Bear Valley Road Inventory (GRAIP) Report

In Support of the Bear Valley Category 4b Demonstration

USDA Forest Service, Boise National Forest

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Executive Summary

Sediment has been identified as the pollutant of concern in multiple stream segments within the Bear Valley Creek and Elk Creek watersheds on the Idaho Department of Environmental Quality's (IDEQ) 2008 Integrated Report. The IDEQ, in conjunction with the Boise National Forest (BNF), is in the process of preparing their 2010 Integrated Report including a Category 4b demonstration of Bear Valley Creek and Elk Creek for submission to the U.S. Environmental Protection Agency (USEPA).

The USEPA funded a site-specific road sediment inventory in 2009 for the Bear Valley and Elk Creek watersheds to assist in the development of a possible Category 4b demonstration. This inventory specifically quantified the extent and location of sediment contributions from roads to streams, using the Geomorphic Road Analysis and Inventory Package (GRAIP, Prasad et al. 2007, http://www.fs.fed.us/GRAIP). This suite of robust inventory and analysis tools evaluates the following road impacts and risks: road-stream hydrologic connectivity, fine sediment production and delivery, upstream sediment accumulation, drain point condition, stream crossing failure risk, gully initiation risk, and shallow landslide risk.

The Boise National Forest with instruction from the Rocky Mountain Research Station (RMRS) of the U.S. Forest Service (USFS) collaborated and worked together in 2009 to execute a comprehensive road inventory in Bear Valley. Over a course of four weeks during the summer of 2009, field crews mapped and collected data on a total of 146 miles of roads. Using the data, risk profiles for the roads were developed to assess impacts and risks to key watershed processes. A summary of predicted risks is displayed in the table below.

Road-stream hydrologic connectivity was calculated to be 18 miles (12.5%). The total amount of fine sediment from roads accumulating in Bear Valley Creek, Elk Creek, and their tributaries was 821 tons/yr, which accounts for 10% of all the sediment produced on Bear Valley roads. The predicted sediment delivery rate from roads of 4.3 tons/mi^2/yr suggests a 17% increase of the natural reference sediment erosion rate as predicted by the BOISED model (Reinig et al. 1991).

Approximately 10% of road drainage features were recorded to be in poor condition or in need of maintenance. The risk of stream crossings becoming plugged was evaluated based on a stream blocking index (SBI) where 1 indicates virtually no risk and 4 indicates high risk. The average SBI for stream crossings in this survey was 2. A total of 21% of all stream crossings have diversion potential, suggesting some risk of stream water flowing down the road prism if the pipe is blocked.

Slope stability data, which includes the frequency and attributes of observed landslides and gullies, is used to calculate gully initiation risk and landslide potential resulting from roads. Very few hillslope failures were observed and recorded in the survey, making necessary calibration to predict such risk impossible. Although 22 gullies were

observed and recorded during the field survey, the distribution of the drain points where they occur in association with all drain points was scattered and suggested no point at which increased gully initiation risk can be expected. No landslides were recorded in the survey, thereby not allowing accurate calibration of risk assessment. Lack of observed landslide and gully data suggests no significant risk of mass wasting is added by the existence of roads in Bear Valley.

Quality assurance measures were taken in order to ensure the integrity of the data collected. Field crews were trained on data collection methods by individuals considered experts in using the GRAIP inventory protocol. Three quality assurance plots were surveyed by each crew and by an expert crew in order to ascertain relative precision and bias of data collected. Results suggest that the margin of error among data collected by the different crews was acceptable and that the data are considered usable for analysis. Crews were audited monthly during the survey of a road by an expert who corrected procedural mistakes in real time and provided additional training.

Taken collectively, inventory results indicate that roads in the Bear Valley and Elk Creek watersheds do result in some hydrogeomorphic impacts and risks to aquatic ecosystems. Relative to road sediment production, however, sediment delivery is low. Areas of high sediment delivery could be reconstructed or otherwise improved in order to drastically reduce road-to-stream sediment transport. GRAIP predictions can be used to address the needs of specific road segments and drain points in the design phase of future road restoration or road maintenance projects.

Summary of GRAIP model risk predictions for the Bear Valley and Elk Creek watersheds.

IMPACT/RISK TYPE	GRAIP PREDICTION
Road-Stream Hydrologic Connectivity	18 miles, 12.5% of total road length
Fine Sediment Production	8,091 tons/year
Fine Sediment Delivery	845 tons/year, 10% of produced road sediment
Upstream Sediment Accumulation	821 tons/year, 10% of produced road sediment
Upstream Sediment Accumulation Rate	4.3 tons/mile^2/year, 17% of natural reference sediment erosion rate
Drain Point Problems	379 drain points, 10% of all drain points
Stream Crossing Failure Risk	
- plug potential	36 stream crossings above average risk, 19% of total
- fill at risk	3,213 meters^3
- diversion potential	41 stream crossings, 21% of total
Gully Initiation Risk	22 observed gullies, not considered a substantial risk
Landslide Risk	No observed landslides, not considered a substantial risk

1.0 Background

The Forest Transportation System is vast and represents an enormous investment of human and financial capital. This road and trail network provides numerous benefits to forest managers and the public, but can have detrimental effects on water quality, aquatic ecosystems, and other resources. There is currently a large backlog of unfunded maintenance, improvement, and decommissioning work on National Forest System Roads (NFSR) and other Forest Roads (FR). Many of these roads and other critical Forest Transportation Facilities (e.g., culverts) are nearing or have exceeded their life-expectancy. This substantially elevates risks to aquatic resources, especially in relation to sediment delivery from roads to streams.

Within the Bear Valley Creek and Elk Creek watersheds, sediment has been identified as the pollutant of concern in four assessment units (AU) which have been proposed to be on the Category 4b list in the Idaho Department of Environmental Quality's (IDEQ) 2010 Integrated Report. Table 1 lists the IDEQ's AUs of concern in the Bear Valley and Elk Creek watersheds, as proposed for the 2010 Integrated Report (see also Figure 1). The IDEQ administers state and federal laws which provide a framework for the protection of water quality in Idaho. Within this framework, water quality standards have been established as parameters for protecting designated beneficial uses of water. The beneficial uses of these AUs are currently undesignated. However, cold water, primary contact recreation, and secondary contact recreation are defined beneficial uses that apply to every waterbody in Idaho, including these AUs.

The IDEQ and the Boise National Forest (BNF) are in the process of preparing a demonstration that would justify the Category 4b listing of Bear Valley Creek and Elk Creek. This demonstration is to be submitted to the U.S. Environmental Protection Agency (USEPA) as part of the 2010 Integrated Report. USEPA regulations recognize that alternative pollution control requirements may obviate the need for a TMDL. Specifically, assessment units are not required to be included on the Section 303(d) list if "other pollution control requirements (*e.g.*, best management practices) required by local, State, or Federal authority" are stringent enough to implement applicable water quality standards within a reasonable period of time. These alternatives to TMDLs are commonly referred to as Category 4b waters.

Table 1. Bear Valley AUs recommended to be Category 4b-listed in IDEQ's 2010 Integrated Report (personal communication, Leslie Freeman, IDEQ, 2010).

Assessment Unit Name	Stream Name	Pollutant	Length (mi)	Beneficial Uses
17060205SL012_02a	Upper Bear Valley Creek and tributaries – 1st and 2nd order	Sediment	28.86	Undesignated
17060205SL012_05	Bear Valley Creek – 5th order	Sediment, Temperature	11.24	Undesignated
17060205SL013_03	Bearskin Creek – 3rd order	Sediment	1.83	Undesignated
17060205SL013_04	Elk Creek – 4th order	Sediment	8.94	Undesignated

In the Bear Valley and Elk Creek watersheds, like any other watershed where roads exist, it is known that roads have some impact on water quality and associated beneficial uses, particularly in terms of sediment delivery to streams. However, to what degree or where this delivery is occurring is largely unknown or speculative given the extensive road mileage in the area. To help complete the Category 4b demonstration, the USEPA funded a site-specific road sediment inventory in 2009 for the Bear Valley and Elk Creek watersheds. This inventory specifically quantified the extent and location of sediment contributions from roads to streams, using the Geomorphic Road Analysis and Inventory Package (GRAIP, Prasad et al. 2007, http://www.fs.fed.us/GRAIP).

The GRAIP data collection method provides forest managers with real data that captures the extent to which roads affect stream channels. Precise locations where sediment delivery is occurring, drainage features are compromised, or road maintenance issues need to be addressed to further minimize undesirable aquatic impacts from roads were identified during the GRAIP inventory.

The road density for the Bear Valley and Elk Creek watersheds combined is 0.87 (miles of road length per miles squared of area). The area of the watershed is 191.4 square miles (495.6 km^2 or 122,504 acres) and the total road length is 167 miles (267 km). A breakdown of road density by sub-watershed is included in Table 2.

Table 2. Road length and density (miles of road length per miles squared of area) for the Bear Valley and Elk Creek watersheds by sub-watershed (HUC6).

Sub-watershed	Forest Road[1] Length (mi)	Unauthorized Road Length (mi)	Total Existing Road Length (mi)	Total Area (mi^2)	Road Density (Rd mi/mi^2)
Wyoming	11	2	13	25.7	0.5
Fir Creek	6	0	6	20.2	0.3
Cache	28	9	37	40.0	0.9
Upper Bear Valley	45	10	55	26.3	2.1
Upper Elk	2	2	4	40.8	0.1
Lower Elk	17	4	21	20.8	1.0
Bearskin	22	9	31	17.6	1.7
Combined Total	**131**	**36**	**167**	**191.4**	**0.9**

All roads in the Bear Valley and Elk Creek watersheds were targeted in the road inventory. However, due to time and resource constraints certain roads were given priority based on assessments made in the field by a crew leader. All 131 miles (210 km) of Forest Roads (including open, closed, or otherwise designated roads) were prioritized and successfully surveyed. Most unauthorized roads (user-created or otherwise unclassified roads) were prioritized, but not all were surveyed. The field crew leader

[1] Forest Roads include all National Forest System Roads and other Forest Roads which have been authorized by a legally documented right-of-way held by Valley County (36 CFR 212.1). Forest Roads do not include unauthorized roads.

visited each unauthorized road and deemed it a priority based on various characteristics including: lower slope position, close proximity to a stream channel, observed stream connection and active sediment delivery between drain points and a channel, active road surface erosion, little vegetation on road surface or in flow paths, concentrated water flow, drainage feature types, existence of drainage problems, and use. As stated in the Quality Assurance Project Plan (QAPP), *a feature will no longer be considered a road when it does not move water along its surface, no longer has stream crossings, and is not located in a position where it can interact with the stream channel* (Black et al. 2009).

Over a course of four weeks during the summer of 2009, Bear Valley field crews mapped and collected data on a total of 146 miles (235 km) of roads (see Table 3). Precisely 3,175 individual road segments and 3,826 unique drain points comprise these 146 miles. These road segments and drain points make up the entirety of the data that are analyzed in this report.

Up to 21 miles (34 km) of unauthorized roads were not surveyed. The decision to forego the survey of these roads was made based on the previously mentioned prioritization criteria which indicated limited impact. Forest GIS files (using aerial photography) estimate approximately 36 miles (58 km) of unauthorized roads in the Bear Valley and Elk Creek watersheds. However, the exact number of unauthorized roads within the watersheds is unknown as many of them are difficult to physically locate (due to overgrowth of vegetation or no access). Therefore, 21 miles of unauthorized roads may be more than double the actual miles of roads not surveyed due to discrepancies among GIS data and field observations.

Table 3. Length of road inventoried and surveyed by field crews by road type[2].

Road Type	Total Existing Length (mi)	Total Length Surveyed (mi)	% Total Length Surveyed
Forest Roads	131	131	100%
Unauthorized Roads	36	15	42%
Combined Total	**167**	**146**	**87%**

2.0 Study Objectives

GRAIP is designed to assess the geomorphic and hydrologic activity and risk of roads as well as the physical condition of roads and their associated drain points. Field crews surveyed roads in the Bear Valley and Elk Creek watersheds in an effort to better

[2] All figures except for Combined Total Length Surveyed may not be accurate as GIS data and field observations did not always align. Many unauthorized and a few NFS road segments displayed in BNF road shapefiles did not match existing roads on-the-ground. Often, the length and shape were drastically different from what was indicated on maps. Some roads displayed on BNF road layers likely never existed or no longer exist as such due to re-growth of vegetation and results of previous restoration work rendering a road no longer identifiable as such.

understand the overall effect of roads on key watershed processes. Specifically, the project is intended to address the following questions.

1. What is the existing level of fine sediment delivery from roads to streams in Bear Valley?
    a. How does the contributed sediment from roads compare to natural reference sediment levels?
2. Where are the locations of highest sediment delivery from roads to streams?
    a. Can these sites be reconstructed to eliminate or minimize delivery?
3. What unknown geomorphic or hydrologic issues exist in Bear Valley's road system that could help forest managers make decisions and plan more effectively?

3.0 Methods

The Geomorphic Roads Analysis and Inventory Package (GRAIP) was used to inventory and model the risk profile of each of the road segments included in the study. The GRAIP system consists of a detailed, field-based road inventory protocol combined with a suite of geographic information system (GIS) models. The inventory is used to systematically describe the hydrology and condition of a road system using Geographic Positioning System (GPS) technology and automated data forms (Black, Cissel, and Luce 2009). The GIS models use these data to analyze road-stream hydrologic connectivity, fine sediment production and delivery, upstream 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. The inventory was conducted in accordance with the Quality Assurance Project Plan (QAPP) developed in cooperation with the USEPA and the RMRS (Black et al. 2009). A summary of QAPP results can be found in Section 6.0 of this report.

Photo 1. Field crew members collecting data on a stream crossing (left) and collecting GPS points for a drainage feature (right).

4.0 Monitoring Location

The 122,500-acre (191 square miles) Bear Valley area is located in the mountains of west-central Idaho. The watershed is approximately 100 miles northeast of Boise, 25 miles northeast of Lowman, and about 20 miles northwest of Stanley. It lies wholly in Valley County at the southeastern margin of the Salmon River Mountains and southern border of the Frank Church River of No Return Wilderness Area. The gentle, high-altitude slopes of Bear Valley are home to meadows, wetlands, and meandering streams, which provide essential habitat for multiple fish and wildlife species. Among these are three endangered fish species including Chinook salmon, steelhead, and bull trout as well as other native species such as westslope cutthroat trout, elk, wolves, and others. Plant species include stands of lodgepole pine, Douglas fir, and whitebark pine as well as sensitive wetland species.

Bear Valley is located in the headwaters of the Middle Fork Salmon River and includes two 5th HU (hydrologic unit) watersheds, Bear Valley Creek and Elk Creek. Bear Valley Creek flows approximately 20 miles to its confluence with Marsh Creek, where they both form the start of the Middle Fork Salmon River. At its widest, the watershed is about 14 miles wide, and it is about 20 miles long. Water tempreatures within the basin are cool and salmonid spawning is a major factor in resource management of the area.

The Bear Valley area contains landforms somewhat atypical of those representative of the central mountains of the granitic Idaho batholith. The terrain in the watershed is unique in that it exhibits realatively gentle topography compared to adjacent watersheds, such as the South Fork Payette and the Deadwood, which are steep and highly dissected. As a whole, the watershed is typified by heavily-forested, mountainous terrain with a relatively high base elevation of about 6,200 feet. Cape Horn Mountain is the highest point in the watershed at nearly 9,600 feet and lies just south of the mouth of Bear Valley Creek. Mountains are slightly to strongly dissected, with wide valleys and meadow basins, some exhibiting laucustrine deposits. Most of the watershed has been glaciated and much of the surface is veneered with glacial outwash and associated quaternary deposits. The higher mountain peaks and ridges of the divide are pronounced, but not sharp and broken; rather, they are somewhat rounded or edgeless and heavily forested.

The watershed is divided nearly down the middle by the broad, main, U-shaped, south-to-north trending Bear Valley Creek valley. Valley sides rise moderately steep to steeply, but rarely precipitously, to the upland mountains. Other dominant stream valleys (e.g. Elk Creek, Bearskin Creek, and some other tributaries) are U-shaped as well, and headwater tributaries are only moderately incised. Streams within the U-shaped valleys typically have a gradient of less than 1% with seasonally high water tables and high sinuousity.

Mean annual precipitation in the watershed ranges between 25 and 60 inches, depending on elevation. Seventy-five percent of the annual precipitation falls from

November through April. Snow pack present on April 1 accounts for 60% of the mean annual precipitation. Higher elevations often retain snow pack well into early summer.

The entire watershed is National Forest System land. Most is administered by the Lowman Ranger District of the BNF, while some area in the northeastern part of the watershed is administered by the Middle Fork Ranger District of the Salmon-Challis National Forest. Portions of National Forest System Roads 568 and 579 are subject to the majority of traffic use in the watershed, most of which is associated with the wilderness access and whitewater recreation. Users drive these roads to obtain access to the Middle Fork Salmon River and the Frank Church River of No Return Wilderness Area. The Middle Fork Salmon River is administered by the Salmon-Challis National Forest. (Shapiro et al. 2000)

Bear Valley roads vary in appearance and drainage features, but most have a surface consisted of native material. The original construction standards of arterial roads such as FR 582, FR 579, and FR 563 included a crowned surface with an inboard ditch and diffuse drainage off the fillslope. Over time and with repeated grading and maintenance, these high-use roads often have an outside berm with frequent non-engineered drainage features where water has cut through the berm and off the road prism. The north end of the Bearskin road (FR 563) had frequent, effective, engineered berm drains that acted like lead off ditches, diverting flow away from the road and streams. The construction style for upper-slope collector and “spur” or local roads was generally at a lower standard. Some of these roads would have a ditch with frequent culverts, while others would drain through broad based dips or water bars. Many roads in Bear Valley pass through vast meadows and wetland areas amidst flat terrain. Such roads did not always have clearly defined flow paths or stream connection. Many sensitive fish, wildlife, and plant habitat areas are within the immediate vicinity of roads in Bear Valley.

Mid- to upper-slope roads at higher elevations and in the south end of the watershed generally had steeper gradients and were constructed with various periodic drainage features. Concentrated flow and clearly defined flow paths were more common in steeper terrain. Many unauthorized, closed, or decommissioned roads existed in these upper-slope areas which drained largely by means of water bars or diffuse drainage. The usage and maintenance level of upper-slope roads in the Bear Valley watershed is generally lower than that of lower-slope roads.

Live stream crossings were especially frequent on lower-slope roads, although they did exist at all slope positions. The watershed has relatively flat topography with limited steep terrain, so stream crossing fills, cutslopes, and fillslopes were typically small. Roads often run parallel to stream channels, especially at lower elevations in the watershed (e.g. FR 582 on Bear Valley Creek, FR 563 on Bearskin Creek, and FR 579 on Elk Creek). Data suggest, however, that the majority of roads in Bear Valley pose little to no risk to water quality and associated beneficial uses.

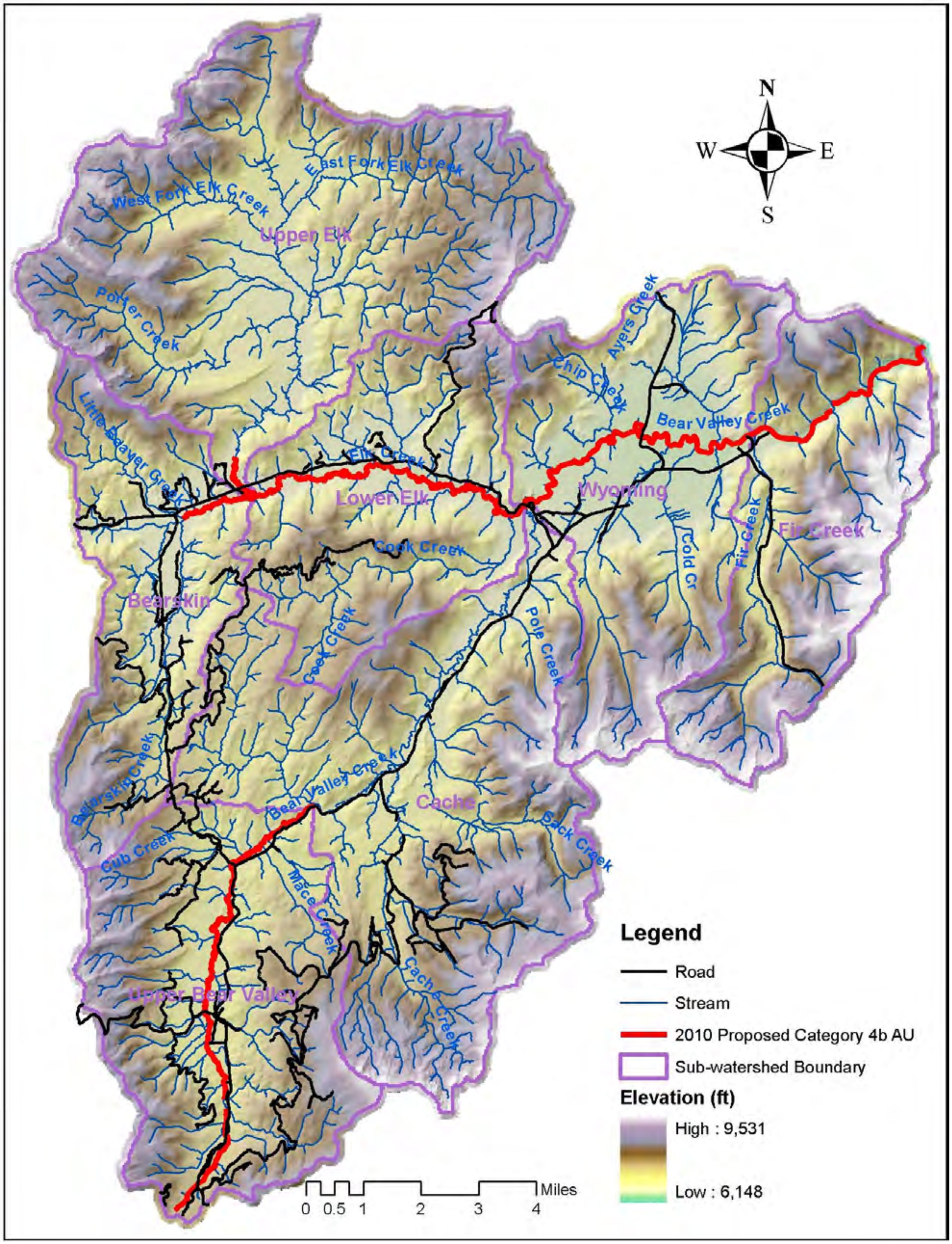


Figure 1. Bear Valley area map including roads surveyed.

5.0 Results

GRAIP inventory and modeling tools were used to characterize the following types of impacts and risks:

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

5.1 Road-stream Hydrologic Connectivity

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

GRAIP calculates the hydrologically-connected portion of the road using the field assessment of drain point connection and a road segment flow routing system. The flow path below each drain point is followed until evidence of overland flow ceases or the flow path reaches a channel. A total of 18 mi (29 km) out of the 146 mi (235 km) of surveyed roads in Bear Valley (12.5%) were hydrologically connected to a stream.

5.2 Fine Sediment Production & Delivery

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

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

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

[3] For this analysis, a base erosion rate of 210 kg/m/yr of road length per unit of slope was assumed. This figure is based on BOISED model base rates for road sediment production where maintained, heavy use roads are present (Reinig et al. 1991). The base rates were developed from Zena Creek (in the nearby South Fork Salmon River drainage) in erosion studies conducted by Megahan. Further work could determine if this rate is appropriate for this climate, geology and road system.

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 identifies drain points at which sediment is delivered to a channel and estimates how much sediment is delivered to the channel at a given drain point in kilograms per year.

Drain Point Analysis

Delivery of fine sediment occurs through a mix of road drainage features including ditch relief culverts, non-engineered drain points, stream crossings and others. In Table 4, sediment delivery is broken out by drain type to assess their effectiveness in preventing sediment from entering the channel. A total of 3,826 drain points were documented, 414 of which (11%) were hydrologically connected to stream channels. However, only 282 of these stream-connected drain points (7% of all drain points) were observed to be actively delivering sediment to a channel (see Table 5). These points deliver 845 tons/year (767 tonnes/yr) of sediment[4], or 10% of the 8,091 tons/year (7,340 tonnes/yr) of sediment produced by the road surfaces and ditches. Existing drain points are always recorded when spotted in the field, but field crews may determine that a drain point is not actively receiving any water flow from the road based on observed evidence. In this case, the drain point is noted to be an “orphan” drain point and no flow or sediment is routed to it.

There are eight different types of drain points defined in the GRAIP model: broad based dips, diffuse drainage, ditch relief culverts, lead off ditches, non-engineered drainage features, stream crossings, sumps, and water bars. The three drain types which delivered the most sediment to a stream channel are stream crossings, non-engineered drains, and ditch reliefs with sediment deliveries of 279.7 tons/year (253.7 tonnes/yr), 210.1 tons/year (190.6 tonnes/yr), and 193.0 tons/year (175.0 tonnes/yr), respectively. This means that 33% of all 845 tons (766.6 tonnes) of road sediment delivered to a stream annually is delivered directly to a stream crossing at a road/stream intersection. Similarly, 25% of all sediment delivered leaves the road prism at a non-engineered drain and 23% at a ditch relief culvert. The other five drain types deliver considerably less sediment to the stream channels, each at less than 7% of total sediment delivered (see Figure 2).

[4] Of the 845 tons/year (766.6 tonnes/yr) of delivered road sediment included in these figures, 24.3 tons/year (22 tonnes/yr) are delivered to streams outside of the Bear Valley and Elk Creek watersheds. This difference is accounted for by four drain points recorded in the survey near watershed boundaries, three of which are on NFSR 569 near the summit of Whitehawk Mountain and the other on NFSR 502A near the headwaters.

Table 4. Summary of sediment production and delivery at drain points.

Drain Type	Count	Total Sediment Production (kg/yr)	Total Sediment Delivery (kg/yr)	% Sediment Delivery	% Length[5] Connected
Broad Based Dip	488	1,274,729	50,110	4%	4%
Diffuse Drain	1,077	1,458,626	53,554	4%	2%
Ditch Relief Culvert	388	1,250,319	175,043	14%	15%
Lead Off Ditch	90	270,864	20,549	8%	7%
Non-Engineered	501	1,019,218	190,590	19%	20%
Stream Crossing	191	253,699	253,699	100%	100%
Sump	14	6,903	0	0%	0%
Water bar	1,077	1,806,088	23,027	1%	2%
All Drains	**3,826**	**7,340,447**	**766,571**	**10%**	**11%**

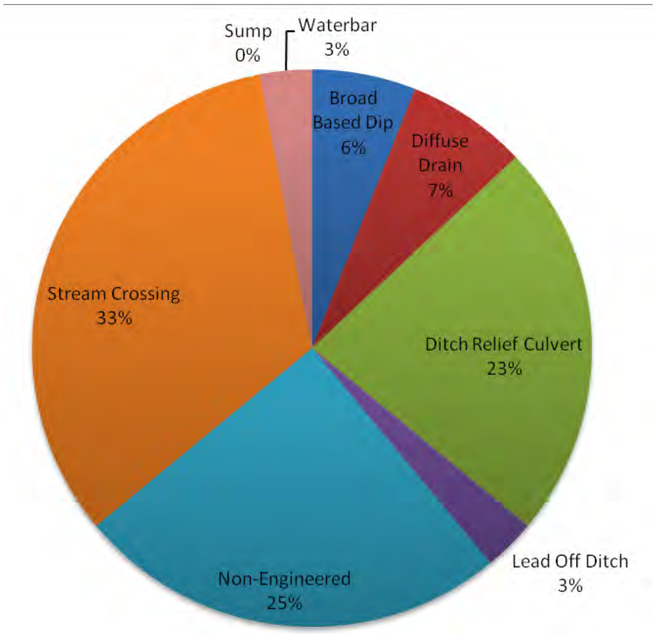


Figure 2. Distribution of total sediment delivered by drain type.

Reasons behind the large difference between the three highest producers and the other five may be that many stream crossings, non-engineered drains, and ditch reliefs exist on lower-slope roads that are close to a stream channel. Many of the lower maintenance level, unauthorized, less-travelled, decommissioned, or closed roads are located far from streams, thickly covered by vegetation, or have been closed to traffic for a number of years. Such roads are often mid- to upper-slope and are drained by closely spaced water bars or broad based dips, or they drain diffusely. Consequently,

[5] *ELength* was used to calculate this figure. It is the effective length of road that was draining to a particular drain point. If a road segment has two distinct flow paths assigned to different drain points, the ELength for that drain point will be equal to one half of the total length of the corresponding road segment.

these low-maintenance, low-traffic roads tend to deliver less sediment to the stream channel. Further analysis could be done using GRAIP data to validate or reject these observations and to better understand other variables surrounding the effectiveness of different drain types in a given location. Geographical location of drain types, slope position, the surface type of adjacent road segments, or other factors that play into sediment production and delivery could be investigated.

The drain types with the highest percentage of features that actively deliver sediment to a stream channel are stream crossings, ditch relief culverts, and non-engineered drains (see Table 5). Any road segment draining directly to a live stream crossing is automatically going to be delivering its produced sediment to that stream. Fifty-one percent of stream crossings in Bear Valley are actively delivering sediment to streams. The remaining 49% of stream crossings in Bear Valley are “orphan” drain points, meaning these do not drain road surface water and sediment which would pass through the culvert directly. Mitigations to prevent continued direct sediment delivery at stream crossings may include establishing ground cover vegetation to filter sediment before it enters the creek or adding additional drainage on the road on either side of the stream crossing to prevent direct delivery. Sediment delivery from non-engineered drains could likely be mitigated through road maintenance, such as removing the outside berm and re-establishing diffuse drainage off the fillslope. Ditch relief culverts delivering sediment may require the installation of more frequent road drainage features up road in order to decrease the volume and energy of water flowing down the road or ditch and through the pipe.

Table 5. Summary of drain point connectivity to streams and observed active sediment delivery at drain points (i.e. orphan drain points may be connected to the stream, but do not actively drain water or sediment from the road surface).

Drain Type	Count	Drain Points Connected to Stream	% of Drain Points Connected	Drain Points Actively Delivering Sediment to Stream	% of Drain points Actively Delivering Sediment to Stream
Broad Based Dip	488	23	5%	18	4%
Diffuse Drain	1,077	22	2%	19	2%
Ditch Relief Culvert	388	67	17%	54	14%
Lead Off Ditch	90	6	7%	6	7%
Non-Engineered	501	87	17%	72	14%
Stream Crossing	191	191	100%	98	51%
Sump	14	0	0%	0	0%
Water bar	1,077	18	2%	15	1%
All Drains	**3,826**	**414**	**11%**	**282**	**7%**

The precise percentage of all drain points contributing 100% of the sediment to the stream system in Bear Valley is 7.37%. Figure 3 displays the distribution of these drain points contributing sediment on a cumulative scale. The data confirm that 1.2% of all drain points contribute 50% of all the sediment. This is equal to a total of 46 drain points causing half of the problem. Furthermore, 116 drain points (3%) account for 80%

of the sediment, 157 (4.1%) for 90% of the sediment, and so on. These figures suggest a feasible amount of maintenance and road improvement could drastically diminish the impact of roads on Bear Valley Creek and its tributaries.

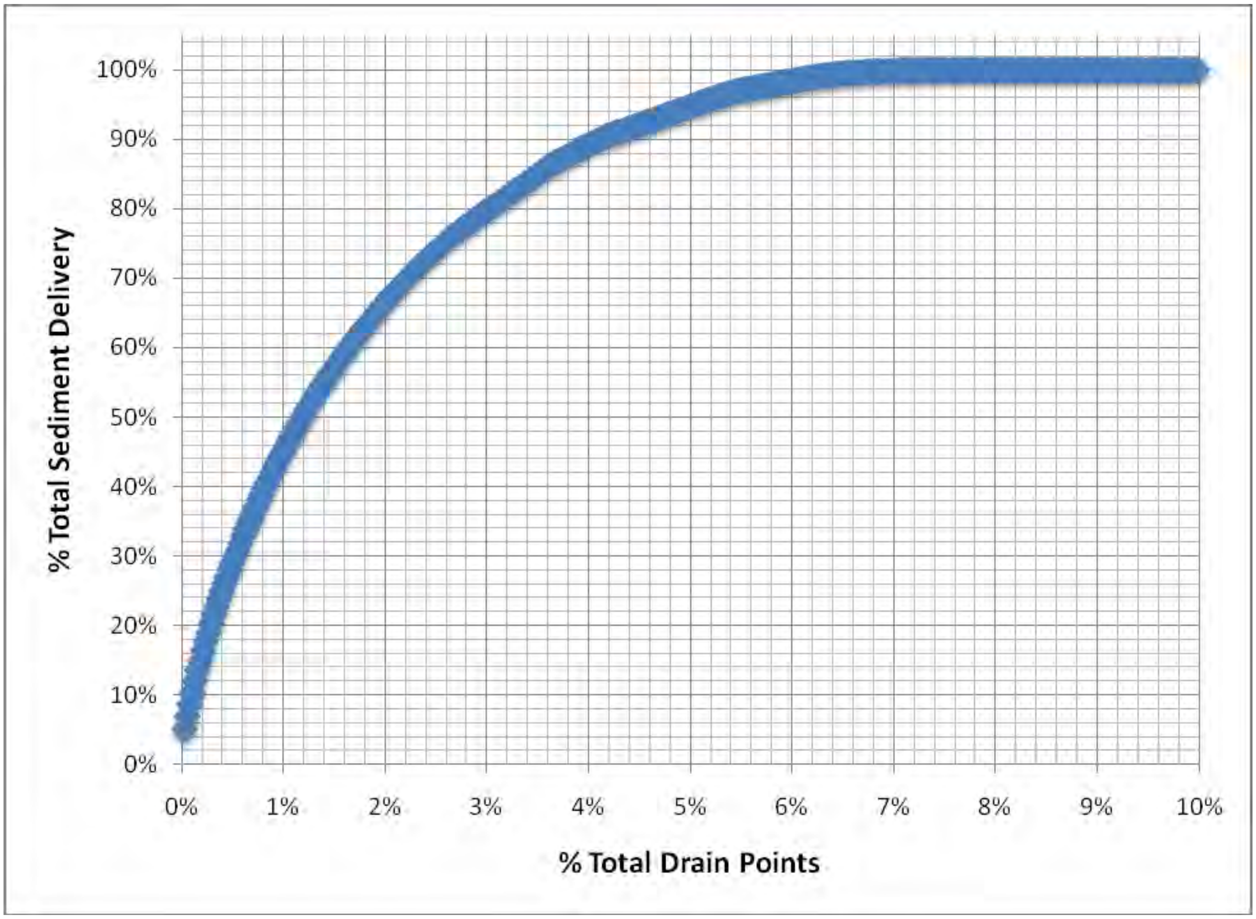


Figure 3. Percentage of the total amount of fine sediment delivered to a stream channel explained by the percentage of the total quantity of drain points.

Areas of High Sediment Delivery to Streams

Sediment delivery from roads in Bear Valley appears to be dispersed throughout the watershed (Figure 4). Specific locations where clusters of drain points with high sediment delivery exist are few with varying characteristics. Initial analysis suggests that the data do not show patterns of consistently similar characteristics among separate areas of high sediment delivery. One observation made in reviewing GRAIP data is that stream delivery often occurred at or near live stream crossings. When a road bends around a draw where a stream is present and water drains on or near that bend, road sediment regularly reaches the stream, whether at the stream crossing or another drainage feature.

Sediment delivery is also common along roads that run parallel to nearby streams. In the Idaho batholith, the median transport distance below ditch relief culverts was found to be 53 meters in a previous study by Megahan and Ketcheson (1996). In Bear Valley, 207 of the 282 drain points actively delivering sediment to a stream (73%) were within 53 meters of a channel. These drain points contribute 572.9 of the 845 tons/year (519.7 of the 766.6 tonnes/yr) or 68% of the total connected sediment. A total of 680 more drain points that were not actively delivering road sediment to the stream also fell within 53 meters of a channel.

Drain points draining extended lengths of road, if connected to the stream, are likely to deliver a large quantity of sediment. Figure 4 shows a map of the top 24 sediment-delivering drain points throughout the entire Bear Valley watershed. These 24 drain points deliver a total of 285.5 tons/year (259 tonnes/yr) of sediment to streams, which equals 34% of the total amount of road sediment reaching streams. The average length of road draining to the top 24 sediment-delivering drain points was 184 meters compared to an overall average of 61 meters per drain point. All but one of these features were within 200 meters of a stream crossing or a stream running parallel to the road and 14 were within 53 meters. Shortening the length between drain points may reduce the amount of sediment produced within these 24 drain points.

A map of the road surface sediment delivery and the accumulated sediment delivered through drain points is shown for portions of NFSR 569, FR 563, NFSR 579, FR 579, FR 582, and NFSR 502 (Figure 5). These road segments have relatively high levels of stream connectivity and sediment delivery.

a) 

b) 

c) 

Photo 2. Photos of high delivery drain points. a) Gully at outlet of highest delivering drain point in the entire basin, located on NFSR 569. b) Sack Creek stream crossing on FR 582, one of top 24 highest delivering drain points in basin. c) Eroded and dilapidated stream crossing of Bearskin Creek on NFSR 563C1.

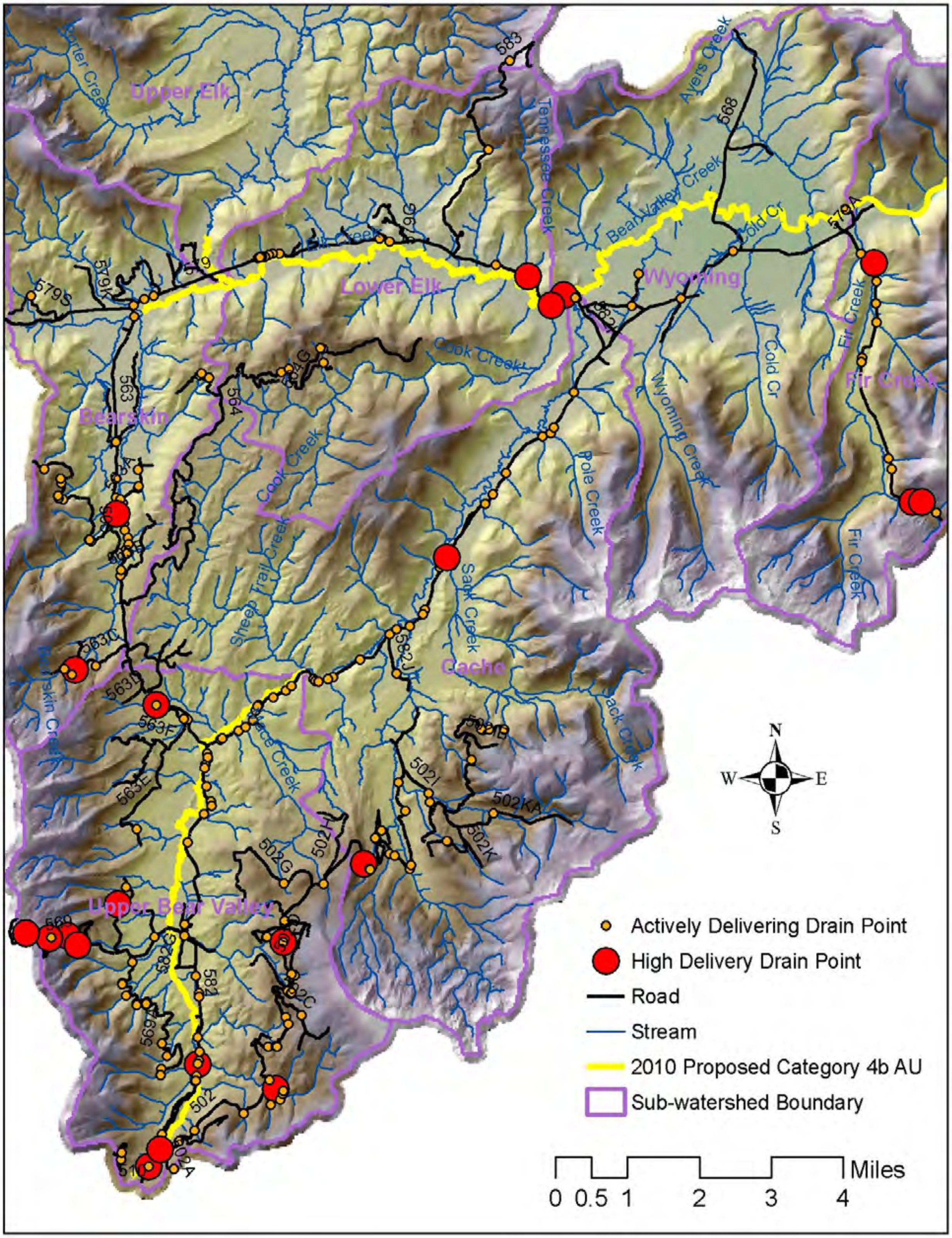
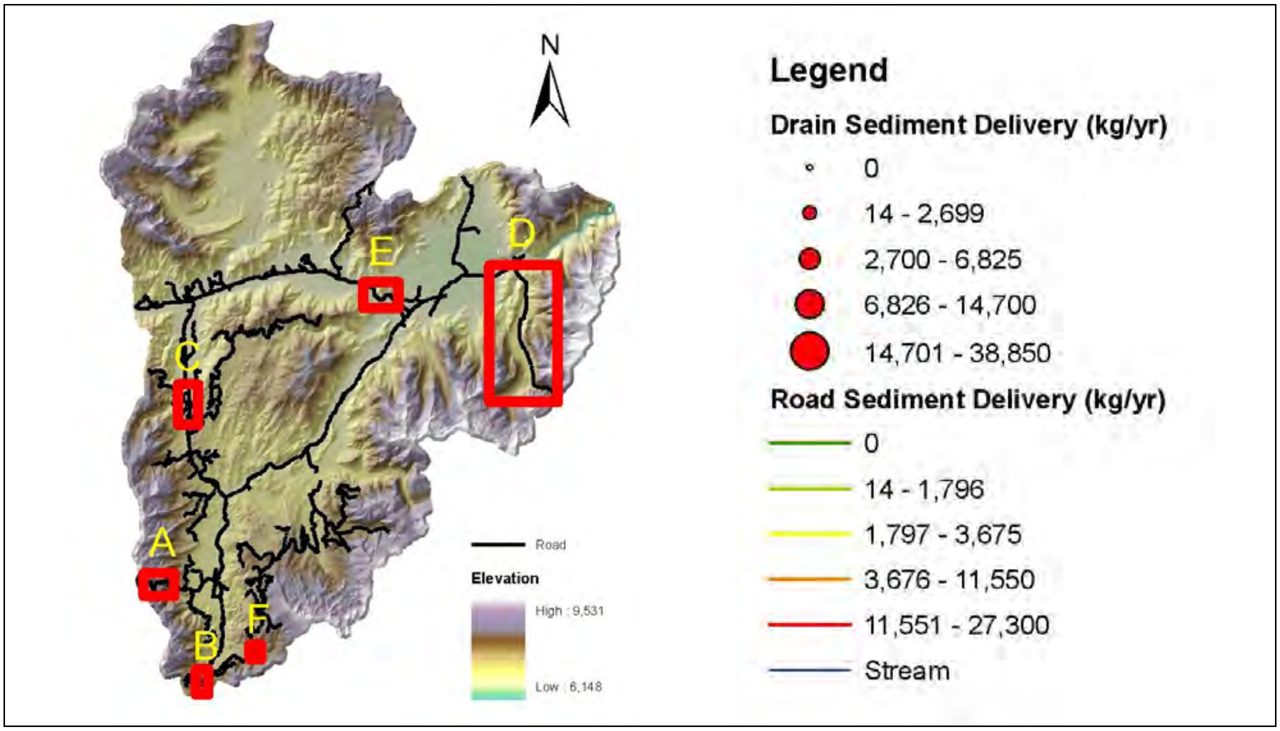
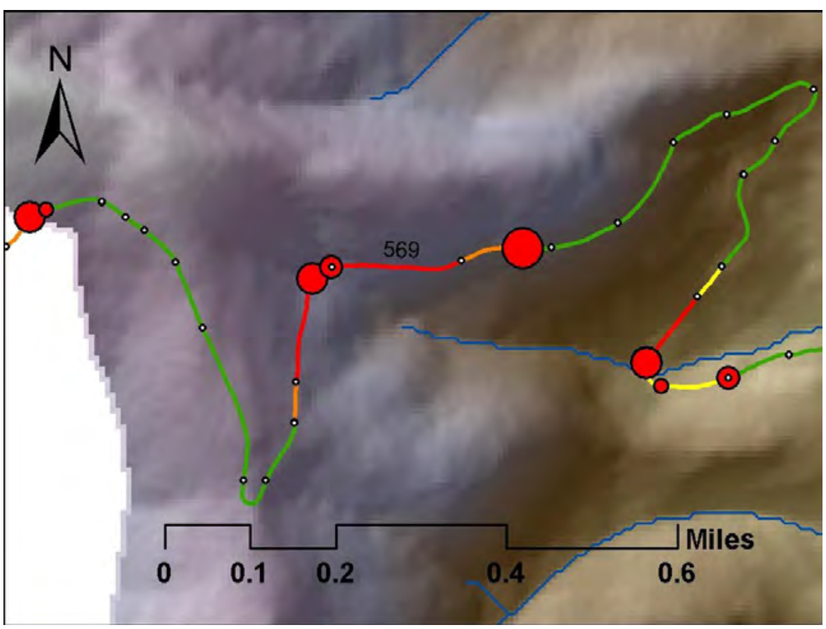


Figure 4. Map of all drain points which are actively delivering sediment to a channel. The top 24 drain points in terms of highest annual sediment delivery are emphasized.

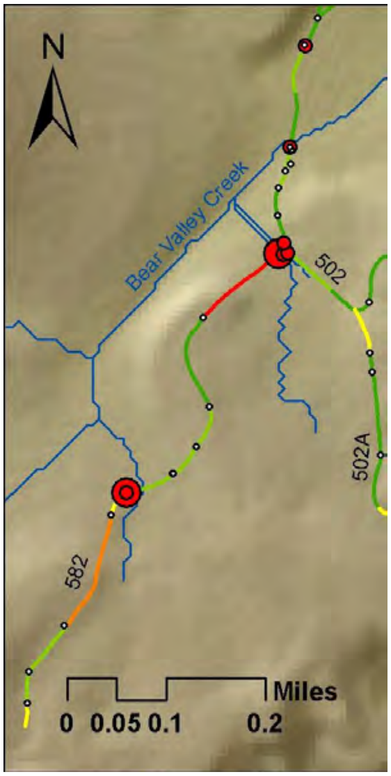
Figure 5. Maps of fine sediment delivery to channels by road segment and drain point. As indicated in the legend below, the road line is colored to indicate the predicted mass of fine sediment that is produced on the road and delivered to the channel. The size and color of the circle indicate the accumulated mass of sediment delivered through each drain point. All red circles indicate a drain point that is actively delivering sediment to streams while small white points represent a drain point not connected to the stream (see Legend below). See Table 6 for length of sediment-contributing road segments and amount of sediment delivery for each displayed road.



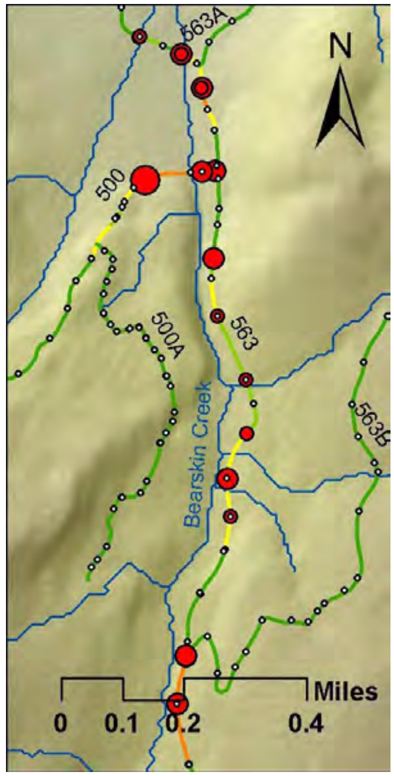


A) **NFSR 569** leading to Whitehawk Lookout has a steeper grade (9% average for displayed segment) compared to most Bear Valley roads and has the highest sediment delivery rate out of any stretch of road in the entire watershed (see Table 6).

B) FR 582

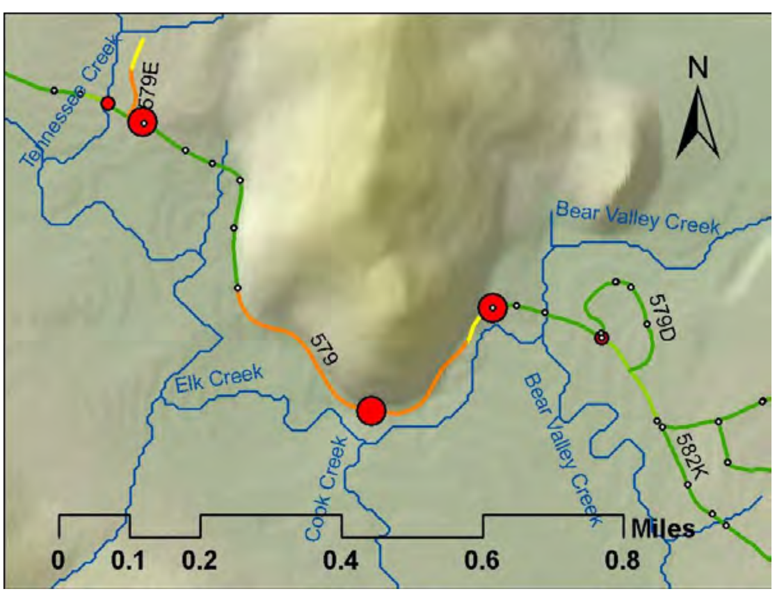


C) FR 563

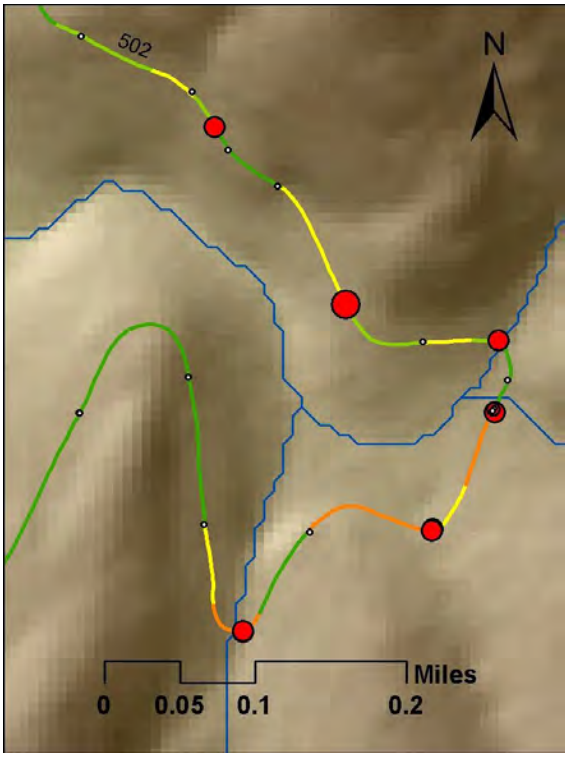


D) NFSR 579

Bear Valley Road, FR 582 (B), at the headwaters of Bear Valley Creek drains large quantities of sediment to streams. This segment of the Bearskin Road, FR 563 (C), has frequent drain points that are connected to a stream. Along Fir Creek from Cape Horn Summit to the cutoff for the Fir Creek Campground, NFSR 579 (D) passes through a burn area and exhibits concentrated flow and frequent sediment delivery. The NFSR 579 culvert crossing of Fir Creek was upgraded to a bridge to allow aquatic organism passage in 2009 after the GRAIP survey was completed. The project included a new ditch lined with rock. The project was designed to significantly reduce the sediment delivery at this stream crossing.



E) FR 579 near the confluence of Elk Creek and Bear Valley Creek runs very close to the banks of Elk Creek. The two delivering drain points nearest Elk Creek, and their adjacent road segments, represent diffuse drainage and not



concentrated flow. Although well-defined flow paths and drain points did not occur on this road segment, evidence of fine sediment reaching the channel was observed by the field crew. It is unlikely that any improvements, short of road re-alignment) could mitigate sediment delivery along this road segment because of the close proximity between the road and the stream and the road is already draining diffusely.

F) **NFSR 502** has multiple stream crossings, many of which are directly receiving sediment. This portion of NFSR 502 has three stream crossings. The streams in this image are unnamed streams in the headwaters of Bear Valley Creek.

Table 6. Sediment delivery values for road segments displayed in Figure 5 including percentage of total annual sediment delivery for the entire basin.

Forest Road	Length of Road Delivering Sediment to Stream (mi)	Sediment Delivered to Stream (tons/yr)	Sediment Delivered to Stream (tonnes/yr)	% of Total Annual Sediment Delivery
NFSR 569	0.75	121.6	110.3	14%
FR 582	0.70	41.7	37.8	5%
FR 563	1.13	70.4	63.9	8%
NFSR 579 (Fir Creek)	1.68	64.9	58.9	8%
FR 579 (Elk Creek)	0.82	30.1	27.3	4%
NFSR 502	0.61	53.9	48.9	6%
Combined Total	**5.69**	**382.6**	**347.1**	**45%**

Road Segment Analysis

Sediment Production on roads in the Bear Valley area occurs at various rates. As previously mentioned, the total amount of fine sediment production from roads is 8,091 tons/year (7,340.4 tonnes/yr). Figure 6 displays the relative sediment production rates on roads throughout the Bear Valley and Elk Creek watersheds. As would be expected, roads with steeper gradients produce the most sediment. For example, NFSR 569 and NFSR 583 appear to be high sediment producers. Given the high level of fine sediment delivery from NFSR 569, it would be assumed that the production rate is also high, which is estimated to be 537.5 tons/year (487.6 tonnes/yr) or 7% of the total. NFSR 583 (Photo 3) delivers very little sediment to streams, yet its production rate is among the highest in the basin at 736.1 tons/year (667.8 tonnes/yr) or 9% of total. Sediment production is also relatively high where NFSR 579 runs alongside Fir Creek and on much of NFSR 502.

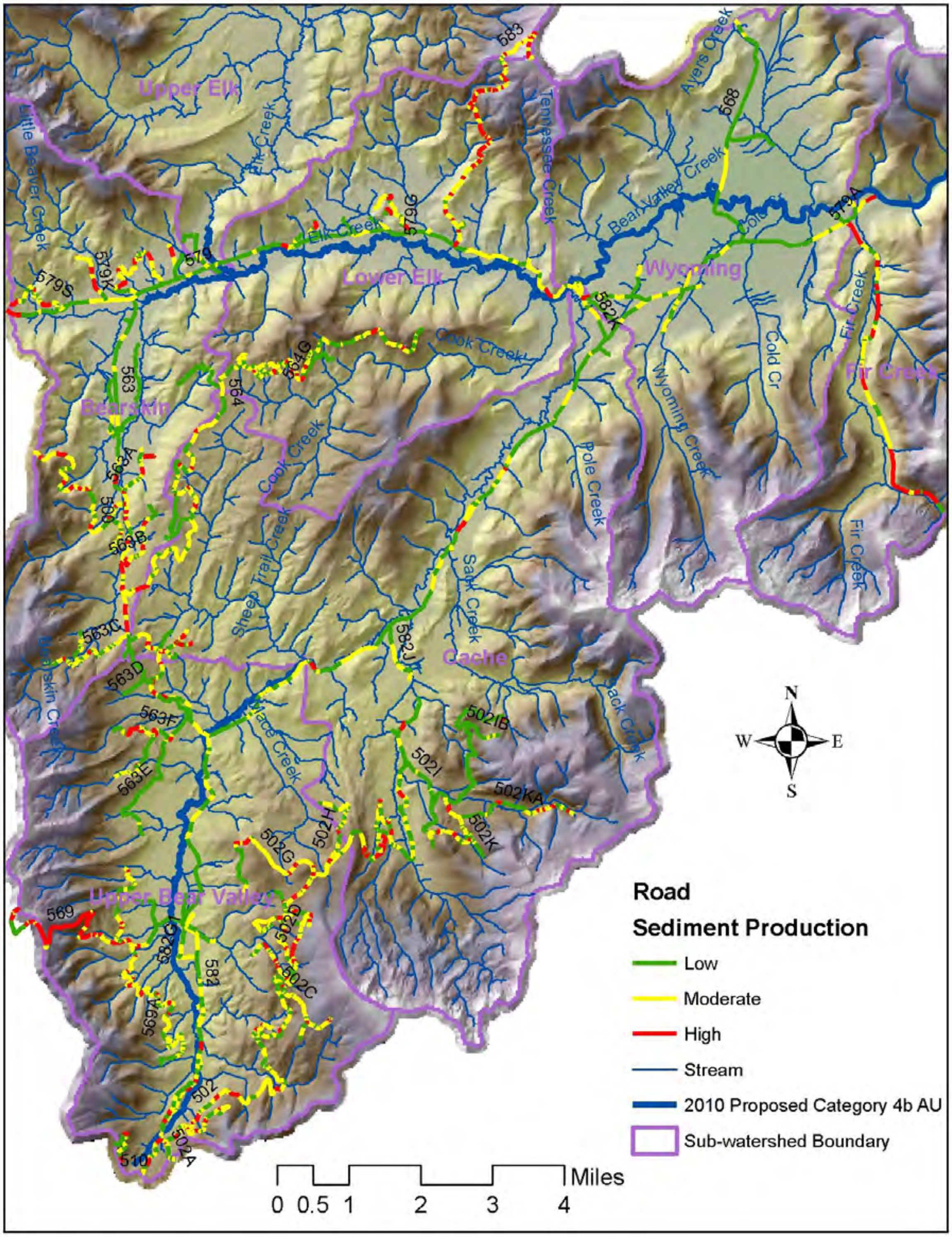


Figure 6. Bear Valley area map of relative sediment production rates by road segment.

Photo 3. Photo of a road segment of NFSR 583 leading to Bear Valley Mountain Lookout. Although, this road delivers very little sediment, much of the road is badly eroded and yields high sediment production rates.

The length and slope of a road segment are both variables in the equation GRAIP uses to calculate sediment production. Longer road lengths and steeper road gradients yield higher sediment production values. Recorded road segments had an average length of 74 meters with a range of 7 to 950 meters and a median of 57 meters. The average slope was 5.1% with a range of 0% to 26% and a median of 4.3%. Of the total road length, 12.2 miles (8%) have a slope of 0% and 51 miles (35%) have a slope of less than 2%.

The fraction of sediment delivered can be quantified in terms of percentiles of road length. Figure 7 displays the distribution of individual road segments contributing fine sediment to a channel by road length. Of the 146 miles (235 km) of total road length, 4.5 miles (7.2 km) are generating 50% of the sediment delivered to streams. That means approximately 3% of the road length surveyed is generating half of the road sediment load found in Bear Valley streams. This includes many of the road segments displayed in Figure 5. Less than 6% (8.6 mi or 13.8 km) of road length generates 80% of sediment delivered, 7.6% (11.1 mi or 17.9 km) generates 90%, and 12.5% (18.3 mi or 29.4 km) generate 100% of sediment delivered.

These data suggest that fine sediment delivery from roads could be substantially reduced with the implementation of a feasible amount of road improvement work. The GRAIP data could be used to identify the specific location of sediment delivering road segments. Various road improvements could be made to these segments to decrease or eliminate sediment delivery including constructing additional drainage features or re-surfacing roads.

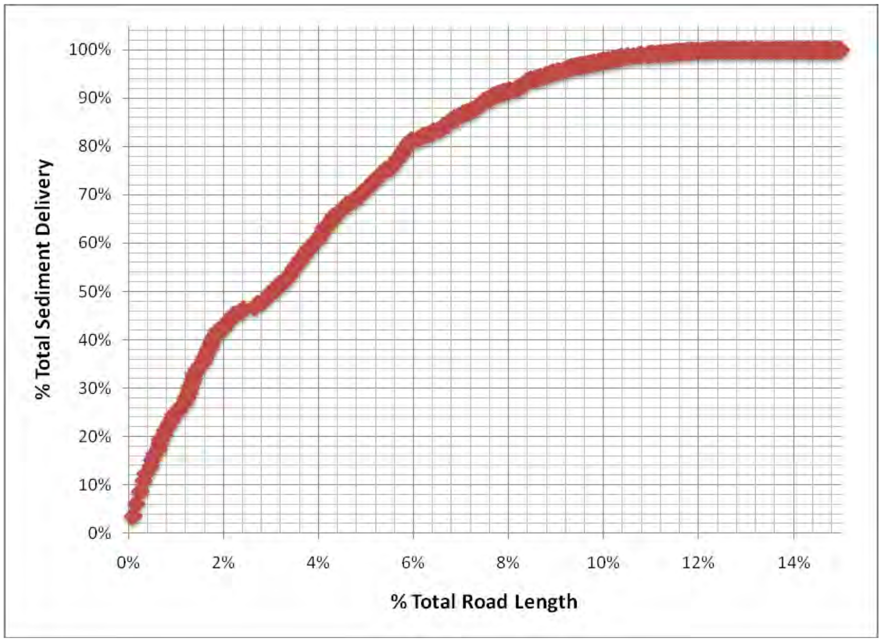


Figure 7. Percentage of the total amount of fine sediment delivered to a stream channel explained by the percentage of the total road length.

The total number of road segments is not meaningful for many analytical puposes because each road segment varies in length and other characteristics. However, it is useful to note the number of recorded road segments that would require attention or repair for management purposes. Not all problematic road segments are adjacent to each other, which may necessitate detailed logistical planning for the implementation of project work. Figure 8 demonstrates the relationship between the percentage of total sediment delivery to streams and the percentage of all road segments contributing sediment. Out of a total of 3,175 individual road segments, 338 (11%) are delivering sediment to streams. Of these segments, 59 (1.9%) are contributing 50% of the sediment, 145 (4.6%) account for 80% of the sediment, and 198 (6.2%) generate 90% of delivered sediment.

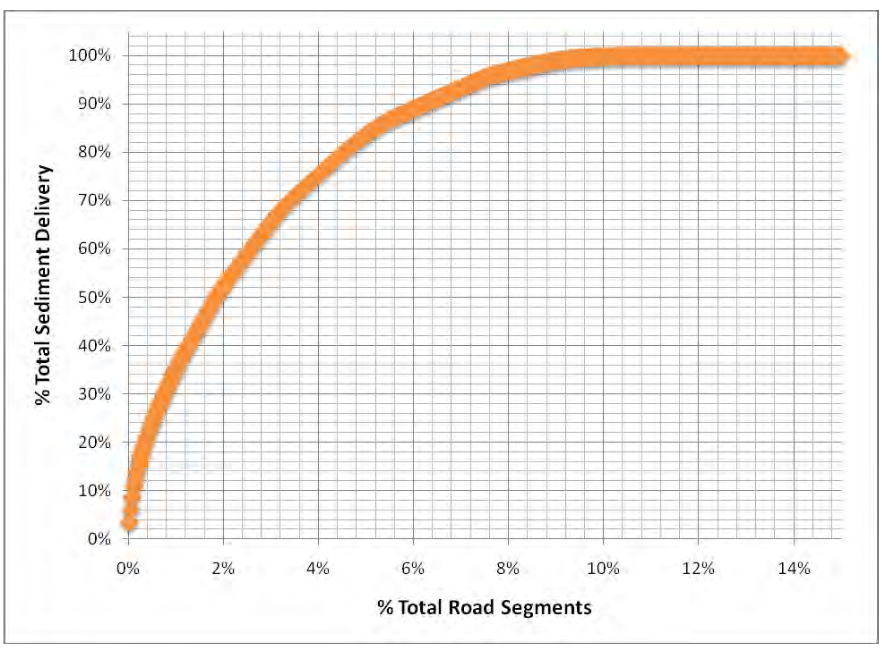


Figure 8. Percentage of the total amount of fine sediment delivered to a stream channel explained by the percentage of the total quantity of road segments.

The dominant surface type found on Bear Valley roads was native material (see Figure 9). Many decommissioned, closed, or otherwise lightly-used roads were found to have grasses and herbaceous vegetation growing abundantly on the road surface. Small lengths of closed or decommissioned roads had significant amounts of brush growing on the surface. A short segment of NFSR 568 to Dagger Falls was previously paved to reduce sediment delivery in this important Chinook spawning reach adjacent to the Bear Valley Creek crossing. Native surfaced roads produce considerably more sediment than other surface types, with paved roads producing the least amount of sediment. The GRAIP model calculates that native surfaced roads produce 25 times the sediment of paved roads, and 5 times that of any other surface type.

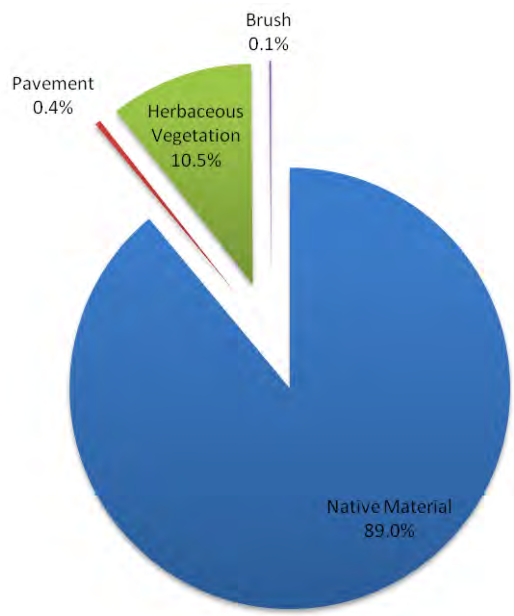


Figure 9. Distribution of road surface types found in Bear Valley by road length.

Vegetation in the flow path is also included in the equation when calculating sediment production on a road segment. Vegetation can slow flow velocity, impede erosion and sediment transport, and allow for filtering or sediment storage. GRAIP significantly reduces its prediction of sediment production when vegetation in the flow path is recorded to be greater than 25%. Field data reported that 27% of the total flow path length was observed to be more than 25% obstructed by any sort of vegetation. The remaining 73% of total flow path length in the watershed had 25% or less vegetated cover, resulting in no reduction of sediment production estimates. Flow paths on the road surface are typically not vegetated. Flow paths in a ditch can be vegetated, but frequently are not due to ditch cleaning during road maintenance activities.

5.3 Upstream Sediment Accumulation

GRAIP generates a stream network that is segmented at each channel confluence and each road/stream intersection. For each stream segment, the model calculates the accumulated road sediment load at the downstream end of that segment, including the total accumulated sediment from upstream stream segments (Figure 10). The total predicted amount of accumulated road sediment found in the stream segment nearest to the mouth of Bear Valley Creek was 820.7 tons/year (744.5 tonnes/yr). The sediment load was greatest after the confluence of Bear Valley and Elk Creeks.

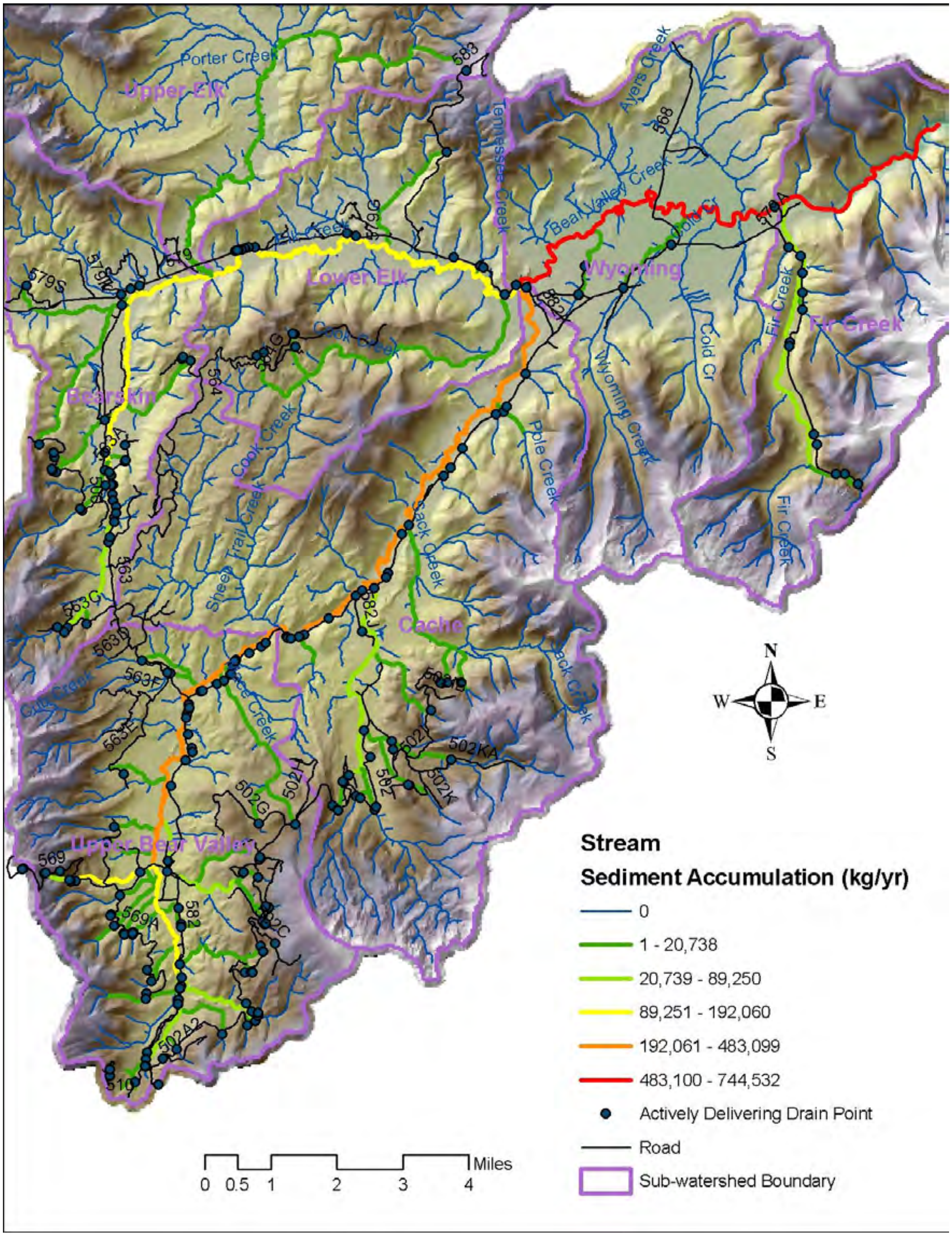


Figure 10. Bear Valley area map of stream sediment accumulation from roads.

The majority of stream sediment accumulation (74%) is produced by roads which drain to Bear Valley Creek and its tributaries, a total of 609.0 tons/year (552.5 tonnes/yr). From this amount 532.5 tons/year (483.1 tonnes/yr) or 65% of total sediment accumulation originates from above the confluence with Elk Creek. Cache Creek contains 52.0 tons/year (47.2 tonnes/yr) at its mouth. Elk Creek and its tributaries carry 211.7 tons/year (192.1 tonnes/yr) of road sediment (26% of total) prior to converging with Bear Valley Creek.

The stream network that the GRAIP model produced was based on both an existing GIS stream layer and a predicted stream layer from the TauDEM model. The total stream length of the stream layer produced by GRAIP was 582 miles (937.1 km). Road sediment is found in 134 miles (215.4 km) of streams, or 23% of the total stream length. Streams with no sediment load are generally first and second order streams located at higher elevations or in small, isolated drainages. These road sediment-free streams (77% of the total stream length) flow at locations that are either above roads, where roads do not exist, or where roads do not actively deliver sediment to a channel. Table 7 displays the accumulated stream sediment values for the basin by sub-watershed.

Table 7. Stream sediment load values by sub-watershed (HUC6).

Sub-watershed	Total Accumulated Road Sediment in Stream (kg/yr)	Total Accumulated Road Sediment in Stream (tons/yr)	Accumulated Road Sediment Rate (tons/mi^2/yr)	Total Accumulated Natural Sediment in Stream[6] (tons/yr)	Accumulated Reference Sediment Erosion Rate[6] (tons/mi^2/yr)	Road Density (Rd mi/mi^2)
Wyoming	8,400	9.3	0.4	540.6	21	0.5
Fir Creek	60,974	67.2	3.3	605.3	30	0.3
Cache	94,441	104.1	2.6	879.3	22	0.9
Upper Bear Valley	388,658	428.4	16.3	788.3	30	2.1
Upper Elk	3,150	3.5	0.1	979.4	24	0.1
Lower Elk	48,336	53.3	2.6	602.9	29	1.0
Bearskin	140,574	154.0	8.8	474.6	27	1.7
Combined Total	**744,532**	**820.7**	**4.3**	**4,870.4**	**25.5**	**0.9**

GRAIP calculates the accumulated road sediment load for each stream segment specific to the total area of land draining to it. The specific accumulated sediment load figure of the stream segment at the mouth of a channel will indicate the value for the entire drainage of that channel. At the mouth of Bear Valley Creek the specific accumulated sediment load is 4.3 tons/mi^2/yr (1.5 Mg/km^2/yr). The total predicted stream sediment load from natural erosion of undisturbed hillslopes within the Bear Valley and Elk Creek watersheds is approximately 4,870 tons/yr. This yields a reference sediment erosion rate of 25.5 tons/mi^2/yr (8.9 Mg/km^2/yr). Therefore, road

[6] The background sediment erosion rates used for this comparison were derived using the BOISED model which calculates sediment erosion rates by land type. These figures were copied from the Bear Valley Watershed Analysis (Shapiro et al. 2000).

sediment accumulation essentially increases the natural stream sediment accumulation rate by 17%. Disturbances such as wildfire, logging, or roads are not accounted for in this reference sediment rate. Such disturbances as wildfire will elevate the indicated natural sediment erosion rate, especially in this basin which has experienced multiple wildfires in recent years. In fact, 59% of the total area (113 mi^2) of the basin has burned since 1985.

In comparing road density to the accumulated road sediment rate (Figure 11), where higher road densities exist, higher accumulated road sediment rates generally occur as well. However, this is not true for all sub-watersheds in the basin. The Fir Creek and Upper Bear Valley sub-watersheds have higher accumulated road sediment rates in comparison to their road densities than do most other sub-watersheds, whereas the Wyoming and Upper Elk sub-watersheds have lower ratios. Upper Elk measures extremely low in both categories, which would be expected as it has a large area and very little road length. Although the sample size of sub-watersheds for this basin is too low to draw out any real statistical correlation, the two sub-watersheds with the highest road density, Bearskin and Upper Bear Valley, also have the highest accumulated road sediment rates. Many other variables, such as terrain and geology, may also be related to this phenomenon.

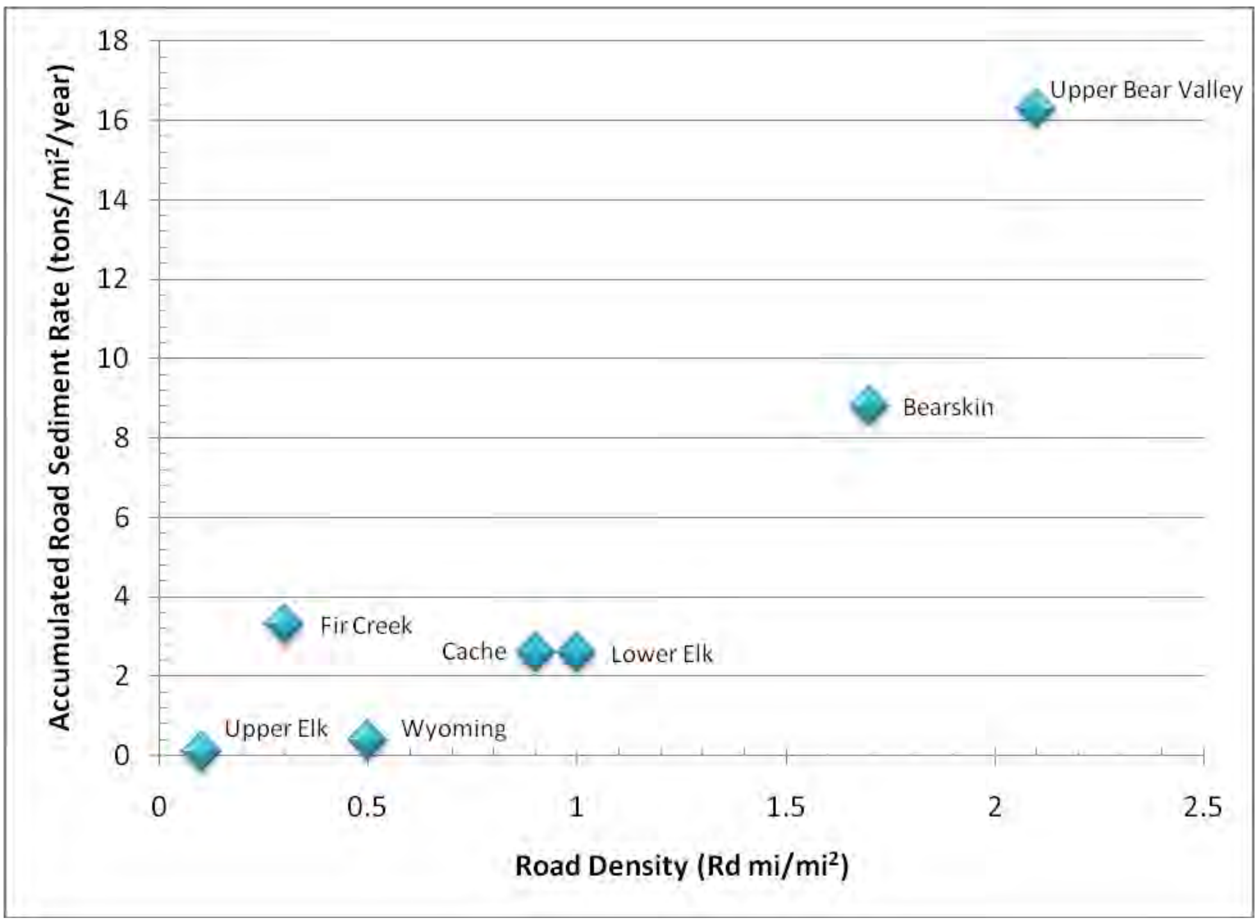


Figure 11. Road density versus accumulated road sediment rate by sub-watershed.

5.4 Drain Point Condition

The GRAIP inventory involves an assessment of the condition of each drain point and a determination of how well it is performing its intended function. Problems with drain point condition are pre-defined for each drain type. Broad based dips are considered to be in poor condition if they are insufficiently outsloped and pond water on the road. Culverts are defined to be in poor condition if they have more than 20% occlusion of the inlet by sediment, substantial inlet crushing, significant rust, or flow around the pipe. Lead off ditches are considered problematic if they have excess deposition or are gullied. Non-engineered features are almost always a problem due to a blocked ditch, a gully, a broken outside berm, or a diverted wheel track. 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. Water bars that are damaged, under sized, or do not drain properly are defined as problematic. Diffuse drains (outsloped roads) are rarely observed to have drain point problems.

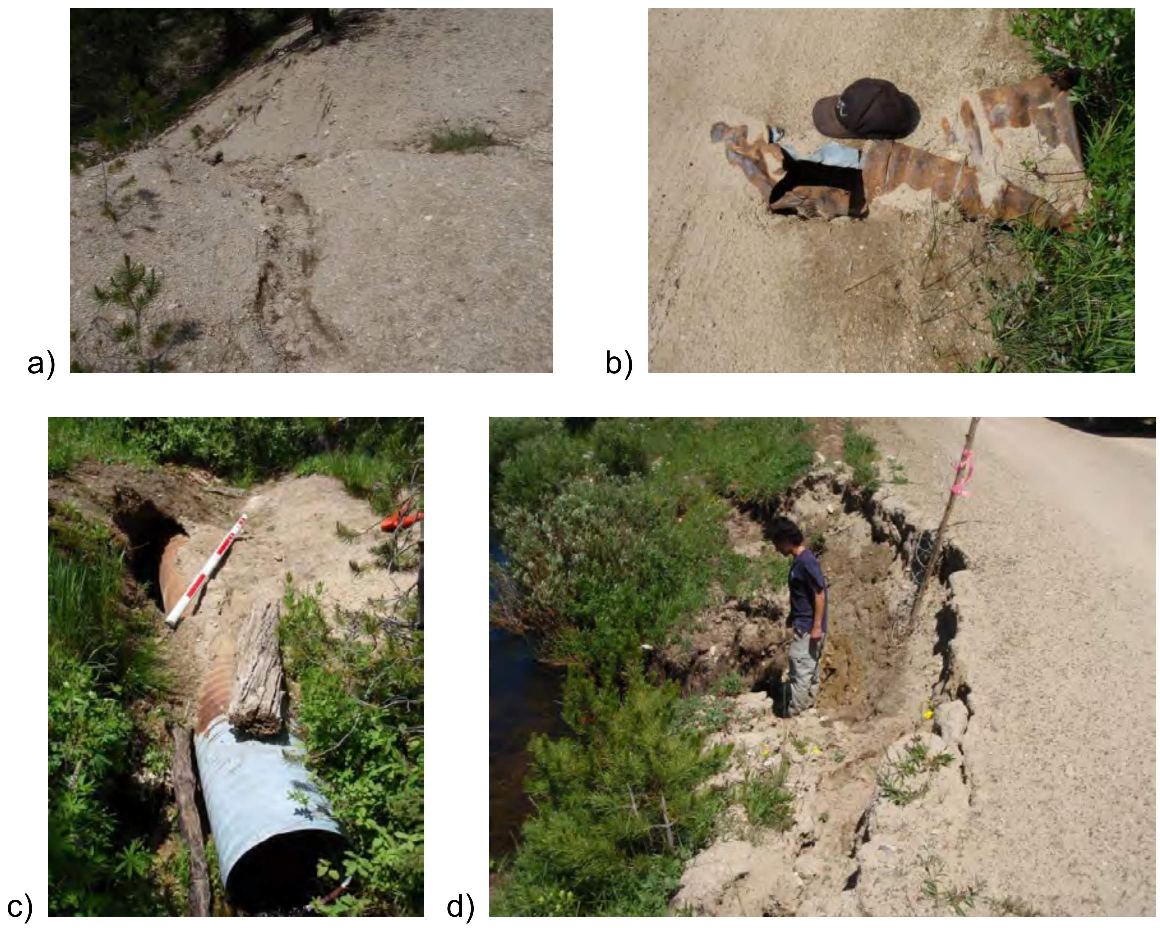


Photo 4. Examples of drain point condition problems including: a) erosion at a broad based dip, b) a rusted and damaged ditch relief culvert, c) a stream crossing with flow around and possibly over the pipe, and d) a non-engineered feature where the stream is cutting into the road fill material.

In Bear Valley, non-engineered features were observed to have the highest rate of problems (58%), while lead off ditches or berms and diffusely drained roads were least likely to have problems (Table 8). Any drain point that causes erosion of fill material at its outlet is considered problematic. Drain point features that most often eroded fill material at the outlet or away from the fillslope were non-engineered features and water bars (both at 4%).

Table 8. Drain point condition problems and fill erosion below drain points.

	TOTAL	CONDITION PROBLEMS		FILL EROSION	
Drain Type	Count	Count	Percentage	Count	Percentage
Broad Based Dip	488	23	5%	6	1%
Diffuse Drain	1,077	0	0%	2	0.2%
Ditch Relief	388	48	12%	11	3%
Lead Off	90	1	1%	0	0%
Non-Engineered	501	291	58%	19	4%
Stream Crossing	191	15	8%	5	3%
Sump	14	2	14%	0	0%
Water bar	1,077	76	7%	45	4%
Total	**3,826**	**379**	**10%**	**88**	**2%**

Features other than actual drain points were often observed and recorded during the field inventory on Bear Valley roads. Field crews are trained to observe and record any existing gates, ends of roads, gullies, landslides, photo points, road closure features, and road hazards are among these additional features. Given that these features are not the focus of the GRAIP model, it is likely that more of these features exist than what was recorded. Of these additional collected features, some were noted to be damaged, hazardous, or in need of maintenance or attention. Two out of seven gates were noted to be damaged or dysfunctional. Four road hazards were recorded where various circumstances pose a risk to vehicles or people using the road.

5.5 Stream Crossing Failure Risk

In addition to contributing fine sediment to streams through surface erosion, stream crossings may fail catastrophically when blocked and deliver large sediment pulses to stream channels. Stream crossing failure risks were assessed using the Stream Blocking Index (SBI, Flanagan et al. 1998). The SBI characterizes the risk of plugging by woody debris by calculating the ratio of the culvert diameter to the upstream channel width and the skew angle between the channel and the pipe inlet.

Field crews recorded a total of 191 stream crossings in Bear Valley. Of these stream crossings, 45 (24%) did not have a round culvert pipe present and were not included in the SBI calculations. These crossings were designed with a bridge or an oval pipe, were decommissioned and excavated, or otherwise did not include a pipe in the design. Risk of pipe plugging does not exist at most of these stream crossing types.

Photo 5. Many stream crossings such as this one have more than one pipe to prevent blockage or flow diversion. SBI figures do not account for the presence of multiple pipes which means some SBIs may predict higher risk than what actually exists.

The SBI values for Bear Valley stream crossings were relatively high with an average value of 2 for the 146 assessed stream crossings (Figure 12). This is out of a range of 1 to 4, where 1 suggests minimal to no risk of blockage. The 36 stream crossings with values of 3 and 4 all had pipe to channel width ratios equal to or less than 0.75. Approximately one third of these crossings had a channel angle (angle at which the channel enters the pipe) greater than 25 degrees. Some stream crossings predicted to be at risk in Bear Valley may not be as prone to failure as predicted. Therefore, a more thorough field survey of stream crossings with high SBIs would indicate where failures would likely occur and where repair is needed.

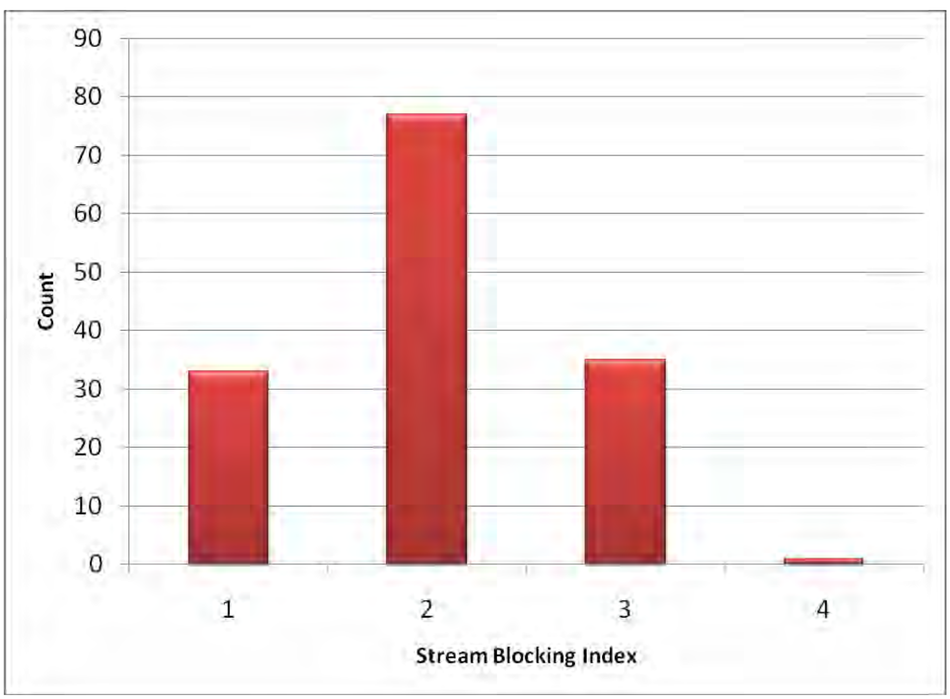


Figure 12. Distribution of Stream Blocking Index values.

The risk of a stream crossing failure can also be viewed in the context of the consequences of failure (Flanagan et al. 1998). A consequence of concern at these stream crossings is the erosion of fill material into the stream channel. The fill material that would likely be excavated in an overtopping type failure was calculated. Then the prism of fill at risk was modeled as bounded at the base by an area 1.2 times the channel width, with side slopes climbing to the road surface at an angle of 33%. The fill volume at risk in the Bear Valley road configuration was approximately 3,213 m^3.

A second, and perhaps greater, consequence of concern at failed stream crossings is the diversion of stream flow onto road surfaces and unchannelled hillslopes. Once a crossing becomes occluded and begins to act as a dam, failure can occur in several ways. If the road grade dips into and rises out of the crossing, the failure is likely to be limited to a localized overtopping of the stream crossing. However, if the road grades away from the stream crossing in one or more directions, the flow may be diverted down the road and ditch and onto adjacent hillslopes, where it can cause gullying and/or landsliding (Furniss et al. 1998, Best et al. 1995). In these situations, volumes of sediment far exceeding those at the crossing can be at risk. A past example of such an event occurred in this basin in 2003 where a flow diversion failure occurred on NFSR 579 due to a post-wildfire debris flow.

GRAIP addresses this issue by classifying the potential for stream crossings to divert streamflow down the adjacent road as: no potential, potential to divert in one direction, or potential to divert in two directions. In Bear Valley, 21% (41 out of 191) of the stream crossings on the roads had the potential to divert streamflow down the road in at least one direction. Taking into account both the diversion potential and the fill material volume at risk, stream crossing failure risk in Bear Valley is low to moderate.

5.6 Gully Initiation Risk

Gullying at drain points below roads can be a substantial source of sediment to stream channels. Gully initiation occurs when the shear stress applied by runoff exceeds the strength of the soil surface on the hillslope. GRAIP computes the Erosion Sensitivity Index (ESI) (Istanbulluoglu et al. 2003), as shown below, at each drainage point.

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

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

Generally, calculated ESI values can then be compared to a critical ESI threshold (ESI_{crit}) to identify areas with a high risk of gully formation (i.e., where drain point ESI > ESI_{crit}). ESI_{crit} is empirically-derived using inventoried gullies. In Bear Valley, a total of 22 gullies were recorded and 17 gullies were associated with a drain point that was actively discharging water to it from the road surface. This means that 0.4% (17 out of 3,826) of all drain points were discharging to a gully. There were not enough observed gullies in proportion to the number of drain points to establish ESI_{crit} for this area. There is no ESI at which the risk of gullying increases significantly, because the drain points with gullies are distributed relatively evenly throughout the road length-discharging hillslope range (Figure 13).

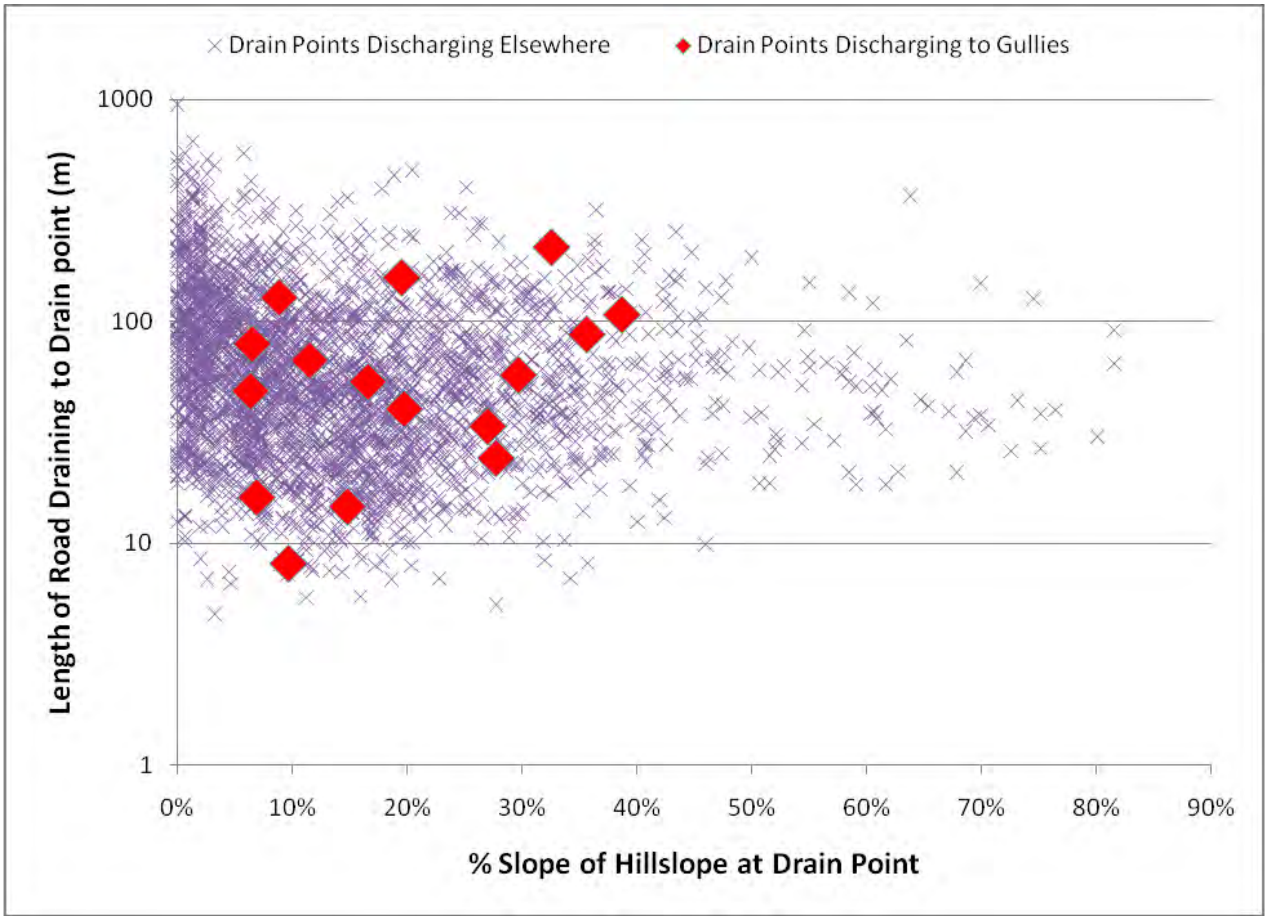


Figure 13. Distribution of where drain points discharge flow from the road by ELength and slope of the hillslope at the drain point.

The average ESI for all drain points was 1.9, with an average contributing road length of 61 m. The average slope of the hillslope at the drain point was 14%. Of all drain points discharging to a gully, 10 (59%) had an ESI less than the average of 1.9. This affirms the conclusion that the sample of observed gullies in Bear Valley is insufficient to determine ESI_{crit}, which suggests that the gullies found in Bear Valley are not strongly tied to road length draining to them or the slope of the hillslope on which they are located. Other factors such as localized geology, past wildfires, or isolated large storm events may be causes of the gullies that do exist. Given the active wildfire history of the basin, it might be predicted that gullying would be a greater risk than observed, especially taking into account concentrated flow from roads. Nearly 30% of the area of Bear Valley burned during the Red Mountain wildfire in 2006 and the Sheep Trail wildfire in 2007, and a total of 59% of the basin has burned within the last 25 years. This emphasizes the prediction that the risk of gullying throughout areas of the watershed with roads is uniformly low.

5.7 Landslide Risk

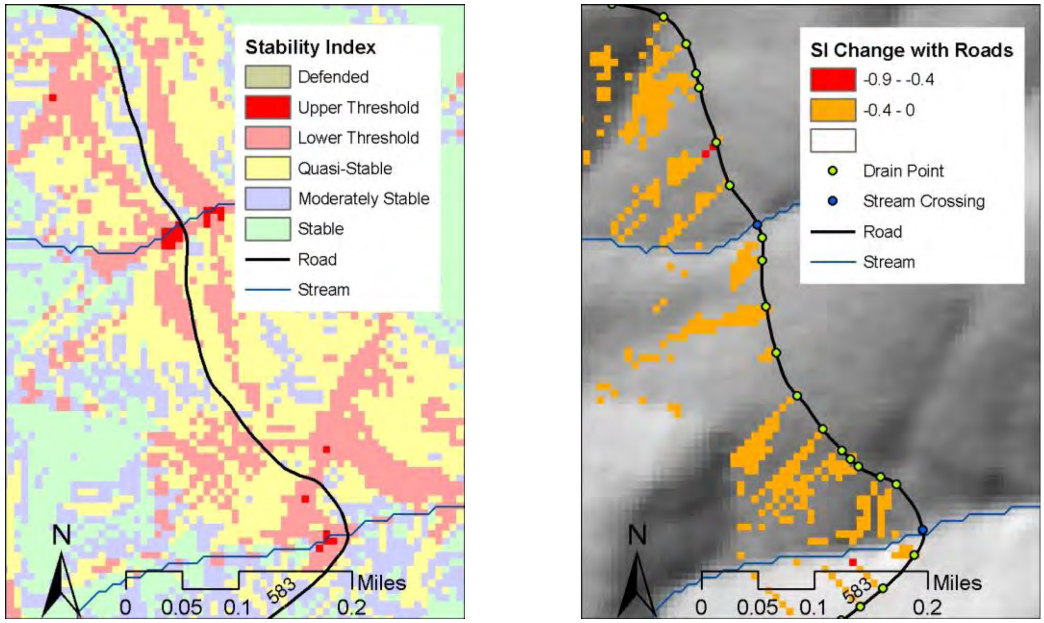
Bear Valley has a very low incidence of shallow landslides or other types of mass wasting. The GRAIP inventory records landslides which are visible from the road and are greater than a minimum threshold of 6 feet in slope length and slope width. However, no such landslides were observed during the inventory. Similar to gully initiation risk, based on the lack of mass wasting events observed during the road inventory in Bear Valley despite recent wildfire history, increased risk of landsliding caused by roads is very low. Managing the land for such events would likely not be an effective use of resources.

The risk of shallow landslide initiation is predicted using SINMAP 2.0 (Pack et al., 2005, http://hydrology.neng.usu.edu/sinmap2/), then modified to account for contributions of road runoff. An example from NFSR 583 is shown in Figure 14 to illustrate the change in risk in an area where the inherent landslide risk is high. This risk is assessed by referring to an index referred to as the Stability Index (SI). SINMAP was run initially to determine the intrinsic stability (SI) of the slopes over which the road traverses and to identify locations that are at high risk of failure without a road(Figure 14a).

A second stability index run was performed to address the effects of road water contribution to drain points on the road network. This second stability index run is referred to as the Stability Index Combined (SIC) because it accounts for both the naturally inherent risk of hillslope failure in a landscape and the added risk from roads. Roads which exhibited the greatest amount of negative change in slope stability in Bear Valley include NFSR 583, NFSR 569, NFSR 564, NFSR 500, and NFSR 502. Because there were no recorded landslides from the GRAIP field survey, an accurate calibration of change in the SI was not possible. This means that the different degrees of slope stability displayed in Figure 14 are only relative to each other and do not necessarily make up reliable predictions of increased risk of mass wasting for this area. Therefore, Figure 14 and its indicated predictions of SI change due to roads are only an estimation of what might actually be happening. The true added risk of mass wasting with road drainage could be higher or lower than GRAIP outputs suggest. More data on existing failures is needed for calibration.

The grid cells surrounding portions of NFSR 583 with increased risk of landsliding due to road drainage are shown in Figure 14b. This stretch of NFSR 583 runs through a previously burned area where flow of water on the road is highly concentrated, resulting in high amounts of energy when water discharges from the road prism. The road surface is highly eroded. The drain points depicted in the figure below are mostly water bars with a few non-engineered drains and one ditch relief culvert. The addition of drain points to the roads primarily increased previously existing high landslide risk. Instances where previously stable hillslopes were classified as unstable due to road drainage were few.

14a **14b**



a) SI values for hillslopes in an un-roaded condition. **b)** Negative changes in SI due to the addition of road drainage.

Figure 14. Stability index for hillslopes in the vicinity of NFSR 583.

Potential improvements that could mitigate the increased landslide potential along at-risk roads such as NFSR 583 primarily include the installation of more frequent drainage features (e.g. water bars, broad based dips, etc.). However, increased drainage may redistribute landslide risk to other locations rather than eliminate it. Risks of mass wasting are often slightly increased in steep, dissected terrain, because it is difficult to redirect discharge from one location without elevating the risk in others. This is consistent with Madej (2001), who concluded that decommissioned roads in high risk areas commonly experience failures after treatment because their effects cannot always be fully mitigated.

6.0 Quality Assurance

As a measure of quality assurance and quality control for data collected during the field inventories, a plan was devised and created in collaboration between RMRS hydrologists and GRAIP model developers and USEPA project managers. The plan is entitled, *Geomorphic Road Analysis and Inventory Package (GRAIP) Field Collection Activities: Quality Assurance Project Plan (QAPP)*. (Black et al. 2009)

The QAPP outlines several data quality objectives (DQOs) that are intended to ensure accuracy and consistency of data among field crews. First, each crew received training from GRAIP experts at the RMRS prior to being deployed to the study area. These crews received further training in the field from the field crew leader upon arrival to the study area. Field crews and the field crew leader coordinated daily to answer any field related questions and to address data collection procedures. The crew leader also acted as part of an “expert” crew for empirical assessment of precision and bias.

Three road sections (QA plots, see Figure 15 in Appendix B) were selected for quality assurance monitoring and analysis in compliance with the QAPP. Each of these roads was individually surveyed by each of the three hired field crews and by an expert crew. Sediment production and sediment delivery results were compared to measure precision and bias. One of these sections was chosen based on having high sediment production and high sediment delivery. Another section was specifically chosen to have low sediment production and low sediment delivery. The third section was chosen by convenience and is more representative of the average road conditions within the watershed. The first of these QA plots was surveyed soon after the hired crews completed training. The second QA plot was completed approximately one month after the initial plot and the third another month after the second.

Precision is a measure of repeatability and consistency. Bias is a measure of accuracy. Since sediment production and delivery values were generally very high in the project watersheds, relative precision and bias were evaluated to assess QAPP objectives. Precision and bias were calculated for each of the three QA plots. For individual QA plots, relative precision of sediment production ranged from 13% to 17% and relative bias ranged from -20% to 18% (Table 9). Relative precision of sediment delivery ranged from 17% to 19% and relative bias from -29% to 9%. The objective outlined in the QAPP was to ensure that relative precision values are within 20% of the mean of all replicates of collected data, including that of the expert crew. The objective for relative bias was defined to be within 20% of the expert crew’s sediment production and delivery predictions. These objectives were met in all but one category of one QA plot, the relative bias for QA Plot 3. Here, the bias for sediment production was -20.27% and -28.65% for sediment delivery. This means that data collected by hired field crews suggest less sediment was being both produced and delivered to streams than did the expert crew’s data. Because this was the last QA data set collected before the end of the field season, corrective action did not take place as there was insufficient time to do so before field crews ended the season.

Total sediment delivery for QA Plot 2 was drastically lower than it was for QA Plots 1 or 3. The QAPP identifies transition values for sediment production and delivery below which absolute values of precision and bias are to be used for assessment rather than relative values. The transition value for sediment delivery is 5 tonnes/km/year. Total estimated sediment delivery calculated from the expert crew’s data for QA Plot 2 was 1.58 tonnes/km/year. Therefore, absolute precision and bias are to be examined. The absolute precision for sediment delivery for QA Plot 2 was 0.40 tonne/km/year and the absolute bias was -0.51 tonne/km/yr. This is within the absolute objective value of 1 tonne/km/year as outlined in the QAPP.

Table 9. Quality assurance statistics for the Middle Fork Payette River[7] and Bear Valley Creek and Elk Creek watersheds.

QA Plot 1								
	Experts	Crew 1	Crew 2	Crew 3	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
Sum_SedDel (kg/yr)	723,146	602,646	1,001,908	763,732				
Sum_SedProd (kg/yr)	807,154	738,724	1,048,186	1,037,079				
Sum_ELength (m)	3530	3525	3530	3527				
SedDel/ELength (t/km/yr)	204.85	170.97	283.85	216.55	40.98	18.71%	18.94	9.24%
SedProd/ELength (t/km/yr)	228.65	209.57	296.96	294.05	38.80	15.08%	38.21	16.71%

QA Plot 2								
	Experts	Crew 1	Crew 2	Crew 3	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
Sum_SedDel (kg/yr)	6,216	3,150	3,150	6,300				
Sum_SedProd (kg/yr)	157,563	207,743	140,301	210,263				
Sum_ELength (m)	3926	3931	3929	3928				
SedDel/ELength (t/km/yr)	1.58	0.80	0.80	1.60	0.40	33.08%	-0.51	-32.48%
SedProd/ELength (t/km/yr)	40.13	52.85	35.71	53.53	7.80	17.12%	7.23	18.02%

QA Plot 3								
	Experts	Crew 1	Crew 2	Crew 3	Abs_Prec	Rel_Prec	Abs_Bias	Rel_Bias
Sum_SedDel (kg/yr)	487,828	341,297	317,345	384,600				
Sum_SedProd (kg/yr)	1,028,792	809,744	913,073	735,271				
Sum_ELength (m)	3831	3826	3823	3832				
SedDel/ELength (t/km/yr)	127.35	89.22	83.01	100.37	16.98	16.98%	-36.48	-28.65%
SedProd/ELength (t/km/yr)	268.56	211.67	238.85	191.89	28.87	12.68%	-54.43	-20.27%

Objective Met

Objective Not Met

[7] Field crews conducting the Bear Valley GRAIP road inventory in the summer of 2009 were concurrently conducting a GRAIP road inventory on the Middle Fork Payette River watershed. This QAPP was designed to be the quality assurance plan for both project areas. QA Plots 1 and 3 were in the Middle Fork Payette River watershed and QA Plot 2 was in the Bear Valley Creek watershed (see Appendix B).

The unachieved DQO of relative bias of sediment production and delivery on QA Plot 3 may be a result of greater misinterpretation of road drainage attributes by the expert crew rather than the hired crews. As shown in the table, both predicted sediment production and predicted sediment delivery outputs from the expert crew's dataset were considerably higher than the same for all three hired crews. This suggests that for this plot, the hired crews were rather consistent in their interpretations of road drainage attributes, but the expert crew was the outlier.

The primary sources of error among the QA plots were discrepancies in flowpath vegetation on road segments and stream connection at drain points as interpreted by the crews. Flowpath vegetation is calculated into the sediment production equation. Where the percentage vegetation cover in the flowpath is recorded to be 25% or more, the sediment production rate is dramatically reduced. This was often the case in comparing the road segment attributes of different crews' datasets for these QA plots. On QA Plot 3, the hired crews recorded an average of 33% of flowpath length to have more than 25% vegetation whereas the expert crew only recorded 15% for the same. The other main source of error for these plots was the observed and recorded road-stream connectivity of drain points. In general, hired field crews recorded fewer drain points to be hydrologically connected to a stream than did the expert crew. On average, hired crews recorded 33% of drain points to be connected to a stream whereas the expert crew recorded 45% to be connected. Further training on measuring flowpath vegetation and on identifying evidence of fine sediment transport and water flow to determine stream connection will help reduce these errors among future crews.

In order to address the observed bias in the flow path vegetation observations, additional crew training will be implemented along with a new calibration element in future GRAIP field inventories. A point/line transect approach will be used to calibrate the field crew on two road segments inventoried each day. First a crew will estimate and record vegetation cover, then a 20 meter tape will be stretched along the flow path and vegetation presence or absence will be recorded at one meter intervals. The transect intersection data will serve to calibrate the ocular estimates through time and between crews. Frequent calibration of ocular estimate values has been shown to be effective in minimizing observer bias in other forestry data collection problems such as estimating tree stem diameter.

In addition to the survey of QA plots, the field crew leader conducted monthly field audits or "ride-a-longs" with each crew in order to evaluate the crew's performance and provide real-time corrective action as needed. During these ride-a-longs, the field crew leader would observe a field crew through the survey of a road segment, point out inaccurate or inconsistent performance and correct it on the spot, and review weaknesses and discrepancies in data collection procedures that might affect data quality.

Due to logistics and the pressing demands of the field season, data collected on QA plots were not processed until after the end of the field season. QA results, including DQOs from QA Plot 3 that were not met and other dissatisfactory QAPP requirements, are currently being evaluated in order to take corrective action before the next phase of this or other similar projects. Despite the few quality assurance objectives that were not met, the

GRAIP data collected during the Bear Valley road inventory project is considered valid and usable for analysis. See Appendix B for more information on the QAPP.

7.0 Summary & Conclusions

The BNF and the RMRS initiated a road inventory project to include all roads in the Bear Valley and Elk Creek watersheds in the summer of 2009. Funding was provided through an interagency agreement with the USEPA. Field crews inventoried road segments in Bear Valley while a data manager and a GIS technician processed and analyzed the data that was collected in the field. The GRAIP model was used to predict the level of impact/risk that existing roads posed on streams. Study objectives were identified as outlined in Section 2.0 of this report. These objectives were met and the questions posed were answered as shown below.

1. What is the existing level of fine sediment delivery from roads to streams in Bear Valley?
    a. How does the contributed sediment from roads compare to natural reference sediment levels?

The length of the sampled road that was hydrologically connected to streams totaled 18 mi (29 km) out of the 146 mi (235 km) of inventoried road (12.5%). The model predicted that the existing level of fine sediment delivery from roads to streams amounts to 845 tons (767 tonnes) annually, which is 10% of the predicted annual fine sediment production total of 8,091 tons (7,340 tonnes). Road sediment that accumulates in the stream network annually is predicted by the model to be 821 tons (745 tonnes). Measuring from the mouth of Bear Valley Creek (which includes both Bear Valley and Elk Creek watersheds), the accumulated road sediment per unit area is predicted to be 4.3 tons/mi^2/yr (1.5 tonnes/km^2/yr). Compared to the watershed's natural reference sediment accumulation rate of 25.5 tons/mi^2/yr (8.9 tonnes/km^2/yr), added road sediment yields a 17% increase.

2. Where are the locations of highest sediment delivery from roads to streams?
    a. Can these sites be reconstructed to eliminate or minimize delivery?

As indicated in Figures 4 and 5, locations of high sediment delivery within the Bear Valley and Elk Creek watersheds are relatively widespread. NFSR 569 has the single highest sediment-delivering drain point and several other high delivery drain points within its length. NFSR 502, FR 582, FR 563, and FR 579 have frequent drain points which are actively delivering fine sediment to streams. Road-stream connection often occurs at or near live stream crossings on roads. Although these predicted locations of high sediment delivery are based on thorough field observations and careful data processing, more thorough field surveys of the indicated road segments and drain points would need to be completed in order to design effective management plans. Reconstruction of such sites is possible and feasible in most cases. In order to decrease sediment delivery, road improvements may involve the addition of more frequent road drainage features, leaving a shorter distance between features. This would decrease the energy of concentrated flow to individual drain points, thus shortening the distance that water and sediment travels down the hillslope.

Treatments may also include re-surfacing the road with a crushed rock aggregate or another type of surface which is less erosive.

3. What unknown geomorphic or hydrologic issues exist in Bear Valley's road system that could help forest managers make decisions and plan more effectively?

Other existing hydrologic issues in Bear Valley consist of drain point features in poor condition and stream crossings with a potential of being blocked or failing. Out of 3,826 individual drain points, 10% (379) of drain point features were recorded to be in poor condition. These are drainage features that may require reconstruction, replacement, basic maintenance, or removal. The average stream blocking index of stream crossings at risk was 2 on a scale of 1 to 4 where 1 indicates virtually no risk. The fill volume at risk if these stream crossings fail in the Bear Valley road configuration was approximately 3,213 m^3. A more thorough field assessment of each stream crossing at risk would be necessary to determine if the predicted failure potential is accurate and if the stream crossing culverts require attention. Although 22 gullies were recorded during the field survey, there are not enough data on gullies or landslides to suggest significant risk of mass wasting in Bear Valley. Critical thresholds to indicate when risk of gully initiation or landslides increases sharply were not established during data analysis. The lack of observed mass wasting events despite the fact that 59% of the basin has burned from wildfire within the last 25 years strengthens the argument that management for such events should be a low priority.

The results of the QAPP suggest that the margin of error among data collected by the different crews was reasonable and that the data are considered usable for analysis. Field crews were regularly trained and audited on data collection methods by individuals considered experts in using the GRAIP inventory protocol. The three quality assurance plots that were surveyed by each crew and by an expert crew yielded acceptable figures of relative precision and bias. The relative precision and bias objectives were identified to be +/- 20% in the QAPP. DQOs were met in all but one category, relative bias of sediment delivery and production for QA Plot 3, which were -28.65% and -20.27% respectively.

As a whole, these results indicate that Bear Valley roads do pose some risk to water quality and associated beneficial uses. It is also evident that a feasible amount of project work could eliminate a substantial portion of this risk. By making improvements to 4.5 miles of road, up to 50% of fine sediment delivery from roads could be eliminated. Reconstructing 10 miles of road could reduce this factor by as much as 85%. Other work could also be effective in greatly reducing many of the hydrogeomorphic impacts and risks that these roads pose to water quality and associated beneficial uses. This analysis will allow forest managers to efficiently prioritize resource restoration plans based on site-specific data.

Appendix A: Glossary

Below is a list of terms and vocabulary associated with the GRAIP model and this report. Adapted from Black, Cissel, and Luce (2009) and the Forest Service Manual.

Accumulated road sediment rate. An output of the GRAIP model that is a prediction of the accumulated road sediment load in an identified stream segment, specific to the total area of land draining to that stream segment. Given in $Mg/km^2/yr$ by GRAIP, then converted to $tons/mi^2/yr$ for this report.

Arterial road. An NFS road that provides service to large land areas and usually connects with other arterial roads or public highways (e.g. NFSR 579).

Assessment unit. (AU) A segment of a water body that is treated as a homogenous unit, meaning that any designated uses, the rating of these uses, and any associated causes and sources must be applied to the entirety of the unit.

Berm. A build-up of sediment or road material generally found on the outside edge of a road, caused by periodic road maintenance such as grading.

Broad based dip. A type of drain point collected during the GRAIP field inventory characterized by a large grade reversal in the road either designed into the road grade or there as a result of two natural hillslopes meeting.

Collector road. An NFS road that serves smaller areas than an arterial road and that usually connects arterial roads to local roads or terminal facilities (e.g. NFSR 502).

Cutslope. The steep slope on the uphill side of a road which is the result of the removal of hillslope material to make a flat surface for the road.

Designated road. An NFS road that is designated for motor vehicle use pursuant to 36 CFR 212.51 on a Motor Vehicle Use Map (36 CFR 212.1).

Diffuse drain. A type of drain point collected during the GRAIP field inventory characterized by a road segment that does not exhibit concentrated flow off the road. Outsloped roads or crowned roads often drain half or all water diffusely off the fillslope. Although collected as a drain point, this feature is representative of an area or a road segment rather than a concentrated point where water is discharged from the road prism. Diffuse drainage is also commonly known as *sheet* drainage.

Ditch relief culvert. A type of drain point collected during the GRAIP field inventory characterized by a pipe (typically metal) that runs perpendicular to and under the road surface. These features generally drain water from the inboard ditch and cutslope of a road, not from a continuous stream channel.

Drain point. A feature collected during the GRAIP field inventory that describes a distinct point along a road where water flows off of the road and out of the road prism.

Fillslope. The steep slope on the downhill side of a road which is the result of the addition of material, often from the cutslope, to make a flat surface for the road.

Flow path. An attribute of a road segment collected during the GRAIP field inventory which describes the course flowing water takes, or would take if present, within the road prism. A flow path is where water is being concentrated and flowing along the road from where it enters the road prism to where it discharges off the fillslope.

Forest Road. (FR) A road wholly or partly within or adjacent to and serving the National Forest System (NFS) that the USFS determines is necessary for the protection, administration, and utilization of the NFS and the use and development of its resources (36 CFR 212.1). May be an NFS road or a public road where a legally documented right-of-way has been issued to a state, county, or local authority (e.g. FR 582 is co-managed by the USFS and Valley County).

Forest Transportation Atlas. A display of the system of roads, trails, and airfields of an administrative unit (36 CFR 212.1).

Forest Transportation Facility. A forest road or trail or an airfield that is displayed in a forest transportation atlas, including bridges, culverts, parking lots, marine access facilities, safety devices, and other improvements appurtenant to the Forest Transportation System (36 CFR 212.1).

Forest Transportation System. The system of NFS roads, NFS trails, and airfields on NFS lands (36 CFR 212.1).

Forest Transportation System Management. Travel planning, analysis, designation of roads, trails and areas for motor vehicle use, recordkeeping, scheduling, construction, reconstruction, maintenance, decommissioning, and other operations undertaken to achieve environmentally sound, safe, and cost-effective access for the use, enjoyment, protection, administration, and management of NFS lands.

Lead off ditch. A type of drain point collected during the GRAIP field inventory characterized by a ditch that moves flow from the roadside ditch and leads it onto the hillslope. Occurs most often on sharp curves in the road and/or where the cutslope switches roadsides. This feature is also known in some areas as a daylight ditch or a mitre drain. In Bear Valley, this feature was occasionally used to describe an engineered drainage feature along an outside berm where the berm is knocked down and a flow is directed onto the forest floor.

Local road. An NFS road that connects a terminal facility with collector roads, arterial roads, or public highways and that usually serves a single purpose involving intermittent use (e.g. a spur road).

National Forest System Road. (NFSR) A forest road other than a road which has been authorized by a legally documented right-of-way held by a state, county, or local public road authority (36 CFR 212.1). Describes a road that is officially classified and managed by the USFS and is thereby assigned to a road maintenance category.

Non-engineered drain. A type of drain point collected during the GRAIP field inventory characterized by a drainage feature where water leaves the road in an unplanned manner. This can occur where a ditch is dammed by debris or where a wheel rut diverts water off the fillslope. A non-engineered drain point is also collected where water flowing against a berm erodes through the berm and drains off the fillslope, or where flow running down the road surface (or wheel tracks) rather than in a ditch flows off the fillslope where the road is outsloped for a short distance. At any point where water leaves the road prism not by design, a non-engineered drain is collected.

Orphan drain point. A drain point collected during the GRAIP field inventory that exists, but does not actively drain water from the road prism. It is likely that such a feature did drain water in the past, but no longer does due to natural geomorphic as well as engineered changes to road drainage. Examples of orphan drain points include blocked or buried ditch relief culverts, stream crossings with no sediment draining to them directly, water bars on overgrown roads that now drain diffusely, etc.

Public road. A road under the jurisdiction of and maintained by a public road authority and open to public travel (23 U.S.C. 101(a)).

Road. A motor vehicle route over 50 inches wide, unless identified and managed as a trail (36 CFR 212.1).

Road construction or reconstruction. Supervising, inspecting, actual building, and incurrence of all costs incidental to the construction or reconstruction of a road (36 CFR 212.1).

Road decommissioning. Activities that result in restoration of unneeded roads to a more natural state (FSM 7734).

Road maintenance. Ongoing upkeep of a road necessary to maintain or restore the road in accordance with its road management objectives (FSM 7714).

Road prism. The portion of a hillslope directly affected by the construction of a road including the road surface, the cutslope, the fillslope, and any other features of a road.

Road segment. (Also referred to as a road line) A linear feature collected during the GRAIP field inventory that describes the road prism attributes for a stretch of road where these attributes are similar. Once an attribute of the road prism changes (e.g. flow path changes from ditch to wheel tracks), a new road segment is collected. Road segment attributes include flow paths, surface type, cutslope and fillslope characteristics, and more.

Sediment accumulation. An output of the GRAIP model that is a prediction of the amount of fine sediment accumulated in a specific stream segment as a direct result of roads.

Sediment delivery. An output of the GRAIP model that is a prediction of the amount of fine sediment added to the stream network as a direct result of the existence of roads. This figure is derived from observed attributes of drain point and road line features collected during the GRAIP field inventory, particularly whether or not water draining at a given drain point reaches a stream channel (stream connection).

Sediment production. An output of the GRAIP model that is a prediction of the amount of fine sediment produced on a given road segment. This figure is derived from observed attributes of road line features collected during the GRAIP field inventory (i.e. surface type and flow path vegetation), the slope and length of a road segment, and a base rate of road sediment production.

Stream connection. An attribute of a drain point which indicates that evidence of flow from the road prism reaching an active stream channel was observed in the field. Where stream connection is observed to exist, all fine sediment that was produced and delivered to that drain point is routed to the stream by the GRAIP model.

Stream crossing. A type of drain point collected during the GRAIP field inventory characterized by a stream channel that intersects a road and flows for at least part of most years. These features may drain water from the road or cutslope, but their primary purpose is to route water flowing down the hillslope in natural stream channels under (and occasionally over) the road. In order to be classified as a stream crossing, the channel must be continuous above and below the road, have defined banks, be at least one foot wide, have a bed armored with gravel, rock, or sand, and display evidence of flow, even if dry at the time of survey.

Sump. A type of drain point collected during the GRAIP field inventory characterized by a closed depression where water is intentionally sent to pond or to infiltrate into the ground. A sump can also be a place where water enters, but cannot escape, such as a blocked ditch on an insloped road.

Temporary road. A road necessary for emergency operations or authorized by contract, permit, lease, or other written authorization that is not a forest road and that is not included in a forest transportation atlas (36 CFR 212.1).

Unauthorized road. A road that is not a forest road or trail or a temporary road or trail and that is not included in a forest transportation atlas (36 CFR 212.1). Unauthorized roads are often user-created, are generally posted as closed, and are not maintained, but may be frequently used for activities such as dispersed camping.

Water bar. A type of drain point collected during the GRAIP field inventory characterized by a drainage feature which diverts water off of the road surface and out of the road prism onto the fillslope, or into a ditch. These features are common on roads with steep grades, upper-slope roads, and closed roads where regular maintenance is not done. Water bars are constructed by a grader blade or other equipment which cut into the road surface at a diagonal across the road. These drain points are typically 1 to 4 feet deep and 5-10 feet in road length. In some areas, these features are also known as cross drains or scratch ditches.

Appendix B: QAPP Compliance

The Geomorphic Roads Analysis and Inventory Package (GRAIP) was used during the summer of 2009 to survey roads in two drainages in the Central Idaho Mountains, the Middle Fork Payette River watershed (4th order hydrologic unit) and the Bear Valley Creek and Elk Creek watersheds (both 5th order hydrologic units surveyed as one combined basin). These inventories were conducted by the Boise National Forest (BNF) and the Rocky Mountain Research Station (RMRS) of the U.S. Forest Service (USFS). The projects were funded by and completed in cooperation with the U.S. Environmental Protection Agency (USEPA). As a measure of quality assurance for data collected during the field inventories, a plan was devised and created in collaboration between RMRS hydrologists and GRAIP model developers and USEPA project managers. The plan is entitled, Geomorphic Road Analysis and Inventory Package (GRAIP) Field Collection Activities: Quality Assurance Project Plan (QAPP).

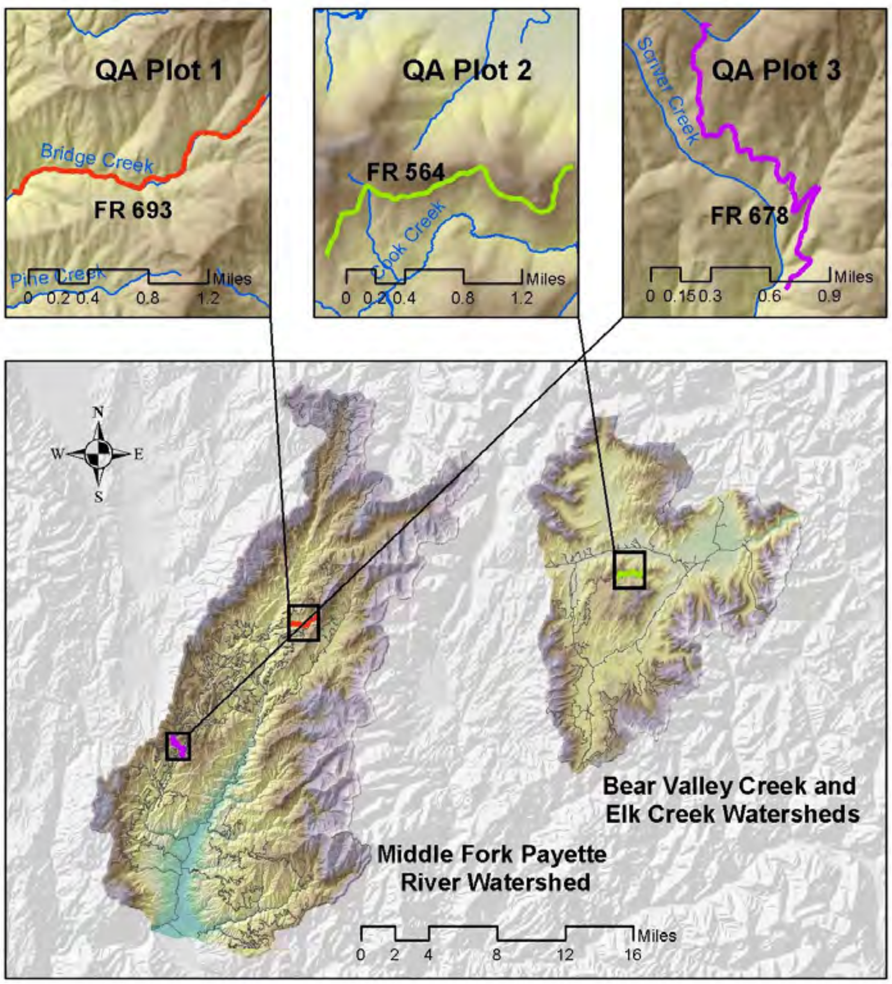


Figure 15. Map of QA plot locations in the Middle Fork Payette River and Bear Valley and Elk Creek watersheds.

Precision is a measure of repeatability and consistency. Since sediment production and delivery values were generally very high in the project watersheds, relative precision was evaluated to assess QAPP objectives. Absolute precision was first measured by calculating the sample standard deviation:

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

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

Relative precision for such measurements is estimated as the relative standard deviation (RSD, or coefficient of variation):

$$RSD = \frac{s}{\overline{X}}$$

where,
s = sample standard deviation
$\overline{X}$ = mean of all replicates, including those produced from expert crew measurements

Bias is a measure of accuracy. Absolute or net bias (B) 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

Bias in relative terms is calculated as:

$$\%B = \left(\frac{B}{T}\right) \times 100$$

where,
T = sediment production or delivery estimate obtained by expert crew
B = Net bias

Outline of actions taken or achievements made to comply with the QAPP:

- **Quality Objectives and Criteria**
    - **Precision, Bias, and Accuracy.** See explanation, equations, and table above.
    - **Representativeness.** The sample of inventoried roads is considered a comprehensive sample.
    - **Completeness.** 100% of National Forest System Roads and other Forest Roads in Bear Valley were surveyed and the majority of unauthorized roads were successfully surveyed. The USFS Project Manager reviewed the progress and considered the sample sufficient to perform GRAIP modeling. A 100% complete data set was collected for each road segment surveyed. As far as was manageable, all roads in a single sub-watershed were sampled before moving to a different sub-watershed. As stated in the QAPP, "A feature will no longer be considered a road when it does not move water along the surface, no longer has stream crossings, and is not located in a position where it can interact with the stream channel" (p. 14). Features which appear on GIS layers as unauthorized roads but were not inventoried meet this criteria.
    - **Comparability.** GRAIP road inventory procedural standards were met be all crews, resulting in comparable data.
    - **Pre-Inventory Training.** Prior to performing the road inventory, field crews received training on GRAIP procedures. Training was conducted by the USFS Project Manager.
    - **Documents and Records.** The "Review and Distribution Acknowledgement" QAPP form was signed by the appropriate personnel. All other documents as outlined in the QAPP were kept except for field audit reports, which were not developed or used during the 2009 field season.
- **Data Generation and Acquisition**
    - **Sampling Process Design.** The GRAIP road inventory was considered a comprehensive sample without bias or statistical inference.
    - **Sampling Methods.** The GRAIP road inventory was performed according to the procedures outlined in Black, Cissel, and Luce (2009).
    - **Sample Handling and Custody.** Procedures were followed as outlined in the QAPP. Field crews transferred data weekly to the data manager. The data manager preprocessed data and transferred it to the GIS technician. The GIS technician corrected errors and backed up data to ensure its security.
    - **Quality Control**
        - **Field Measurement Devices.** GPS units and all other field data collection equipment items were tested and checked for accuracy.
        - **Field Measurement and Observation Procedures.** Field crews were observed on field measurement procedures and corrected where necessary.
    - **Instrument/Equipment Testing, Inspection, and Maintenance.** Field equipment was maintained and kept in working order or else it was not used.

- **Instrument/Equipment Calibration and Frequency.** Field instrument calibration was performed according to manufacturer specifications including updates of software and firmware.
- **Inspection/Acceptance for Supplies and Consumables.** All field supplies were kept in proper working order or replaced if not.
- **Data Acquisition (Non-direct Measurements).** Field crews were trained and frequently corrected on interpretation of non-direct measurements (e.g. vegetation in the flowpath). Although, data do suggest that some discrepancies exist in the collection of such attributes, procedures outlined in the QAPP were followed.
- **Data Management.** See *Sample Handling and Custody*.

- **Assessment and Oversight**
  - **Assessment and Response Actions**
    - **Field Audits.** As mentioned in discussion above, monthly field audits were performed where the field crew leader would observe a field crew's survey of a road segment in order to review procedures and correct mistakes.
    - **Data Preparation Audits.** The data manager and GIS Technician reviewed the data regularly in order to ensure its completeness and accuracy.
  - **Reports to Management.** The USFS and USEPA Project Managers were in regular contact on the status of the project. Progress Reports were created at two different times to provide a formal update of the project's progress.
- **Data Validation and Usability**
  - **Data Review, Verification, and Validation**
    - All required signatories signed and approved the QAPP.
    - All field crew members received training on GRAIP road inventory procedures.
    - All agreed to field procedures were used in the project area.
    - Equipment was maintained in proper working order.
    - Instrument calibration procedures were performed according to manufacturer requirements.
    - All project DQOs were achieved with the exception of relative bias figures for QA Plot 3 which were -20.27% for sediment production and -28.65% for sediment delivery.
    - Field audits were performed monthly with each crew.
  - **Verification and Validation Methods.** The USFS Project Manager and designees took part in the review, verification, and validation of data collected during the 2009 field season before crews had completely demobilized from field activities. It is recommended that future GRAIP inventories include at least daily calibration of the ocular estimates of percent vegetation cover in the flow path.
  - **Reconciliation with User Requirements.** This is the data evaluation report that discusses the results and quality of the data collected. The data is considered usable for the project.

Appendix C: Bear Valley GRAIP Data Files

GRAIP data files from the Bear Valley GRAIP road inventory and this report are available to forest managers and interested parties. To receive such electronic files, please contact the Boise National Forest or the Boise Aquatic Sciences Lab of the Rocky Mountain Research Station. The following list includes names and formats of some of the available files.

1. Bear Valley Road Inventory (GRAIP) Report (Microsoft Word document or PDF)

2. Bear Valley Road Inventory (GRAIP) Slideshow (Microsoft PowerPoint presentation or PDF)

3. Bear Valley Inventory spreadsheet describing raw data files of all surveyed roads (Microsoft Excel spreadsheets)

4. Various Microsoft Excel spreadsheets containing data from GRAIP outputs

5. Bear Valley .graip file and dataset (all files needed to view GRAIP outputs using the GRAIP toolbar in ArcMap)

6. Photos of various road segments and drain points

7. GIS shapefiles of GRAIP model outputs for Bear Valley

    a. DrainPoints (contains data for all drain points including GRAIP predictions such as sediment production and sediment delivery)

    b. RoadLines (contains data for all road segments including GRAIP predictions such as sediment production and sediment delivery)

    c. StreamNet (contains data for all stream segments in the stream network including GRAIP predictions such as upstream sediment accumulation)

    d. Individual shapefiles for each type of drain point (e.g. stream crossings, non-engineered drains, ditch relief culverts, etc.)

    e. Road shapefile of all road segments and their attributes as collected by field crews, before being run through the model

8. GIS grids of GRAIP model outputs for Bear Valley

    a. Original DEM used for GRAIP analysis

    b. Slope stability grids

    c. Grids related to the stream network

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