivery predictions relative to those of the expert crew.

The net outcome is an increase in predicted sediment production and delivery relative to the experts' predictions. Using all three combined QAQC plots, relative precisions and biases for sediment delivery per unit length were 25.7 and 9.4 percent, and for sediment production per unit length were 17.1 and 16.6 percent.

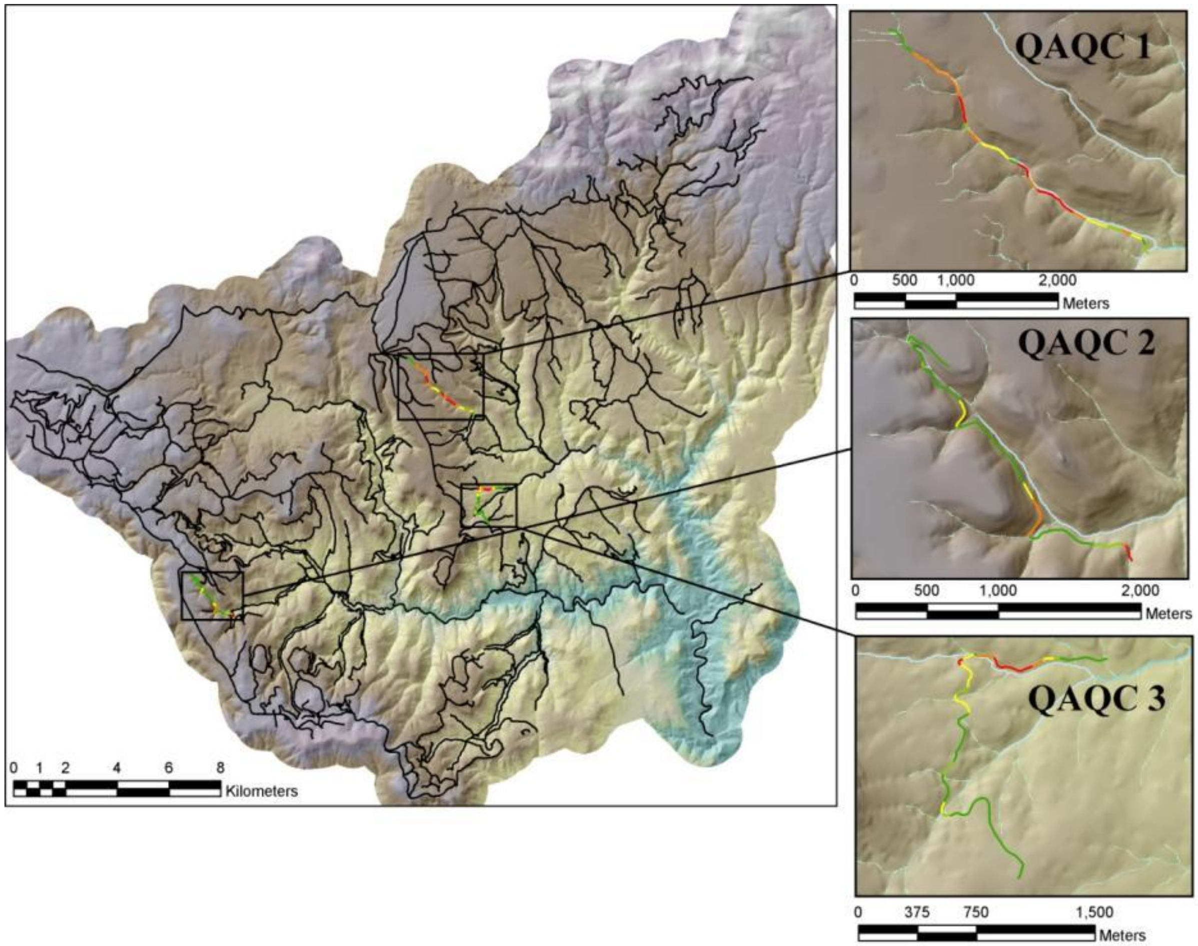

Figure 25. Locations of the QAQC Plots. Details shown in Appendix 3.

Table 18. Expanded QAQC test results. Additional factors include the percent road-lengths recorded as having native surface type, flowpath vegetation <25 percent, and stream-connected, and the percentage of drainpoints that were recorded as stream-connected. Values are also shown for sediment delivery, sediment production, and road length.

	Experts	Crew 1	Crew 2	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
QAQC 1							
Percent Native	100.0%	100.0%	100.0%	0.00	0.00%	0.00	0.00%
Percent FPVeg <25%	94.7%	82.1%	97.1%	0.08	8.83%	-0.05	-5.39%
Percent Connected	70.0%	85.7%	77.3%	0.08	10.13%	0.11	16.42%
Percent Length Connected	96.5%	71.9%	86.8%	0.12	14.57%	-0.17	-17.77%
Sum DP_SedDel	1415	892	1272	270.53	22.68%	-333.35	-23.56%
Sum DP_SedProd	1440	1258	1438	104.27	7.56%	-92.03	-6.39%
Sum_RD_Length	3598	3592	3617	13.22	0.37%	6.29	0.17%
SedDel/Length (T/km)	0.393	0.248	0.352	0.07	22.56%	-0.09	-23.74%
SedProd/Length (T/km)	0.400	0.350	0.398	0.03	7.33%	-0.03	-6.57%
QAQC 2							
	Experts	Crew 1	Crew 2	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
Percent Native	11.5%	42.8%	92.7%	0.41	83.58%	0.56	489.13%
Percent FPVeg <25%	96.2%	95.0%	94.5%	0.01	0.92%	-0.01	-1.51%
Percent Connected	37.5%	58.8%	73.1%	0.18	31.71%	0.28	75.87%
Percent Length Connected	23.9%	47.9%	63.9%	0.20	44.51%	0.32	133.89%
Sum DP_SedDel	118	399	712	296.91	72.49%	436.90	369.32%
Sum DP_SedProd	454	688	1220	392.20	49.81%	499.39	109.89%
Sum_RD_Length	3163	3161	3157	2.79	0.09%	-3.67	-0.12%
SedDel/Length (T/km)	0.037	0.126	0.225	0.09	72.56%	0.14	369.94%
SedProd/Length (T/km)	0.144	0.218	0.386	0.12	49.90%	0.16	110.16%
QAQC 3							
	Experts	Crew 1	Crew 2	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
Percent Native	32.8%	32.0%	42.0%	0.06	15.61%	0.04	12.80%
Percent FPVeg <25%	95.8%	100.0%	100.0%	0.02	2.46%	0.04	4.38%
Percent Connected	51.9%	40.7%	68.0%	0.14	25.61%	0.03	4.86%
Percent Length Connected	43.3%	35.6%	66.1%	0.16	32.82%	0.08	17.44%
Sum DP_SedDel	306	235	513	144.26	41.09%	68.03	22.25%
Sum DP_SedProd	540	486	580	47.01	8.78%	-6.82	-1.26%
Sum_RD_Length	3185	3172	3173	7.01	0.22%	-12.10	-0.38%
SedDel/Length (T/km)	0.096	0.074	0.162	0.05	41.17%	0.02	22.71%
SedProd/Length (T/km)	0.169	0.153	0.183	0.01	8.76%	0.00	-0.89%
All QAQC							
	Experts	Crew 1	Crew 2	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
Percent Native	50.3%	60.0%	79.2%	0.15	23.28%	0.19	38.37%
Percent FPVeg <25%	95.5%	91.9%	97.2%	0.03	2.85%	-0.01	-0.99%
Percent Connected	50.6%	60.0%	72.6%	0.11	18.05%	0.16	30.95%
Percent Length Connected	56.4%	52.6%	73.1%	0.11	17.97%	0.06	11.44%
Sum DP_SedDel	1839	1525	2496	495.54	25.37%	171.58	9.33%
Sum DP_SedProd	2434	2432	3237	464.14	17.18%	400.54	16.45%
Sum_RD_Length	9946	9925	9948	12.76	0.13%	-9.48	-0.10%
SedDel/Length (T/km)	0.185	0.154	0.251	0.05	25.27%	0.02	9.40%
SedProd/Length (T/km)	0.245	0.245	0.325	0.05	17.10%	0.04	16.55%

7.0 GRAIP and RBS analysis

Relative Bed Stability (RBS) is an index derived by comparing the observed mean particle size of the stream bed with the estimated critical mean particle size at bankfull flow (Kauffman et al., 2007). It is often expressed as $\log_{10}$RBS with positive values indicating greater stability (armoring) of the stream bed. Negative values indicate the presence of an increased sediment supply relative to a stream's transport capacity, often due to increased intensity of land use (Kauffman et al., 2007).

The Geomorphic Road Assessment and Inventory Package (GRAIP) provides spatially explicit predictions of road-related sediment production, delivery, and accumulation within the road-stream network based on a detailed inventory of roads and drain points within a target watershed. Specific sediment is the road-related accumulated sediment at a given point or reach normalized by the contributing area of that point or reach. Specific sediment is expressed in units of $kg/km^2/yr$. Direct sediment inputs are the mass of road-related sediment that enters a reach directly from the road, and is expressed in units of kg/yr. We tested both metrics because the seasonality (summer) of road derived sediments could localize impacts to reaches where the sediment was delivered.

If RBS were sensitive to road-related sediment impacts in watershed, then a negative relationship between RBS and either specific sediment accumulation or direct sediment would be expected. We found no relationship; in fact, both graphs show slight positive trends between RBS and GRAIP predicted road-derived sediment (Figures 26 and 27). This suggests no relationship between modeled road sediment and RBS, and that RBS would have limited utility as a monitoring tool to detect road impacts.

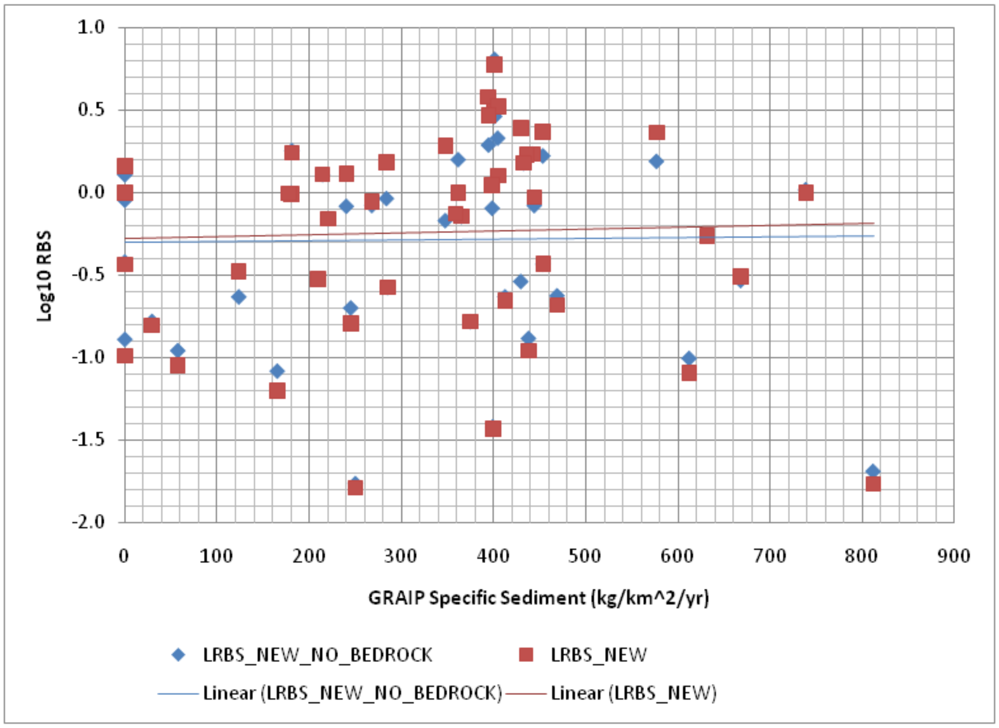

Figure 26. Specific sediment (total upstream road contribution divided by contributing area) vs measured LRBS (with and without bedrock).

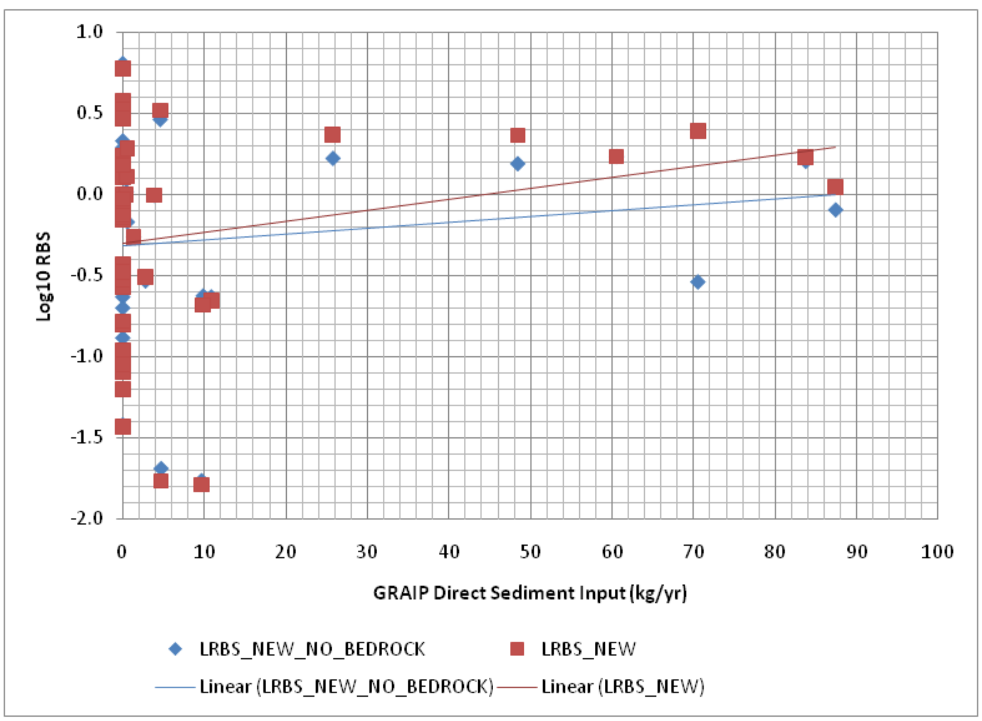

Figure 27. Direct sediment input to reach from upslope road drainage vs measured LRBS. Note that the most of the LRBS points below -0.5 (indicative of higher surface fines) are associated with direct sediment inputs of ~10 kg/yr or less. Higher road sediment inputs are associated with LRBS scores between ~0 and ~0.5.

8.0 Summary & Conclusions

Field inventory and analysis of the majority of public roads in the Wall Creek watershed using GRAIP provided detailed, site specific data on watershed impacts from roads (connectivity, sedimentation) and road condition. Impacts are both "chronic" in terms of annual sediment input to streams, and "pulsed" during more extreme events when road connectivity to the channel network is at maximum.

Inventory data was collected on 450 miles of road, including 6473 drain points, by two field crews during a four month field season. An investment made in crew training and oversight paid off in the form of well documented precision and accuracy measures.

The analysis indicates relatively low sediment contribution above background ("sediment connectivity") from roads but potentially high hydrologic connectivity (flow increase) during snowmelt and storm runoff. The majority of sediment production and delivery is localized on a small number of segments and points, sites are scattered across the watershed, with some concentrated "hot spots" in Middle Big Wall and Little Wall.

The GRAIP process produced a ranked list of hydrologically connected and high sediment delivery road segments and drain points. These data and the resulting maps will provide the basis for an effective road restoration prioritization strategy for Wall Creek. Results will be useful in targeting future road treatments to the highest risk sites and improve cost-benefit of future investment in the road system. Field observations show that landsliding and gullying associated with roads do not constitute a significant risk within the study area.

Both GRAIP sediment delivery and RBS metrics indicate low levels of stream sedimentation at the watershed scale, however, the "response" indicator (RBS) does not appear to be related to the "source" indicator (GRAIP).

The findings provide options for addressing 303(d) listed streams in the watershed, including delisting based on low sediment contribution from the largest active source in the watershed, or, developing sediment goals based on reducing contributions from roads, and continuing other watershed restoration actions identified in the 2009 Watershed Action Plan. For example, treating 1.6 percent of the drainpoints (104 sites) would reduce sediment delivery by 50 percent. Treating 12 percent of the inventoried road length (93 km) would reduce sediment delivery by 90 percent.

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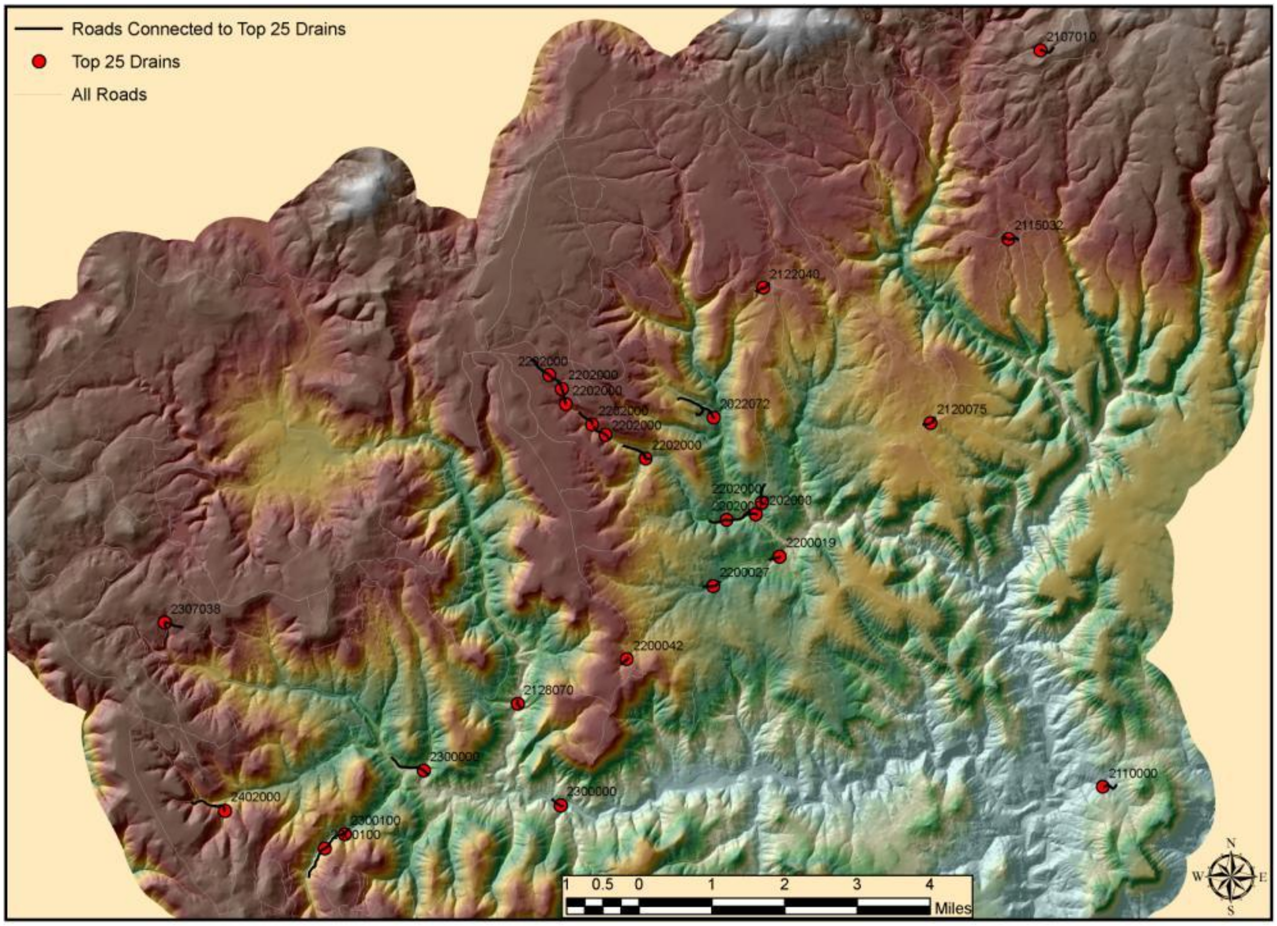
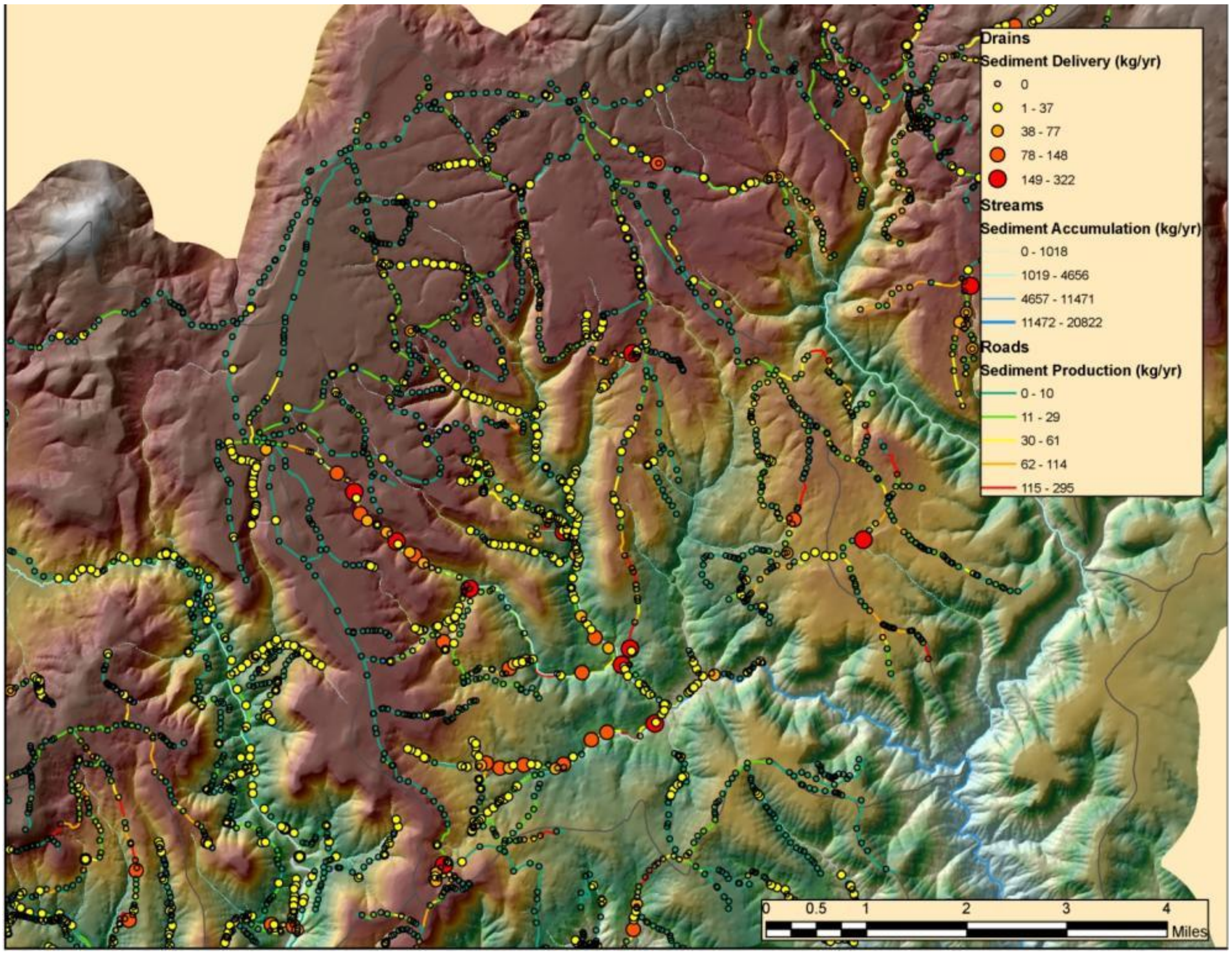
Appendix 1 – Top 25 Drain Points by sediment delivery, and Associated Road Segments.

Route Number	Count	Total Effective Length (m)	Total Sediment Delivery (kg/yr)
2202000	9	4032	1656
2300100	2	812	419
2300000	2	744	261
2402000	1	679	259
2200019	1	258	201
2122040	1	424	196
2110000	1	261	185
2022072	1	824	172
2200042	1	179	165
2115032	1	267	159
2120075	1	309	154
2128070	1	147	148
2307038	1	257	144
2200027	1	249	137
2107010	1	344	122
Totals	25	9786	4379

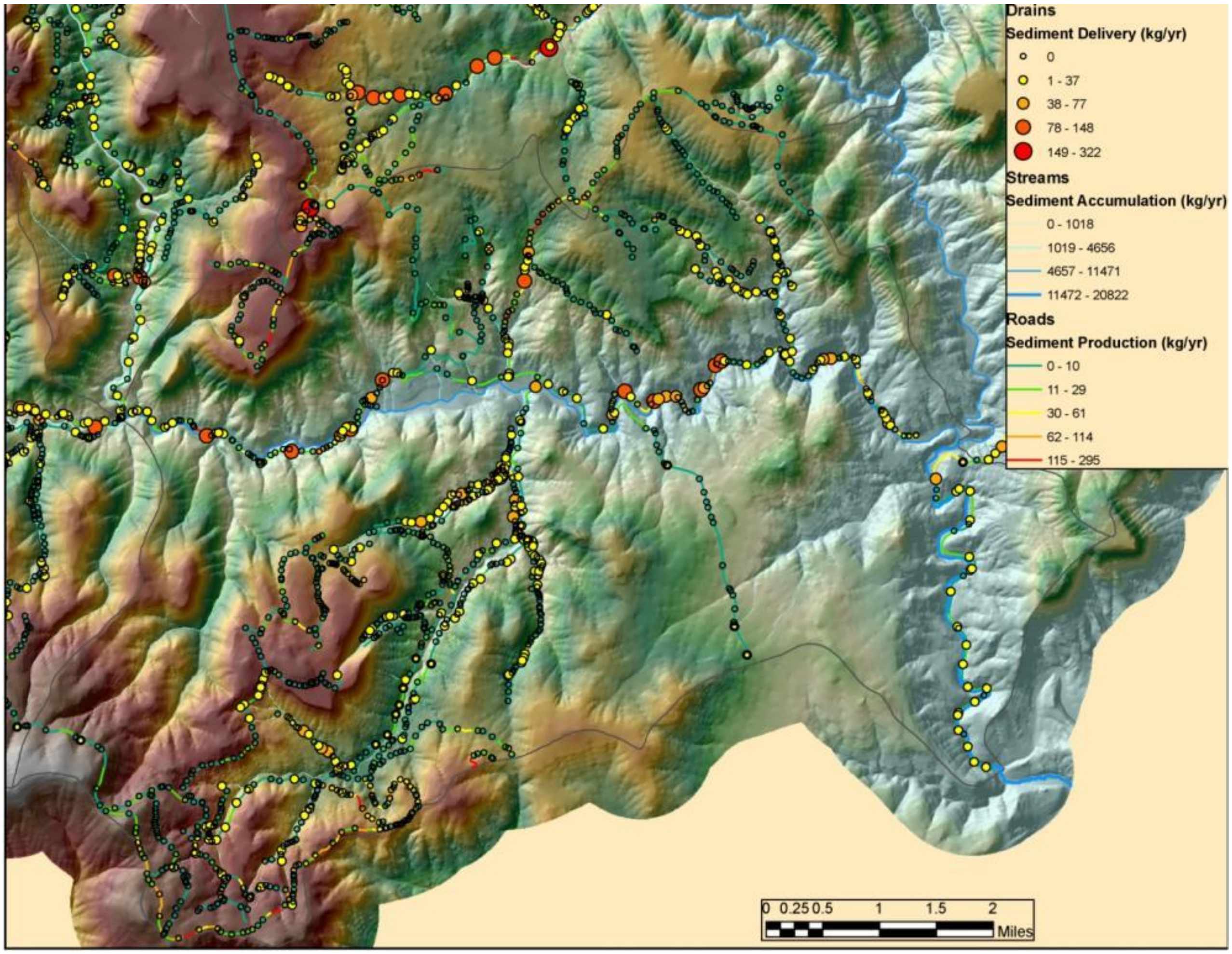


Locations of the top 25 sediment delivery points and the road segments that drain to them.

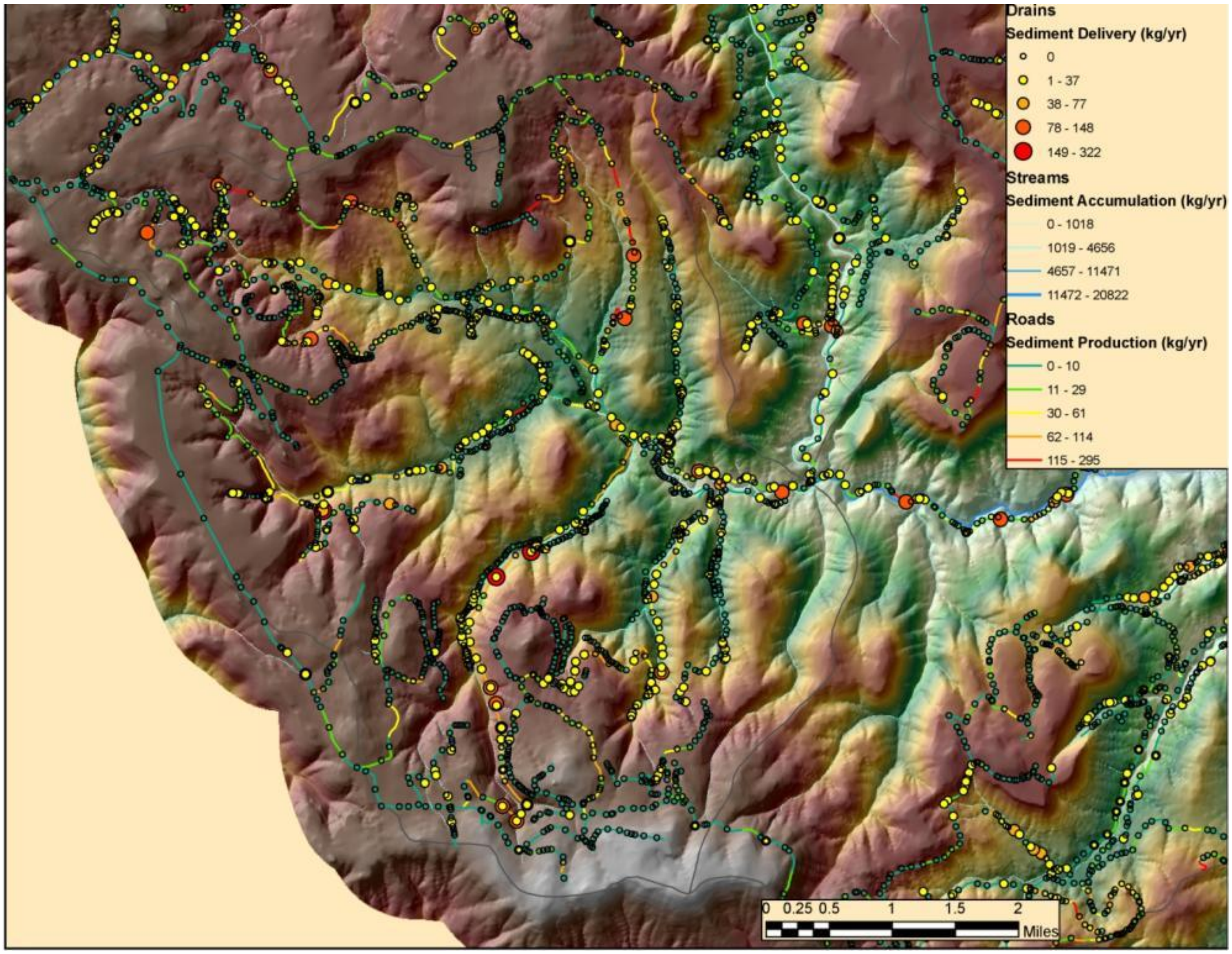
Appendix 2 - Subwatershed Sediment Production, Delivery, and Accumulation Maps



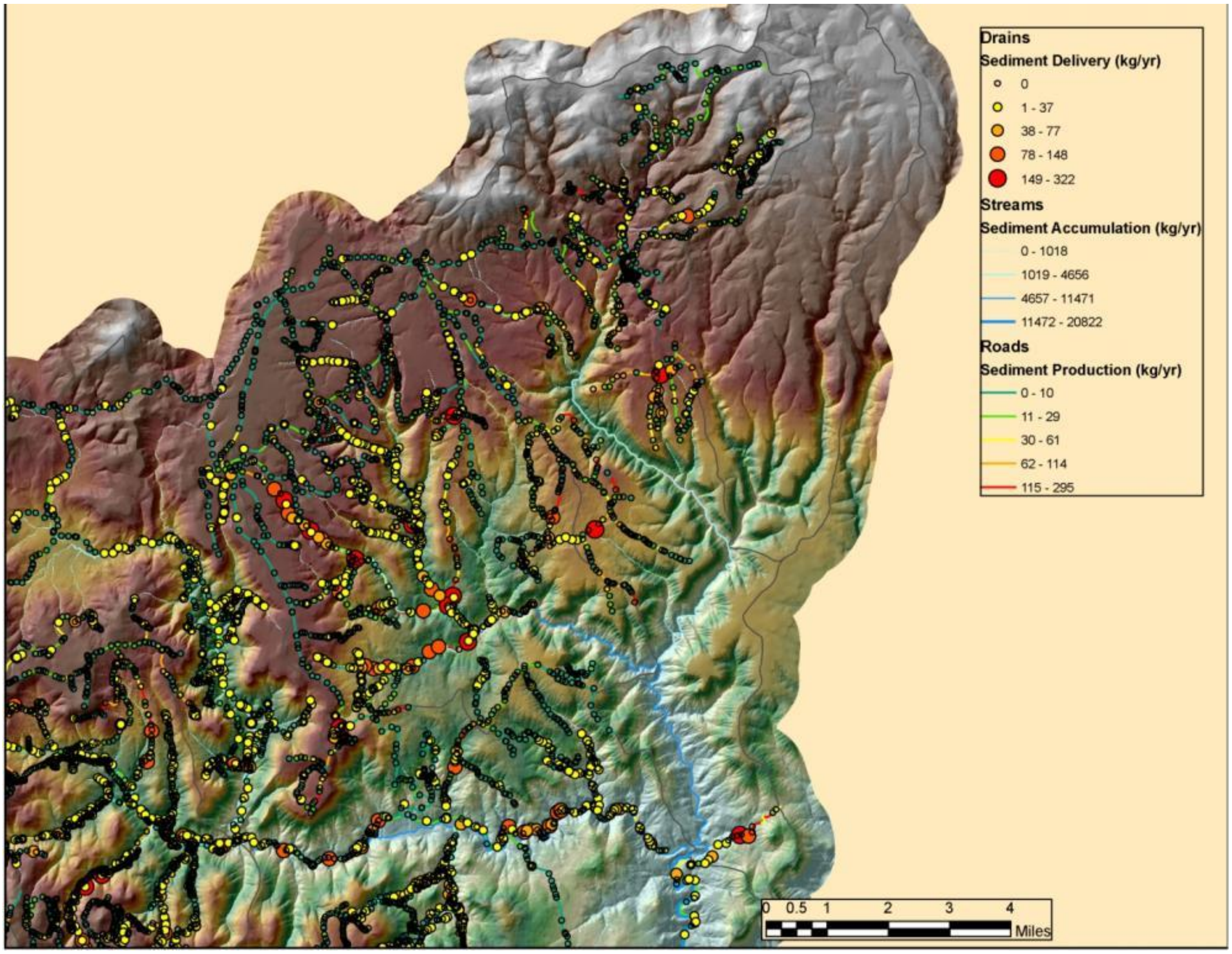
Little Wall Creek Subwatershed



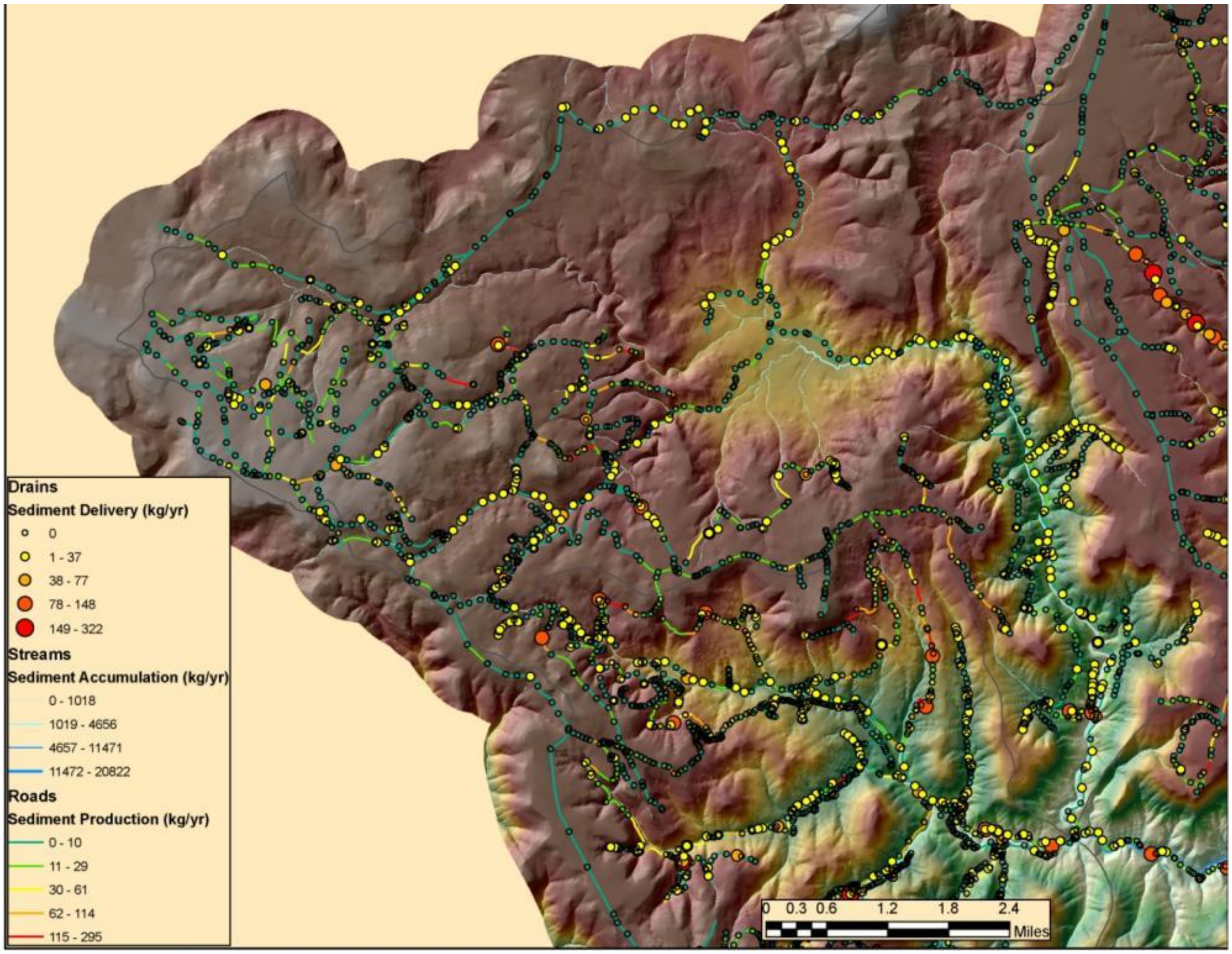
Lower Big Wall Creek Subwatershed



Middle Big Wall Creek Subwatershed

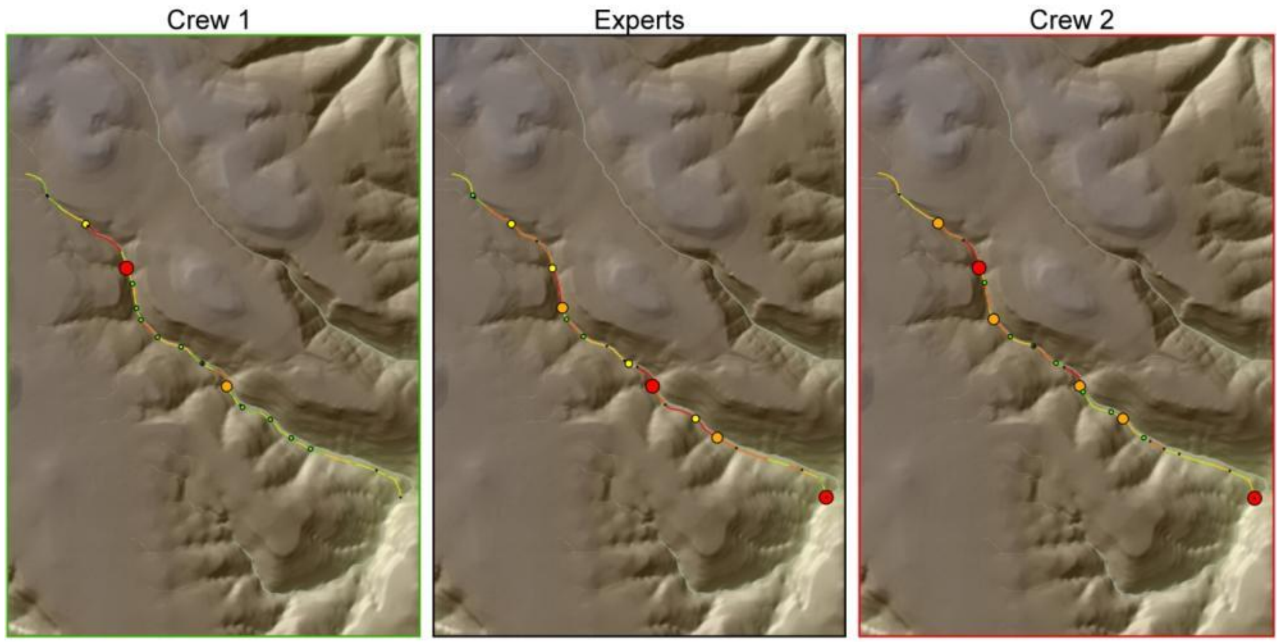


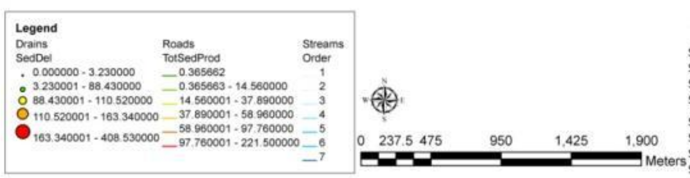
Little Wall – Skookum Creek Subwatershed



Wilson Creek Subwatershed

Appendix 3 - QAQC Maps

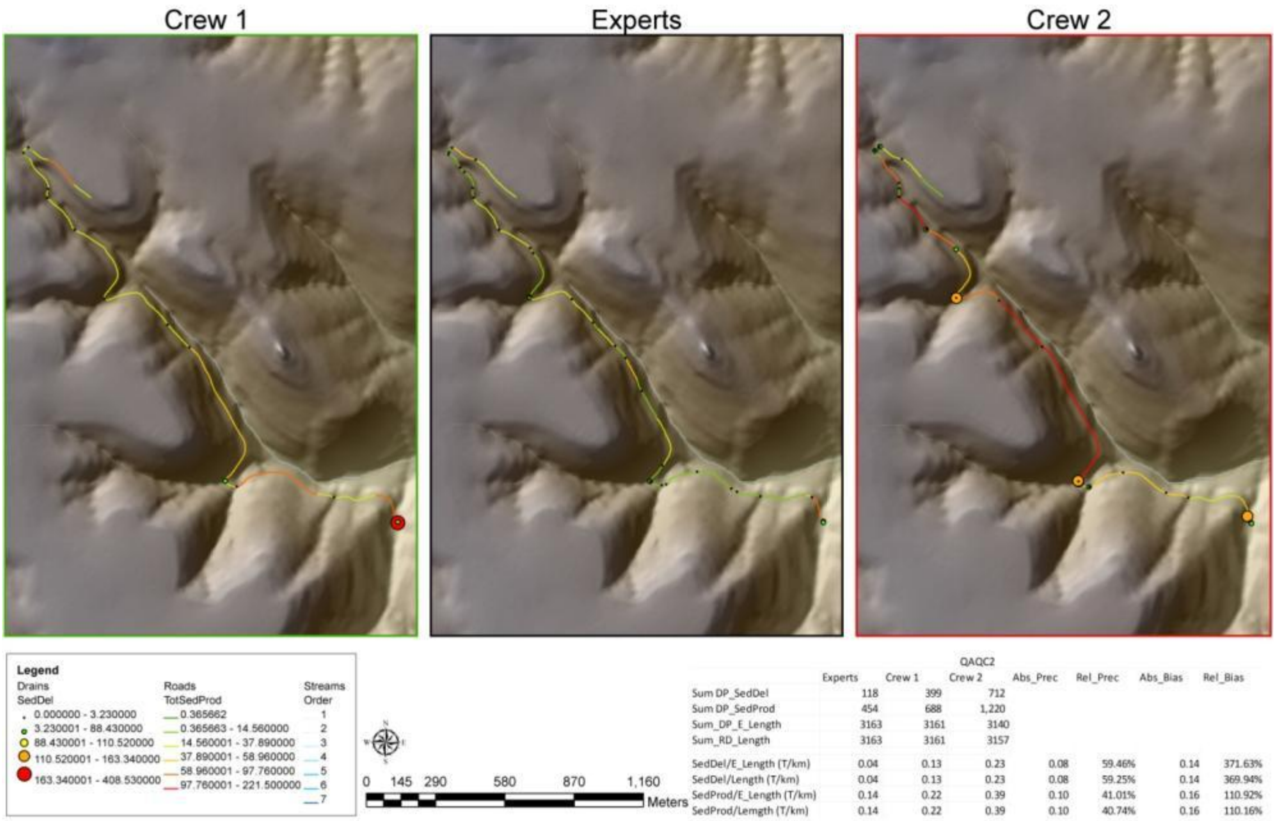




QAQC1

	Experts	Crew 1	Crew 2	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
Sum DP_SedDel	1,415	892	1,272				
Sum DP_SedProd	1,440	1,258	1,438				
Sum_DP_E_Length	3598	3592	3617				
Sum_RD_Length	3598	3592	3617				
SedDel/E_Length (T/km)	0.39	0.25	0.35	0.06	18.42%	-0.09	-23.74%
SedDel/Length (T/km)	0.39	0.25	0.35	0.06	18.42%	-0.09	-23.74%
SedProd/E_Length (T/km)	0.40	0.35	0.40	0.02	5.98%	-0.03	-6.57%
SedProd/Lemgth (T/km)	0.40	0.35	0.40	0.02	5.98%	-0.03	-6.57%

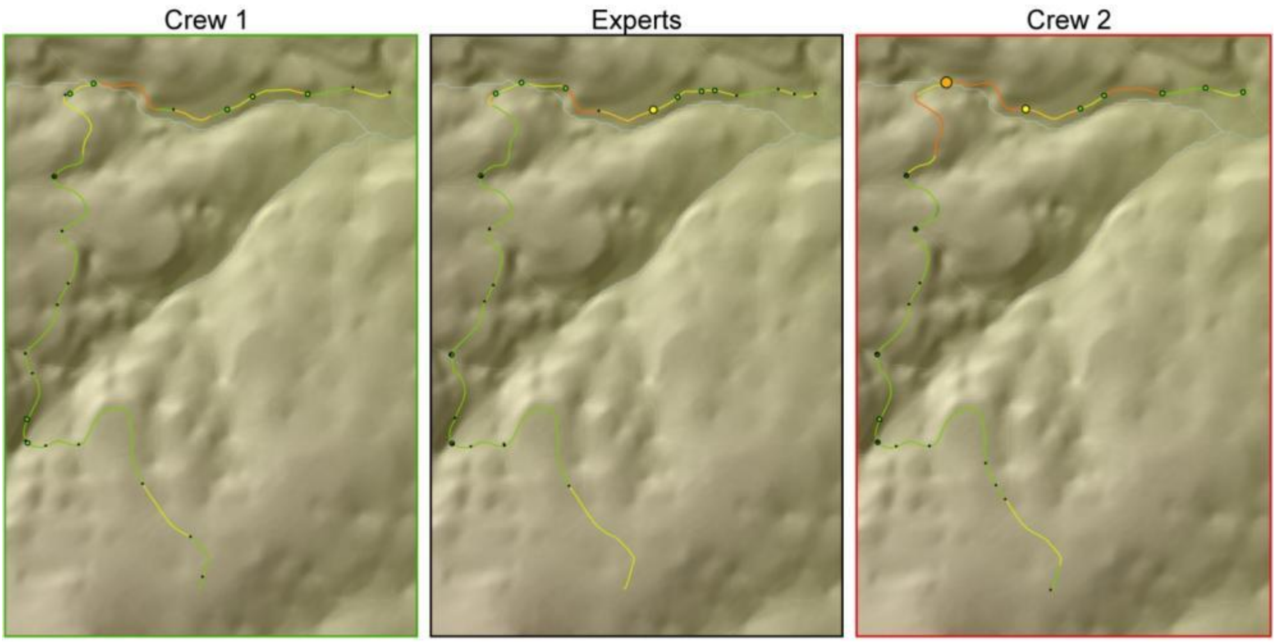
QAQC Plot 1

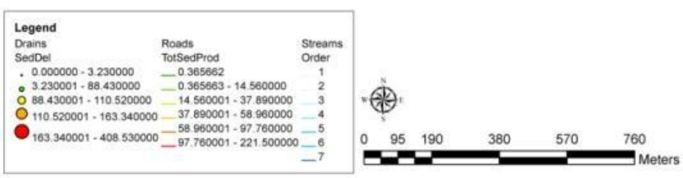


QAQC2

	Experts	Crew 1	Crew 2	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
Sum DP_SedDel	118	399	712				
Sum DP_SedProd	454	688	1,220				
Sum_DP_E_Length	3163	3161	3140				
Sum_RD_Length	3163	3161	3157				
SedDel/E_Length (T/km)	0.04	0.13	0.23	0.08	59.46%	0.14	371.63%
SedDel/Length (T/km)	0.04	0.13	0.23	0.08	59.25%	0.14	369.94%
SedProd/E_Length (T/km)	0.14	0.22	0.39	0.10	41.01%	0.16	110.92%
SedProd/Lemgth (T/km)	0.14	0.22	0.39	0.10	40.74%	0.16	110.16%

QAQC Plot 2



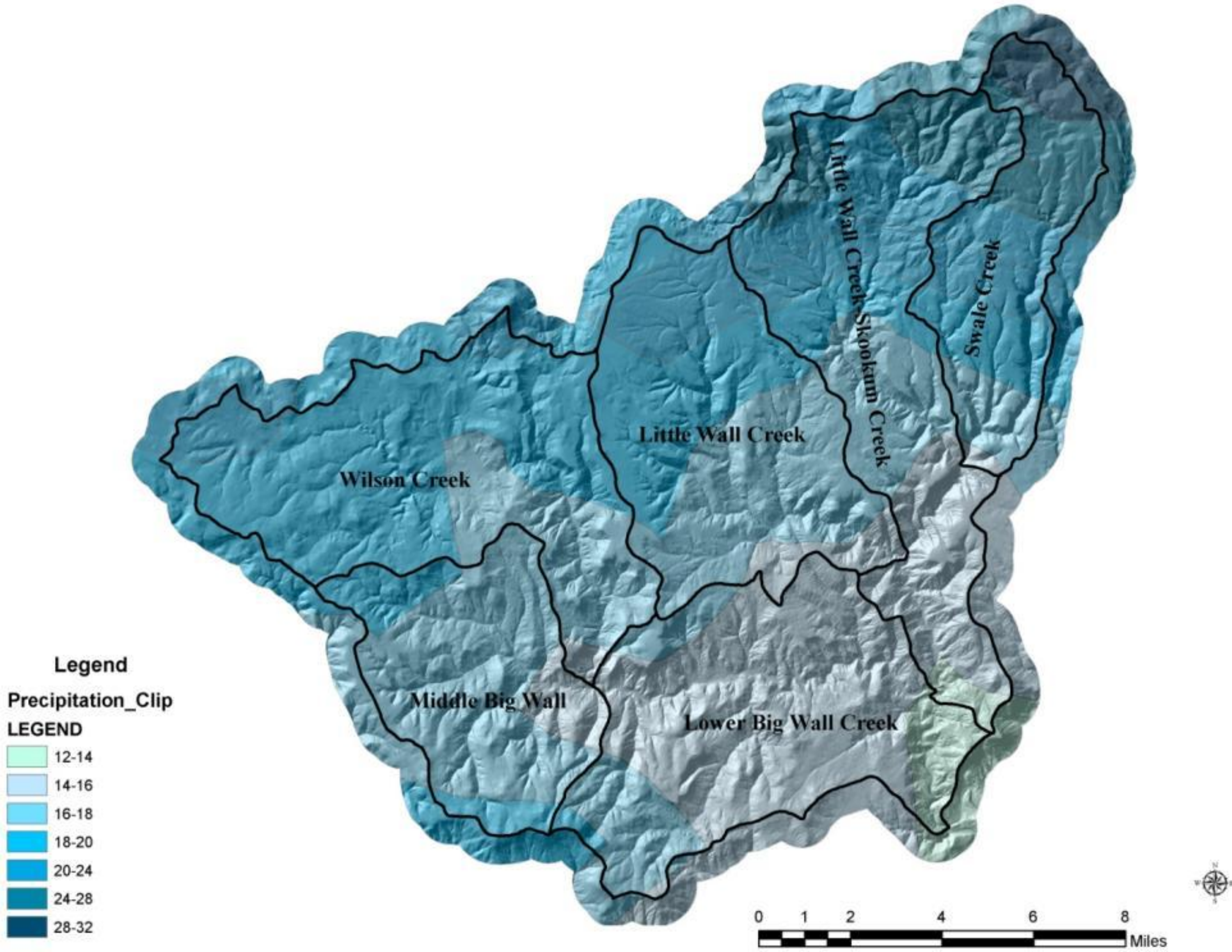


QAQC3

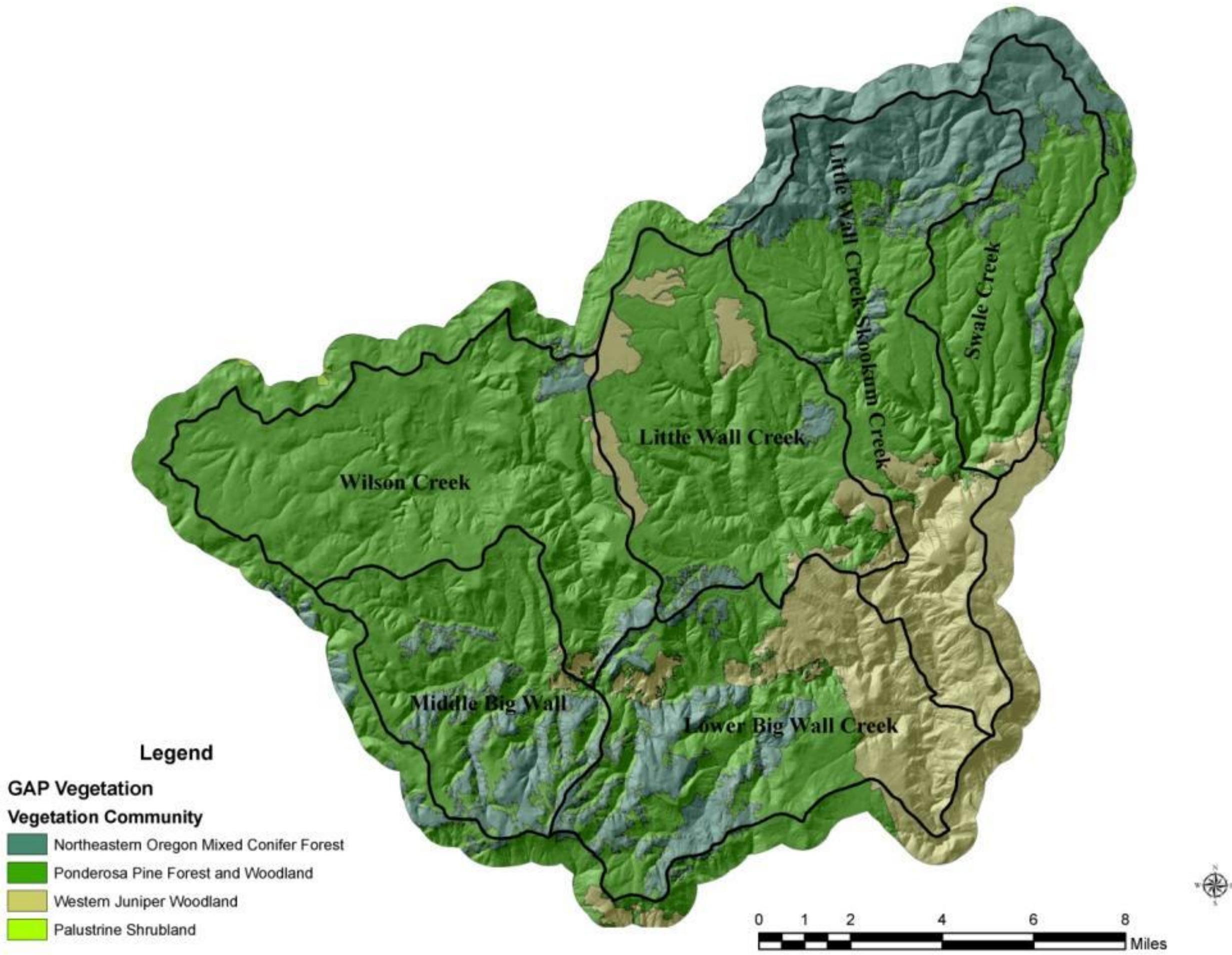
	Experts	Crew 1	Crew 2	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
Sum DP_SedDel	306	235	513				
Sum DP_SedProd	540	486	580				
Sum_DP_E_Length	3185	3172	3022				
Sum_RD_Length	3185	3172	3173				
SedDel/E_Length (T/km)	0.10	0.07	0.17	0.04	36.09%	0.03	26.91%
SedDel/Length (T/km)	0.10	0.07	0.16	0.04	33.62%	0.02	22.71%
SedProd/E_Length (T/km)	0.17	0.15	0.19	0.02	9.22%	0.00	1.80%
SedProd/Length (T/km)	0.17	0.15	0.18	0.01	7.15%	0.00	-0.89%

QAQC Plot 3

Appendix 4 - Other Maps



Precipitation in Wall Creek



Oregon GAP vegetation map for Wall Creek.