Southwest Crown of the Continent GRAIP Roads Assessment

Center Horse and Morrell/Trail Project Area, Poorman Creek, and Cold Creek Lolo, Helena, and Flathead National Forests, Montana

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Richard Cissel[1], Tom Black[1], Nathan Nelson[1], and Charlie Luce[2]

[1]Hydrologist
[2]Research Hydrologist

U.S. Forest Service
Rocky Mountain Research Station
322 E. Front St, Suite 401
Boise, ID 83702

Boise Aquatic Sciences Lab

Great Northern Landscape Conservation Cooperative

Southwestern Crown Collaborative

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The full dataset from this project will be available to the public through the GNLCC website, at http://greatnorthernlcc.org/.

Executive Summary

This report presents results from three watershed-wide inventories and assessments of roads in the Center Horse and Morrell/Trail project area, Poorman Creek watershed, and Cold Creek watershed in western Montana using the Geomorphic Road Analysis and Inventory Package (GRAIP). GRAIP is a field-based model developed by the Forest Service Rocky Mountain Research Station and Utah State University. The primary objectives of the project were to:

- Identify the current level of fine sediment delivery from roads to streams compared to reference.
- Identify the types and sources of road-related hydrologic risk in the watershed.
- Select and prioritize future restoration actions to improve watershed conditions and move towards an ecologically and economically sustainable road system.
- Establish a pre-treatment condition for comparison to the same roads after treatments have been applied in certain areas.
- Compare GRAIP results with modified PACFISH/INFISH Biological Opinion (PIBO) monitoring program instream observation data for the watershed, collected concurrently with the GRAIP inventory, to investigate the ability to link instream conditions with upslope processes. (This will be a separate report).

Field inventory and modeling analysis of the public roads in the Center Horse and Morrell/Trail project area, the Poorman Creek watershed area, and the Cold Creek watershed area in the Southwest Crown of the Continent in western Montana using the GRAIP model provided detailed, site specific data on sediment-related watershed impacts from roads. Impacts are both chronic, in terms of annual sediment input to streams, and pulsed, such as during storm events when road connectivity to the channel networks is at its maximum. Inventory data was collected on 779 km (484 mi) of road, including 10,835 drain points, by two field crews during the summer months of 2012 and 2013 (June to October). Additionally, jammer-type logging roads were sampled and their road-stream intersections were surveyed in the Center Horse and Morrell/Trail project area.

The GRAIP model was used to predict sediment risk and sediment-related impacts from roads. The model predicts road to stream hydrologic connectivity, sediment delivery to streams, downstream sediment accumulation, risks of shallow landslides caused by roads, gully initiation risk below drain points, and risks to road-stream crossings (Tables A, B, and C). Inventory data is also used to locate and describe problems with existing drain points. In addition, GRAIP model data will be compared to in-stream PIBO monitoring for these project areas in a separate document.

Center Horse and Morrell/Trail Project Area Summary

In the Center Horse and Morrell/Trail project area, there were 407 km (253 mi) of road and 5061 drain points surveyed. Table A presents a summary of the findings for this project area. Hydrologic connectivity was found to be a relatively low 4% of all road length at 16 km out of 407 km (10 mi out of 252 mi). The model predicted 21.4 Mg/yr of delivered road surface fine sediment to stream channels, which is 5% of the 456 Mg generated annually by the road surface. This sediment was delivered through 314 of 5061 (6%) drain points. There was 16.2 Mg/yr of delivery that occurred within 10 m of a stream crossing. This is 76% of all sediment delivery and 57% of all sediment produced within 10 m of a stream crossing.

Specific sediment due to road surface-related sediment for the whole Center Horse and Morrell/Trail project area was 0.10 $Mg/km^2/yr$, or 1% of the observed total average fine sediment yield for five nearby areas as determined by reservoir coring or suspended sediment extrapolations. Including sediment delivered to streams through other sources (landslides, gullies, and fill erosion at drain points), the specific sediment for the whole project area was 0.21 $Mg/km^2/yr$, or about 2% of the observed average fine sediment yield for the nearby areas. Some heavily impacted stream reaches had road sediment delivery values as high as 4.9 $Mg/km^2/yr$ with only road surface fine sediment, or 18.1 $Mg/km^2/yr$ including mass wasting sediment. Reaches in Shanley, Little Shanley, Blacks Canyon, and lower Spring Creeks showed particularly high specific sediment values above 0.3 $Mg/km^2/yr$, or 3% to 19% above the reference sediment yield.

Table A. *Summary of GRAIP-predicted road risk predictions, Center Horse and Morrell/Trail project area.*

Impact/Risk Type	GRAIP Predicted Risks
Road-Stream Hydrologic Connectivity	4% of road length, 16 km; 6% of drain points connected
Fine Sediment Delivery	5% of sediment produced, 21.4 Mg/yr
Sediment in Streams	0.21 $Mg/km^2/yr$; 2% of average sediment yield for nearby areas
Landslide Risk	Estimated 176 Mg of sediment delivered to streams, 3% of watershed area with elevated risk due to roads
Gully Risk	Estimated 11 Mg/yr of sediment delivered to streams, 16% of all drain points exceed ESI_{crit} threshold
Stream Crossing Risks	
- plug potential	27 sites (23%) with elevated risk (SBI > 2)
- fill at risk	6843 m^3 fill at risk, average 60 m^3 per crossing
-diversion potential	61 sites (42%) with diversion potential
Drain Point Problems	811 drain points (16% of all drain points) with problems, 61 m^3 of fill erosion (2% of drain points), estimated 2.9 Mg/yr of fill delivered to streams

There were 18 landslides observed by field crews in the course of the inventory, with a total volume of 1319 m^3 (1726 yd^3). Of those, 10 were road related. It was conservatively estimated that 176 Mg of landslide derived sediment has been delivered to streams, which is roughly half the rate of that from road surfaces over 20 years (8.8 Mg/yr). It would take about eight years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from landslides. Calibrated stability index modeling with SINMAP conservatively showed that 6 km^2 (2 mi^2), or 3%, of the watershed area was put at higher risk of shallow landslide initiation by road drainage.

Gullies were observed at 33 locations by field crews, totaling 208 m^3 (272 yd^3) in volume, and all occurring in wet swales. It was estimated that these gullies delivered 217 Mg of sediment to the stream channel, equivalent to half the rate of that from road surfaces over 20 years (11 Mg/yr). It would take about ten years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from gullies. Of 3713 applicable drain points, 587 (16%) had an elevated risk of gullying. The critical gully initiation index (ESI) was found to be 14. The average ESI for the points without gullies was 9, while it was 11 for the points with gullies. The gully occurrence rate for drain points that fell above the ESI threshold was 1.0% versus 0.5% for points that fell below the ESI threshold.

There were 116 stream crossings with culverts (as opposed to bridges or fords) recorded. The average blocking index (SBI) for these points was a moderate to low 1.9. There were 25 crossings with an elevated SBI of 3. Two crossings had an SBI of 4, which is the highest possible value. The total calculated volume of fill at risk in an overtopping type event was 6840 m^3 (8950 yd^3). There were 55 stream crossings with the potential to divert stream flow from a plugged culvert down the road and onto unchanneled hillslopes. There were 14 stream crossings with an SBI of 3 or 4 and diversion potential, four of which were observed to have already failed or be at risk for imminent failure. There was a total of 824 m^3 (1077 yd^3) of fill at risk at these points. Six overtopped crossings were observed, five due to sediment plugging and one due to wood plugging. Three of those were due to undersized pipes, and one delivered 26 m^3 (910 ft^3) to streams.

Of the 5061 recorded drain points, 811 (16%) had one or more problem of some type (e.g. blocked or crushed culvert, excess puddling on the road surface). Sumps had the highest rate of problems, with 11 of 24 (46%), followed by ditch relief culverts (155 of 392, 40%). Fill erosion was recorded at 83 drain points (2%), with a total volume of 85 m^3 (3000 ft^3). Fill erosion was most common at non-engineered drains with 28 instances and 23 m^3 (820 ft^3). Stream crossings had 44 m^3 (1550 ft^3) eroded from 4 of 146 crossings (2%). It was estimated that fill erosion delivered 87 Mg of sediment to the stream channel, or about a quarter of the rate of the of road surface sediment over 20 years (4.4 Mg/yr). It would take about four years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from fill erosion.

Poorman Creek Summary

In the Poorman Creek area, there were 174 km (108 mi) of road and 2190 drain points surveyed. Table B presents a summary of the findings for this project area. Hydrologic connectivity was found to be a relatively low 4.7% of all road length at 8 km out of 174 km (5 mi out of 106 mi). The model predicted 11.5 Mg/yr of delivered road surface fine sediment to stream channels, which is 4.6% of the 247 Mg generated annually by the road surface. This sediment was delivered through 97 of 2190 (4%) drain points. There was 5.6 Mg/yr of delivery that occurred within 10 m of a stream crossing. This is 49% of all sediment delivery and 77% of all sediment produced within 10 m of a stream crossing.

Specific sediment due to road surface-related sediment for the whole Poorman Creek area was 0.11 $Mg/km^2/yr$, or 1% of the observed total average fine sediment yield for five nearby areas as determined by reservoir coring or suspended sediment extrapolations. Including sediment delivered to streams through other sources (landslides, gullies, and fill erosion at drain points), the specific sediment for the whole project area was 0.19 $Mg/km^2/yr$, or about 2% of the observed average fine sediment yield for the nearby areas. The most heavily impacted stream reaches had road sediment delivery values as high as 0.8 $Mg/km^2/yr$ with only road surface fine sediment, or 4.0 $Mg/km^2/yr$ including mass wasting sediment.

There were 5 landslides observed by field crews in the course of the inventory, with a total volume of 252 m^3 (329 yd^3). All were road related. It was conservatively estimated that 91 Mg of landslide derived sediment has been delivered to streams, which is roughly half the rate of sediment from road surfaces over 20 years (4.5 Mg/yr). It would take about 8 years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from landslides. Calibrated stability index modeling with SINMAP conservatively showed that 3 km^2 (1 mi^2), or 2%, of the watershed area was put at higher risk of shallow landslide initiation by road drainage.

Table B. *Summary of GRAIP-predicted road risk predictions, Poorman Creek area.*

Impact/Risk Type	GRAIP Predicted Risks
Road-Stream Hydrologic Connectivity	4.7% of road length, 8 km; 4% of drain points connected
Fine Sediment Delivery	4.6% of sediment produced, 11.5 Mg/yr
Sediment in Streams	0.19 $Mg/km^2/yr$; 2% of average sediment yield for nearby areas
Landslide Risk	Estimated 91 Mg of sediment delivered to streams, 2.2% of watershed area with possible elevated risk due to roads
Gully Risk	Estimated 0.2 Mg/yr of sediment delivered to streams, too few gullies to determine ESI^{crit}
Stream Crossing Risks	
- plug potential	5 sites (17%) with elevated risk (SBI > 2)
- fill at risk	1399 m^3 fill at risk, average of 48 m^3 per crossing
- diversion potential	8 sites (17%) with diversion potential
Drain Point Problems	270 drain points (12% of all drain points) with problems, 11 m^3 of fill erosion (1% of drain points), estimated 0.2 Mg/yr of fill erosion delivered to streams

Gullies were observed at 7 locations by field crews, totaling 157 m^3 (206 yd^3) in volume, with none occurring in wet swales. It was estimated that these gullies delivered 4 Mg of sediment to the stream channel, which is negligible compared to the rate of road surfaces over 20 years (0.2 Mg/yr). It would take less than one year for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from gullies. There were too few gullies to determine an ESI_{crit}, suggesting that the gully initiation risks here may be very low. The average ESI across the Poorman Creek area was 8.

There were 29 stream crossings with culverts (as opposed to bridges or fords) recorded. The average blocking index (SBI) for these points was a moderate to low 1.7. There were 5 crossings with an elevated SBI of 3. No crossings had an SBI of 4, which is the highest possible value. The total calculated volume of fill at risk in an overtopping type event was 1399 m^3 (1830 yd^3). There were eight stream crossings with the potential to divert stream flow down the road and onto unchanneled hillslopes. There was one stream crossing with an SBI of 3 and diversion potential. There was a total of 21 m^3 (27 yd^3) of fill at risk at this point. Two natural ford type crossings were observed to divert flow down the road, though no major erosion was observed at the time of the survey.

Of the 2190 recorded drain points, 270 (12%) had one or more problem of some type (e.g. blocked or crushed culvert, excess puddling on the road surface). Ditch relief culverts had the highest rate of problems, with 18 of 56 (32%), followed by broad based dips (120 of 412, 29%). Fill erosion was recorded at 22 drain points (1%), with a total volume of 11 m^3 (400 ft^3). Fill erosion was most common at non-engineered drains with 16 instances and 8 m^3 (300 ft^3). It was estimated that fill erosion delivered 3 Mg of sediment to the stream channel, which is negligible compared the amount of road surface sediment over 20 years (0.2 Mg/yr).

Cold Creek Summary

In the Cold Creek area, there were 198 km (123 mi) of road and 3584 drain points surveyed. Table C presents a summary of the findings for this project area. Hydrologic connectivity was found to be a relatively low 4% of all road length at 9 km out of 198 km (6 mi out of 123 mi). The model predicted 9.8 Mg/yr of delivered road surface fine sediment to stream channels, which is 6% of the 162 Mg generated annually by the road surface. This sediment was delivered through 205 of 3584 (6%) drain points. There was 6.6 Mg/yr of delivery that occurred within 10 m of a stream crossing. This is 67% of all sediment delivery and 75% of all sediment produced within 10 m of a stream crossing.

Table C. *Summary of GRAIP-predicted road risk predictions, Cold Creek area.*

Impact/Risk Type	GRAIP Predicted Risks
Road-Stream Hydrologic Connectivity	4% of road length, 9 km; 6% of drain points connected
Fine Sediment Delivery	4% of sediment produced, 9.8 Mg/yr
Sediment in Streams	0.10 Mg/km2/yr; 1% of average sediment yield for nearby areas
Landslide Risk	No landslide sediment delivered to streams; 0.6% of watershed area with possible elevated risk due to roads
Gully Risk	No gully sediment delivered to streams, too few gullies to determine ESI_{crit}
Stream Crossing Risks	
- plug potential	28 sites (39%) with elevated risk (SBI ≥ 2)
- fill at risk	2095 m^3 fill at risk, average of 31 m^3 per crossing
- diversion potential	39 (34%) sites with diversion potential
Drain Point Problems	284 drain points (8% of all drain points) with problems, 3 m^3 of fill erosion (1% of drain points), estimated 0.005 Mg/yr of fill erosion delivered to streams

Specific sediment due to road surface-related sediment for the whole Cold Creek area was 0.1 $Mg/km^2/yr$, or 1% of the observed total average fine sediment yield for five nearby areas as determined by reservoir coring or suspended sediment extrapolations. No other sources were observed to deliver sediment to streams. The most heavily impacted stream reaches had road sediment delivery values as high as 1.1 $Mg/km^2/yr$.

There were 9 landslides observed by field crews in the course of the inventory, with a total volume of 175 m^3 (229 yd^3). Only one landslide was not road related. No landslide sediment was observed to have been delivered to streams. Calibrated stability index modeling with SINMAP conservatively showed that

0.6 km^2 (0.2 mi^2), or 0.6%, of the watershed area was put at higher risk of shallow landslide initiation by road drainage.

Gullies were observed at 3 locations by field crews, totaling 5 m^3 (7 yd^3) in volume, with none occurring in wet swales. No gullies were observed to deliver sediment to the stream channel in Cold Creek. There were too few gullies to determine an ESI_{crit}, suggesting that the gully initiation risks here may be very low. The average ESI across the Cold Creek area was 4.

There were 71 stream crossings with culverts (as opposed to bridges or fords) recorded. The average blocking index (SBI) for these points was a moderate to low 2.3. There were 26 crossings with an elevated SBI of 3. Two crossings had an SBI of 4, which is the highest possible value. The total calculated volume of fill at risk in an overtopping type event was 2090 m^3 (2730 yd^3). There were 39 stream crossings with the potential to divert stream flow from a plugged culvert down the road and onto unchanneled hillslopes. There were 14 crossings with an SBI of 3 or 4 and diversion potential. There was a total of 332 m^3 (434 yd^3) of fill at risk at these points. Of those 14 crossings, half received the stream flow from the ditch, though this appeared to be intentional.

Of the 3584 recorded drain points, 284 (8%) had one or more problem of some type (e.g. blocked or crushed culvert, excess puddling on the road surface). Stream crossings had the highest rate of problems, with 45 of 115 (39%), followed by ditch relief culverts (80 of 266, 30%). Fill erosion was recorded at 23 drain points (1%), with a total volume of 3 m^3 (110 ft^3). Fill erosion was most common at broad based dips with 18 instances and 3 m^3 (90 ft^3). It was estimated that fill erosion delivered 0.5 Mg of sediment to the stream channel, which is negligible compared the amount of road surface sediment over 20 years (0.005 Mg/yr).

Jammer Roads Summary

Two complete jammer road complexes totaling 19 km (11 mi) of road and 325 drain points in the Center Horse project area were inventoried using the GRAIP method. These vegetated and shallow-slope roads delivered 0.02 Mg/yr, which is 2% of the 1 Mg/yr generated on the road surfaces (Table D). If this delivery rate is applied to all jammer roads in the Center Horse and Morrell/Trail project area, then it can be expected that these roads deliver less than 1 Mg/yr from the road surface. A small stream diversion was observed that resulted in two delivering gullies (29 Mg) and two non-engineered points with fill erosion, one of which delivered to the stream (23 Mg). There were no other observed instances of mass wasting, including anything not related to the stream crossing or any landslides.

We conducted a census of all of the stream crossings on jammer roads in the Center Horse and Morrell/Trail project area, for a total of 71 crossings. Streams were defined as continuous features with a bed, banks, and evidence of flow for some part of most years. There were 61 natural ford-type crossings (no infrastructure) and ten crossings with culverts. Nine crossings (13%) were observed to have evidence of stream diversion or other problems. There were 31 crossings (44%) with fill erosion, totaling 207 m^3 (7300 ft^3), all of which was assumed to deliver (331 Mg). This was roughly equivalent to that from road surfaces on non-jammer roads in the Center Horse and Morrell/Trail project area over 20 years (17 Mg/yr).

The average volume of fill available to erode at each crossing was estimated to be 12 m^3 (16 yd^3) per crossing. Of this amount, an average of 3 m^3 (4 yd^3) per crossing has already been eroded, suggesting that 25% of possible erosion has already occurred, and up to 75% remains (about 600 m^3 or 22,000 ft^3). Differences in the shape and construction of each stream crossing, and the timing of high flows and transport capacity of the streams, suggest that each stream crossing will respond at a different rate, and may include some deposition. It was found that on hillslopes of greater than about 40%, every stream crossing in the Center Horse area had fill erosion, suggesting that the stream crossings on steeper slopes may be at higher risk of failure than those on lower slopes.

Table D. *Summary of observed and predicted jammer road risks.*

Impact/Risk Type		Predicted Risks
Complete Complex Inventory		
	Fine Sediment Delivery	2% of sediment produced; 0.02 Mg/yr
	Estimated Sediment Delivery for All Jammer Roads	0.4 Mg/yr, using a delivery rate of 0.001 Mg/yr/km
	Gullies and Fill Erosion Risks	29 Mg delivered to streams from gullies, 23 Mg delivered to streams from fill erosion, estimated 3 Mg/yr
Stream Crossing Survey		
	Fill Erosion Risks, Observed	44% of stream crossings with fill erosion, estimated 17 Mg/yr delivered to streams
	Fill Erosion Risks, Future Estimated	25% of estimated risk has been realized, up to 75% (600 m^3) may remain
	Other Problems	9 crossings (13%) with observed stream diversions or other problems

Conclusions

Under the observed conditions, the GRAIP inventories in the Southwest Crown of the Continent suggest low risk across the measured metrics when considered at the watershed scale. The Center Horse and Morrell/Trail project area had the most risk overall. There are two other non-watershed GRAIP sites in the northern Rockies; one site in the Clearwater National Forest (Cissel et al. 2011A), and one in the Gallatin National Forest (Cissel et al. 2011B). Compared to these sites, these three watersheds fall within the typical range for landslide risk, gully risk, stream crossing plugging potential and diversion potential, and drain point problems and fill erosion for both sites. The stream crossing fill at risk is slightly higher in the Center Horse and Morrell/Trail project area and Poorman Creek, but within the typical range in Cold Creek. The Clearwater site had much higher road surface sediment delivery and hydrologic connectivity, while this data is in range of the Gallatin site. Compared to a site in the Olympic National Forest in western Washington (Cissel et al. 2011C), which is considered to have high risk in all metrics, the Center Horse and Morrell/Trail project area has low to moderately low risk in all areas.

Although sediment delivery risk related to roads is low from the watershed perspective, several road segments were identified that may need treatment to minimize sediment delivery effects that are significant at the stream reach scale. Depending on downstream habitat and species presence, fine sediment delivery effects may be significant at a stream reach scale. Ongoing work comparing aquatic habitat conditions between managed and unmanaged reaches using PIBO data will help refine these questions.

Road maintenance level appears to have a small to moderate effect on the various risk metrics. Higher maintenance levels (ML 3 and 4; more traffic, more frequent and more intense maintenance) had somewhat more sediment delivered from their road surfaces, but mass wasting risks were lower. Lower maintenance level roads (ML 1 and 2; little to no traffic, little to no maintenance) had higher mass wasting risks. These relationships suggest that traffic has an important effect on road surface fine sediment production, but regular more intense maintenance can prevent mass wasting problems. On some lower maintenance level roads, it may be beneficial to treat spots that are at high risk of erosion.

The sediment delivery from fill erosion and mass wasting at jammer road-stream intersections in the Center Horse and Morrell/Trail project area was on the same scale as the road surface fine sediment delivery from non-jammer roads in the same area. The highly vegetated and low slope jammer road surfaces themselves did not appear to have significant impacts. Treatments to jammer roads should be focused on the roads with stream crossings. However, the consequences of removing vegetation on the road surface to access the jammer road stream crossings may increase the contributions of their surface fine sediment to streams. Data to be collected in the summer of 2014 may help to further understand the causes and distribution of erosion at stream crossings on jammer roads.

1.0 Background

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

The Center Horse and Morrell/Trail project area, and the Poorman Creek and Cold Creek watersheds are part of an ongoing collaborative project in the southwest Crown of the Continent of western Montana designed to assess the impacts of forest roads and jammer-type logging roads on aquatic habitat. Collaborators include the Lolo, Helena, and Flathead National Forests; Wildlands CPR; the Clearwater Resource Council; The Wilderness Society; and many others. Cottonwood Creek within the Center Horse area is listed under a 1996 TMDL for sediment (Montana Department of Environmental Quality 2008).

The GRAIP data collection and analysis procedure provides land managers with field-based data that captures the extent to which roads and associated features deliver uncharacteristic amounts of fine sediment to the stream network. GRAIP identified precise locations where sediment delivery was occurring, where drainage features were compromised, and where road maintenance or decommissioning was required. This detailed information can then be used to prioritize actions to minimize adverse watershed and aquatic impacts from roads.

All roads that were managed by the Forest Service or were otherwise located on public lands were targeted for inventory in 2012 and 2013, including jammer-type roads which were inventoried in 2013. Roads on existing geographic information system (GIS) layers were targeted for inventory (about 1280 km, 790 mi in all three areas). However, some additional previously unmapped roads were found and inventoried during the course of the study. Jammer-type roads totaled 380 km (230 mi) in existing GIS layers, and these were sampled as opposed to completely inventoried. A total of 407 km (253 mi) of road was inventoried within the Center Horse and Morrell/Trail project area boundary. Within the Poorman Creek area, 174 km (108 mi) were surveyed. Within Cold Creek, there were 198 km (123 mi) of road surveyed. In the Center Horse Morrell/Trail project area, 18 km (11 mi) of jammer roads were surveyed. The majority of field work has been completed, and work in 2014 includes closer examination of jammer road stream crossings. Field work in 2012 began on June 5 and was completed on October 16. Work began in 2013 on June 5 and was completed on October 25. Two crews collected data by vehicle or by foot each season.

2.0 Objectives and Methods

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

- Identify the current level of fine sediment delivery from roads to streams compared to reference.
- Identify the types and sources of road-related sediment risk in the watershed.
- Select and prioritize future restoration actions to improve watershed conditions and move towards an ecologically and economically sustainable road system.
- Establish a pre-treatment condition for comparison to the same roads after treatments have been applied in certain areas.
- Compare GRAIP results with PIBO data for the watershed collected concurrently with the GRAIP inventory to investigate the ability to link instream condition with upslope processes. (This will be a separate report).

GRAIP is used to inventory and model the risk profile of each of the road segments and drain point features included in the study. The GRAIP system consists of a detailed, field-based road inventory protocol combined with a suite of GIS models. The inventory is used to systematically describe the hydrology and condition of a road system with Geographic Positioning System (GPS) technology and automated data forms (Black et al. 2012). The GIS applications couple field data with GIS terrain analysis tools to analyze road-stream hydrologic connectivity, fine sediment production and delivery, downstream sediment accumulation, stream sediment input, shallow landslide risk 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 (Cissel et al. 2012).

3.0 Study Areas

These three projects areas (Center Horse and Morrell/Trail, Poorman Creek, and Cold Creek) are the first watershed-scale GRAIP inventories to be completed in the U.S. Forest Service Northern Region (Region 1; Figure 1). Other inventories have been completed or are underway in Oregon, Washington, California and Idaho (Regions 6, 5, and 4, respectively). Additionally, there is an ongoing region- and western U.S.-wide Legacy Roads monitoring project, encompassing eight sites in Region 1 where road decommissioning, storage, and storm damage risk reduction has been or will be implemented, including two sites within the Lolo National Forest (in the Fishtrap Creek watershed) and one site in the Flathead National Forest (at Hungry Horse Reservoir).

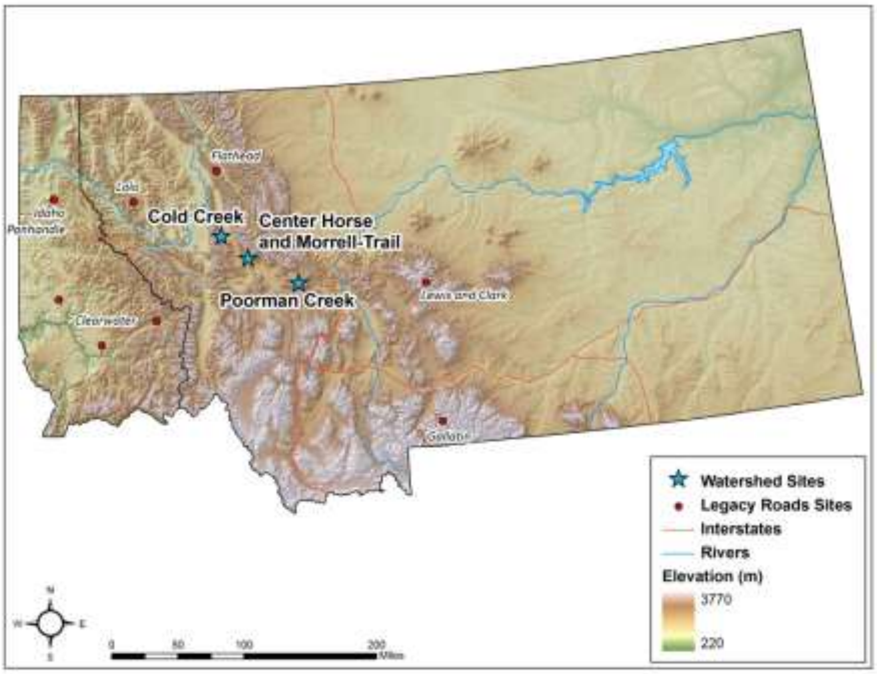


Figure 1. Location of these watershed inventories and Legacy Roads Monitoring Project sites in Region 1.

Center Horse and Morrell/Trail Project Area

The Center Horse and Morrell/Trail project area is located within the Clearwater River watershed, which is located east of Seeley Lake, MT, and drains into the Blackfoot River and then the Clark Fork River in western Montana. The project area watersheds drain about 220 km^2 (80 mi^2; 53,100 aces), and the Clearwater River drains about 3140 km^2 (1210 mi^2; 775,900 acres).

The project area covers two main geologic units (Figure 2). Glacial deposits and other alluvium cover the valley bottoms (about 139 km^2 or 54 mi^2), and carbonates and quartzite of the Mesoproterozoic Belt Supergroup underlay the valley walls and ridges (131 km^2 or 51 mi^2). There are two faults in the area, running roughly northwest-southeast (Ludington et al. 2005). Terrain in the project area is heavily influenced by Pleistocene glaciation, with steep valley walls and flat hummocky valley bottoms. Elevations in the project area range from 1230 m (4040 ft) to 2620 m (8600 ft), and inventoried roads range from 1270 m (4170 ft) to 2360 m (7740 ft). Average annual precipitation in the project area ranges from 460 mm/yr (18 in/yr) to 1880 mm/yr (74 in/yr; Montana Department of Environmental Quality 2011).

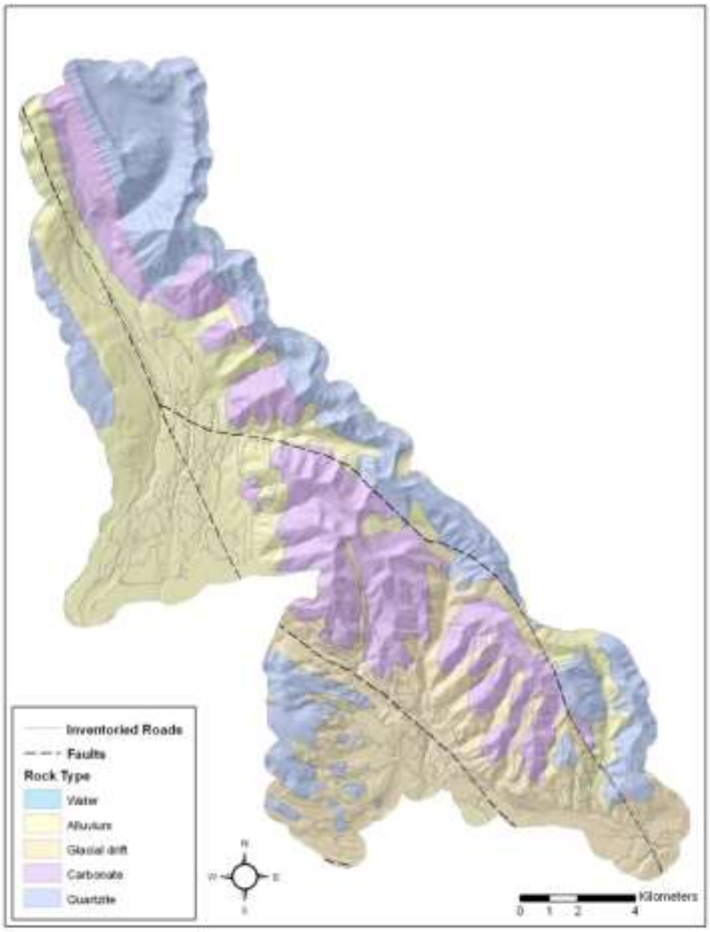


Figure 3. Geology of the Center Horse and Morrell/Trail project area.

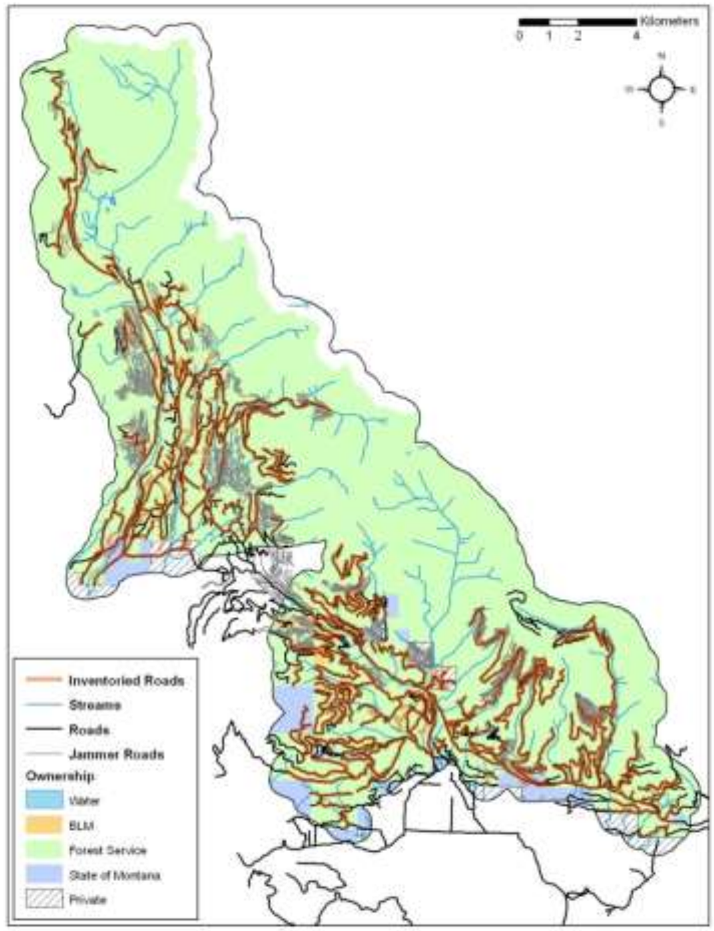


Figure 2. Land ownership and all roads within the Center Horse and Morrell/Trail project area. The watershed boundary is buffered by 500 m (1640 ft).

The Center Horse and Morrell/Trail project area is comprised of primarily federally owned and managed land (Figure 3). The Forest Service manages 240 km^2 (90 mi^2, 59,300 acres, 94%); 7 km^2 (3 mi2, 1700 acres, 3%) is private; the remaining 9 km^2 (3 mi^2, 2200 acres, 4%) managed by the Bureau of Land Management and the State of Montana.

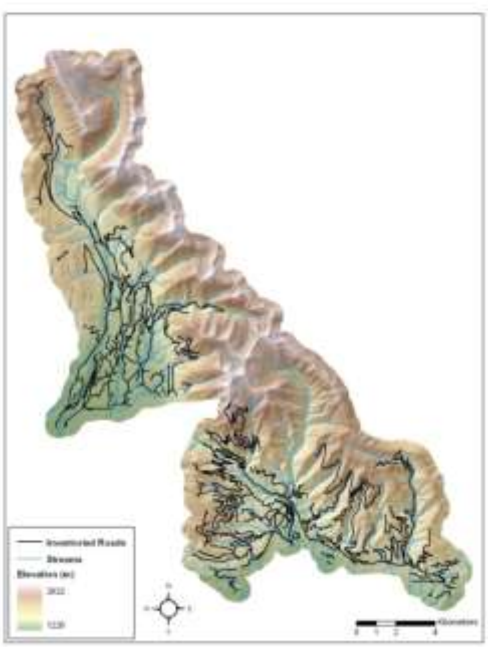


Figure 4. Elevation and location of inventoried roads within the Center Horse and Morrell-Trail project area.

All roads on federal and state lands were inventoried, for a total of 407 km (253 mi), with the exception of jammer-type logging roads (410 km, 250 mi), which were sampled in 2013 instead of fully inventoried. About 30 km (19 mi) of road had been previously mapped, but was found to not exist on the ground. Conversely, about 20 km (12 mi) of road was inventoried that was not previously mapped (Figure 4). About 10 km (6 mi) of mapped road had been recontoured, and was not inventoried.

Poorman Creek

Poorman Creek is also located within the Blackfoot River watershed, south of Lincoln, MT. The Poorman Creek watershed drains about 100 km^2 (40 mi^2, 26,000 acres). The Blackfoot River drains about 6200 km^2 (2400 mi^2, 1.5 million acres).

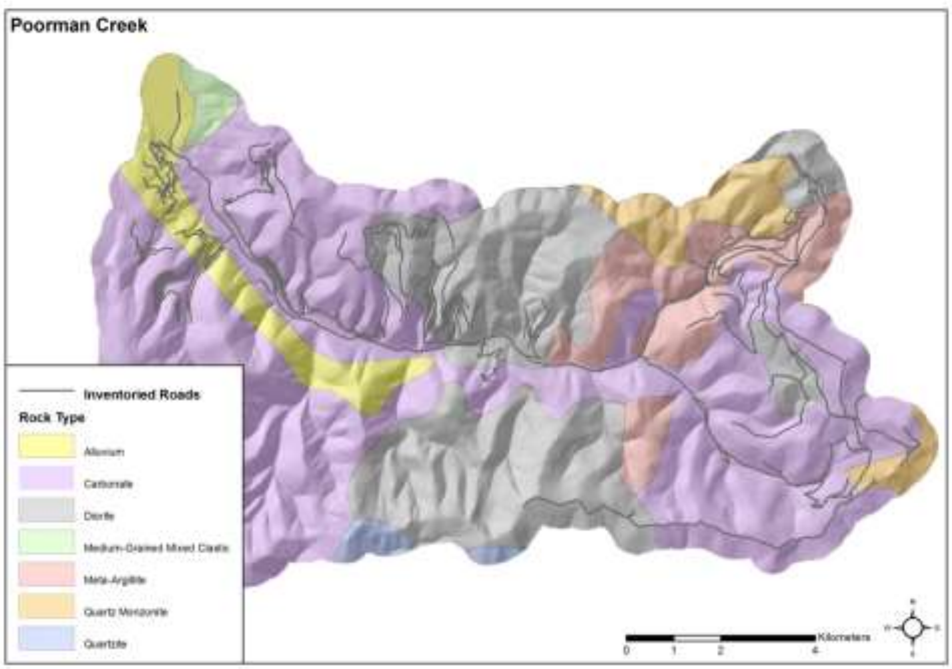


Figure 5. Geology of the Poorman Creek area. The alluvium shown in the southern side of the valley is probably actually located on the valley floor.

Poorman Creek covers three main geologic units (Figure 5). Alluvium covers the lowest valley bottoms (about 8 km^2 or 3 mi^2). Carbonates of the Mesoproterozoic Belt Supergroup (85 km^2 or 33 mi^2) and igneous intrusive diorite of possibly Cretaceous origin underlay the bulk of the rest of the watershed (39 km^2 or 15 mi^2; Ludington et al. 2005). Terrain in Poorman Creek is not as heavily influenced by glaciation as the other two project areas. Valley walls are shallower, and valley bottoms are less broad. The terrain is more dissected by streams. Elevations in the project area range from 1390 m (4550 ft) to 2350 m (7720 ft), and inventoried roads range from 1400 m (4600 ft) to 2340 m (7670 ft). Average annual precipitation in the project area ranges from 490 mm/yr (19 in/yr) to 760 mm/yr (30 in/yr; Montana Department of Environmental Quality 2011).

The Poorman Creek area is comprised of primarily federally owned and managed land (Figure 6). The Forest Service manages 96 km^2 (37 mi^2, 23,600 acres, 93%); the remaining 9 km^2 (3 mi^2, 2130 acres, 7%) is private.

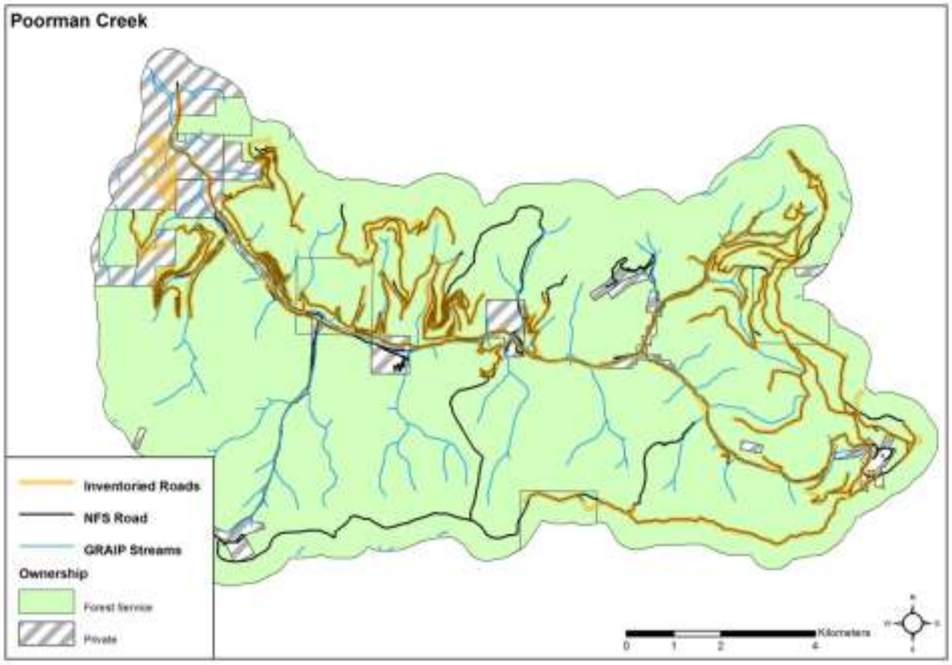


Figure 6. Land ownership and all roads within the Poorman Creek area. The watershed boundary is buffered by 500 m.

All roads on federal and state lands were inventoried, for a total of 174 km (106 mi). About 47 km (29 mi) of road had been previously mapped, but was found to not exist on the ground. Many of these may be ATV trails. Conversely, about 20 km (12 mi) of road was inventoried that was not previously mapped (Figure 7).

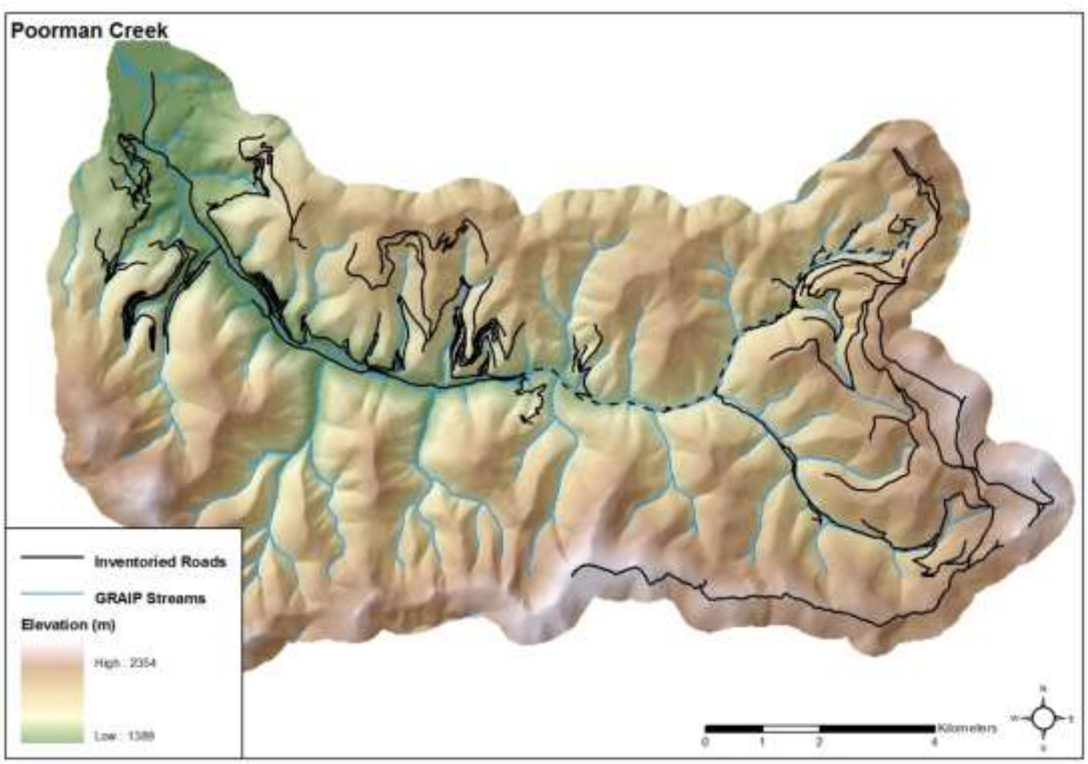


Figure 7. Elevation and location of inventoried roads within the Poorman Creek area.

Cold Creek

Cold Creek is located within the Swan River watershed, and is located west of Condon, MT. The Swan River drains into the Flathead River. The Cold Creek watershed drains about 90 km^2 (30 mi^2, 21,000 acres), and the Swan River drains about 1810 km^2 (700 mi^2, 448,000 acres).

Cold Creek covers two main geologic units (Figure 8). Glacial deposits and other alluvium cover the valley bottoms (about 28 km^2 or 11 mi^2), and carbonates and quartzite of the Mesoproterozoic Belt Supergroup underlay the higher elevations (104 km^2 or 40 mi^2; Ludington et al. 2005). Terrain in the project area is heavily influenced by Pleistocene glaciation, with steep valley walls and flat hummocky valley bottoms. The bulk of the roads in Cold Creek are in the hummocky zone. Elevations in the project area range from 1070 m (3520 ft) to 2580 m (8470 ft), and inventoried roads range from 1080 m (3540 ft) to 1730 m (5670 ft). Average annual precipitation in the project area ranges from 560 mm/yr (22 in/yr) to 1830 mm/yr (72 in/yr; Montana Department of Environmental Quality 2011).

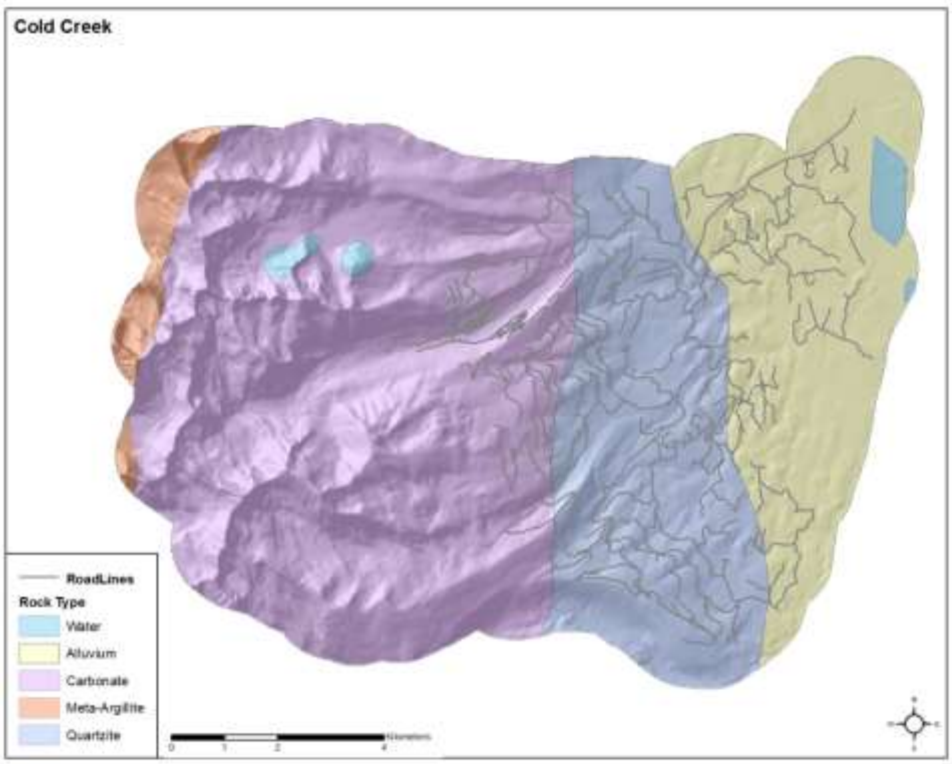


Figure 8. Geology of the Cold Creek area.

The Cold Creek area is comprised of primarily federally owned and managed land (Figure 9). The Forest Service manages 116 km^2 (45 mi^2, 28,660 acres, 93%); the remaining 9 km^2 (3 mi^2, 2130 acres, 7%) is private.

All roads on federal and state lands were inventoried, for a total of 198 km (123 mi). About 27 km (17 mi) of road had been previously mapped, but was found to not exist on the ground. Conversely, the same length of road was inventoried that was not previously mapped (27 km or 17 mi; Figure 10). Some of this may be on private land.

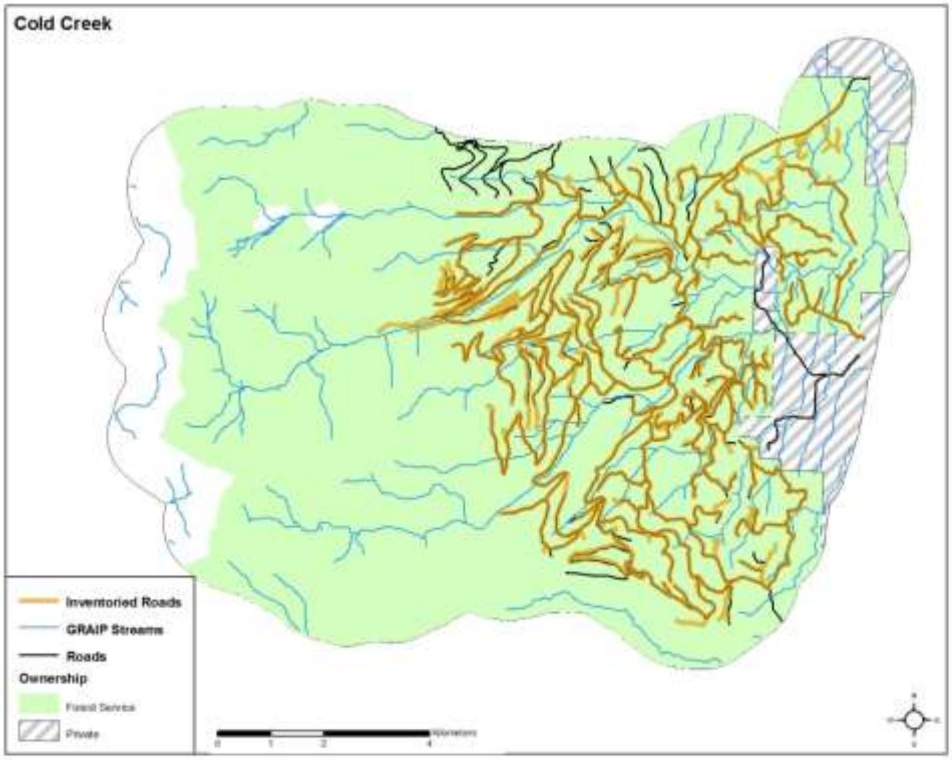


Figure 9. Land ownership and all roads within the Cold Creek area. The watershed boundary is buffered by 500 m.

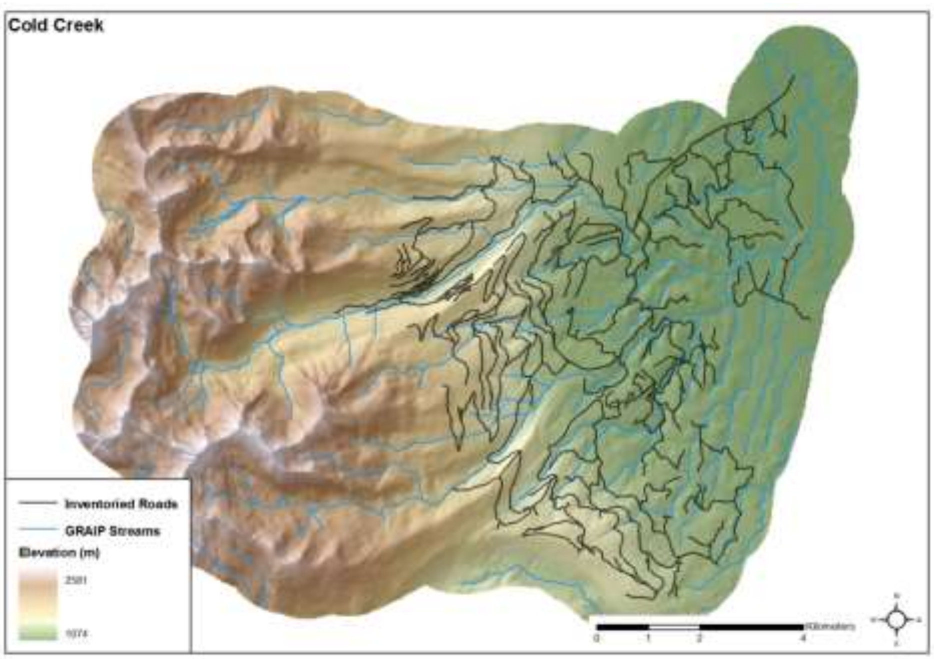


Figure 10. Elevation and location of inventoried roads within the Cold Creek area.

4.0 Results

A total of 10,835 drain points, 14,912 road lines, and 3110 other associated features (including 44 gullies, 32 landslides, and 1880 photo points) were inventoried in nine months of field work over the summers of 2012 and 2013 by two field crews. Each crew collected an average of 3 km (1.8 mi) of road per day. Data analysis provides specific information on the condition and function of 779 km (484 mi) of roads (Figures 4, 7, and 10). These results are for the non-jammer roads in the three areas. Jammer roads are discussed in in section 5.0. GRAIP inventory and data modeling tools were used to characterize the following types of impacts and risks:

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

4.1 Road-Stream Hydrologic Connectivity

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

Table 1. *Summary of effective road lengths by drain type for the Center Horse and Morrell/Trail Project Area. Sumps cannot be stream connected, while streams crossings are stream connected by definition.*

Drain Type	All Drain Points			Connected Drain Points			Not Connected Drain Points			% Length Connected
	Count	Average Contributing Length (m)	Σ Contributing Length (m)	Count	Average Contributing Length (m)	Σ Contributing Length (m)	Count	Average Contributing Length (m)	Σ Contributing Length (m)	
Broad Based Dip	1413	110	157,650	42	110	4490	1371	110	153,160	3%
Diffuse Drain	931	90	84,710	11	60	700	920	90	84,010	0.8%
Ditch Relief Culvert	392	60	24,160	30	30	1020	362	60	23,140	4%
Excavated Stream Crossing	4	50	180	4	50	180	0	0	0	100%
Lead Off Ditch	135	70	9640	13	50	580	122	70	9050	6%
Non-Engineered Drain	1102	60	67,090	39	60	2300	1063	60	64,780	3%
Stream Crossing	146	40	5680	146	40	5680	0	0	0	100%
Sump	24	140	3280	0	0	0	24	140	3280	0%
Water Bar	914	60	54,850	29	50	1470	885	60	53,3780	3%
All Drains	**5061**	**80**	**407,230**	**314**	**50**	**16,420**	**4747**	**80**	**390,800**	**4%**

The hydrologically-connected portion of the road system is calculated in GRAIP using field observations of connection at each drain point 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.

Center Horse Morrell-Trail Project Area

In the Center Horse and Morrell-Trail project area, a total of 16.4 km (10.2 mi) out of 407 km (252 mi) of inventoried road (4%) was hydrologically connected to the stream network. Broad based dips and non-engineered drains were the most common types of drainage features (1413 and 1102 features, respectively), and, along with diffusely draining road segments (931 features) and water bars (914 features), drained 90% (364 km, 226 mi) of the road network (Table 1). The bulk of the hydrologic connectivity occurred at stream crossings and broad based dips. There were 146 stream crossings, and they drained 6 km (4 mi) of the road network, all of which was connected. The broad based dips drained 158 km (98 mi) of the road network, 4 km (2 mi) of which was connected to the stream network.

Poorman Creek

In Poorman Creek, a total of 8.1 km (5.0 mi) out of 174 km (108 mi) of inventoried road (5%) was hydrologically connected to the stream network. Broad based dips (412 features), diffuse drains (417 features), non-engineered drains (693 features), and water bars (549 features) were the most common types of drainage features, and drained 92% (160 km, 100 mi) of the road network (Table 2). The bulk of the hydrologic connectivity occurred at stream crossings, ditch relief culverts, and non-engineered drains. There were 53 stream crossings, and they drained 4 km (2 mi) of the road network, all of which was connected. The ditch relief culverts drained 9 km (5 mi) of the road network, 2 km (1 mi) of which

Table 2. *Summary of effective road lengths by drain type for the Poorman Creek area. Sumps cannot be stream connected, while streams crossings are stream connected by definition.*

Drain Type	All Drain Points			Connected Drain Points			Not Connected Drain Points			% Length Connected
	Count	Mean Contributing Length (m)	Σ Contributing Length (m)	Count	Mean Contributing Length (m)	Σ Contributing Length (m)	Count	Mean Contributing Length (m)	Σ Contributing Length (m)	
Broad Based Dip	412	120	49,750	8	120	930	404	120	48,820	2%
Diffuse Drain	417	110	47,210	2	50	100	415	110	47,110	0.2%
Ditch Relief Culvert	56	160	8710	9	170	1550	47	150	7160	18%
Lead Off Ditch	8	120	950	0	0	0	8	120	950	0%
Non-Engineered Drain	693	60	42,830	24	70	1600	669	60	41,220	4%
Stream Crossing	53	70	3900	53	70	3900	0	0	0	100%
Sump	2	60	130	0	0	0	2	60	130	0%
Water bar	549	40	20,620	1	30	30	548	40	20,590	0.1%
All Drains	**2190**	**80**	**174,090**	**97**	**80**	**8110**	**2093**	**80**	**165,980**	**5%**

were connected to the stream network. The non-engineered drains drained 43 km (27 mi) of the road network, 2 km (1 mi) of which was connected to the stream network.

Cold Creek

In the Cold Creek area, a total of 8.7 km (5.4 mi) out of 198 km (123 mi) of inventoried road (4%) was hydrologically connected to the stream network. Broad based dips and non-engineered drains were the most common types of drainage features (1050 and 1097 features, respectively), and, along with diffusely draining road segments (670 features) and ditch relief culverts (266 features), drained 90% (178 km, 111 mi) of the road network (Table 3). The bulk of the hydrologic connectivity occurred at stream crossings, ditch relief culverts, and broad based dips. There were 115 stream crossings, and they drained 4 km (3 mi) of the road network, all of which was connected. The ditch relief culverts (266 features) drained 17 km (10 mi) of the road network, 2 km (1 mi) of which was connected (13%). The broad based dips drained 70 km (44 mi) of the road network, 1 km (0.8 mi) of which was connected to the stream network (2%).

Table 3. *Summary of effective road lengths by drain type for the Cold Creek area. Sumps cannot be stream connected, while streams crossings are stream connected by definition.*

Drain Type	All Drain Points			Connected Drain Points			Not Connected Drain Points			% Length Connected
	Count	Mean Contributing Length (m)	Σ Contributing Length (m)	Count	Mean Contributing Length (m)	Σ Contributing Length (m)	Count	Mean Contributing Length (m)	Σ Contributing Length (m)	
Broad Based Dip	1050	70	70,030	23	60	1320	1027	70	68,710	2%
Diffuse Drain	670	80	50,180	0	0	0	670	80	50,180	0%
Ditch Relief Culvert	266	60	16,870	44	50	2240	222	70	14,630	13%
Lead Off Ditch	139	50	7110	9	40	360	130	50	6750	5%
Non-Engineered Drain	1097	40	41,270	10	40	360	1087	40	40,910	1%
Stream Crossing	115	40	4320	115	40	4320	0	0	0	100%
Sump	1	130	130	0	0	0	1	130	130	0%
Water Bar	246	30	7940	4	30	110	242	30	7830	1%
All Drains	**3584**	**55**	**197,860**	**205**	**40**	**8720**	**3379**	**60**	**189,140**	**4%**

4.2 Road Surface Fine Sediment Production and Delivery

Fine sediment production at a drain point (E) is estimated with a base erosion rate and the properties of two flow paths along the road (Luce and Black 1999, Cissel et al. 2012, Prasad 2007), as shown below.

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

B is the base erosion rate[1] (kg/m)
L is the road length (m) contributing to the drain point
S is the slope of the road contributing to the drain point (m/m)
V is the vegetation cover factor for the flow path
R is the road surfacing factor

Delivery of eroded sediment to the channel network is determined by observations of each place that water leaves the road. Each of these drain points is classified as either delivering or not delivering. 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.

Delivery of fine sediment occurs through a mix of road drainage features, including broad based dips, diffuse road segments, ditch relief culverts, non-engineered drains, water bars, and others (Appendix A). In the tables below, sediment delivery is broken out by drain type to assess their effectiveness in preventing sediment from entering the channel.

Center Horse Morrell-Trail Project Area

There were 5061 drain points observed in the Center Horse and Morrell/Trail Project Area, 314 of which delivered sediment to stream channels (Table 4). Model predictions indicate that these points delivered an estimated 21.4 Mg/yr, or 4% of the 456 Mg/yr generated on the road surfaces and ditches (Figure 11). Broad based dips and non-engineered drains delivered the most sediment (6.8 Mg/yr and 7.4 Mg/yr, respectively; Figure 12). There was 16.2 Mg/yr of delivery that occurred within 10 m of a stream crossing. This is 76% of all sediment delivery and 57% of all sediment produced within 10 m of a stream crossing (compared to the 4% delivery rate for all sediment). A map of the road surface sediment delivery and the accumulated sediment delivered through each drain point is shown for upper Little Shanley Creek and upper Black Canyon Creek in the Center Horse project area (Figure 13).

The fraction of sediment produced and delivered from the road system can also be evaluated in the context of road length. Of the 407 km (252 mi) of total inventoried road length, 16.4 km (10.2 mi, 4%) deliver sediment to streams (Table 4).

[1] For this analysis, base erosion rates of 17 kg/meter of road elevation for open roads and 1 kg/meter of road elevation for closed roads was used, based on observations at eight local sediment plots over two years (Black and Luce 2013). These numbers may be revised once more data can be collected. Sugden and Woods (2007) measured erosion on open roads in western Montana and found low to moderate rates that equate to GRAIP base rates of 7 kg/meter of road elevation for Belt geology and 11 kg/meter of road elevation for glacial till.

Table 4. *Summary of sediment production and delivery at drain points in the Center Horse and Morrell/Trail Project Area.*

Drain Type	Count	Σ Sediment Production (kg/yr)	Σ Sediment Delivery (kg/yr)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	1413	163,010	6860	4%	4490	3%
Diffuse Drain	931	104,870	1010	1%	700	1%
Ditch Relief Culvert	392	13,400	830	6%	1020	4%
Excavated Stream Crossing	4	110	110	100%	180	100%
Lead Off Ditch	135	7800	810	10%	580	6%
Non-Engineered Drain	1102	97,430	7410	8%	2300	3%
Stream Crossing	146	3140	3140	100%	5670	100%
Sump	24	1520	0	0%	0	0%
Water Bar	914	64,920	1190	2%	1470	3%
Discharge at Stream Crossings*	**241**	**28,280**	**16,170**	**57%**	**10,150**	**60%**
All Drains	**5061**	**456,200**	**21,360**	**5%**	**16,420**	**4%**

** includes stream crossings, excavated stream crossings, and any other drain point within 10 m of stream crossings*

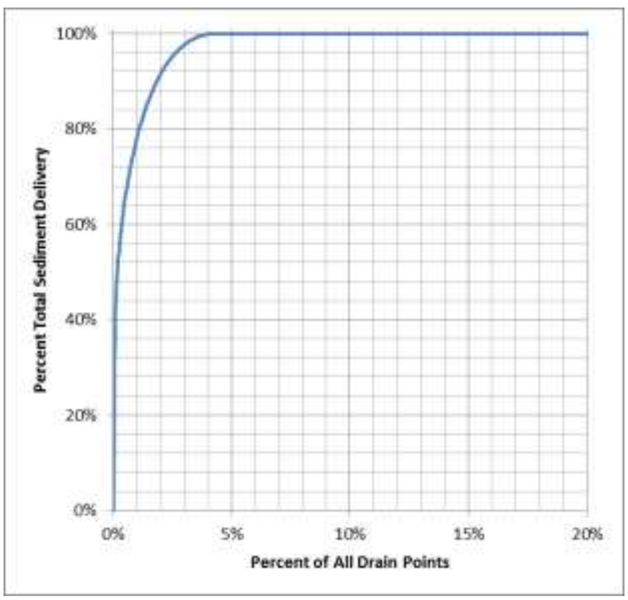


Figure 11. Percent total sediment delivered to streams by percent of drain points. 4% of all drain points deliver 100% of the delivered sediment.

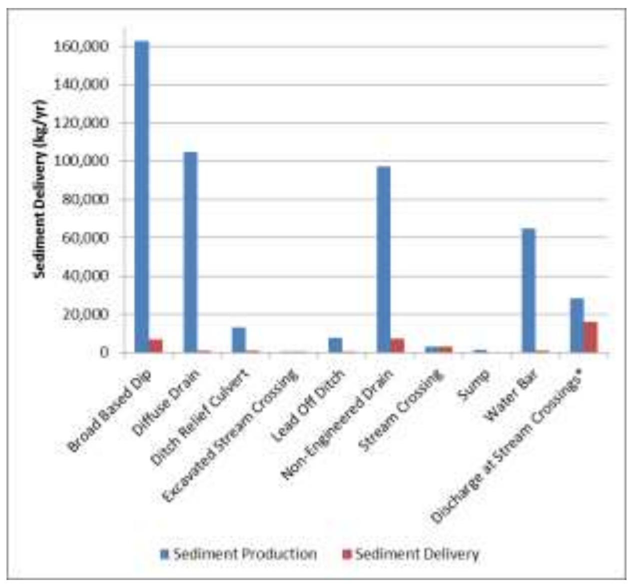


Figure 12. Sediment production and delivery by drain point type.

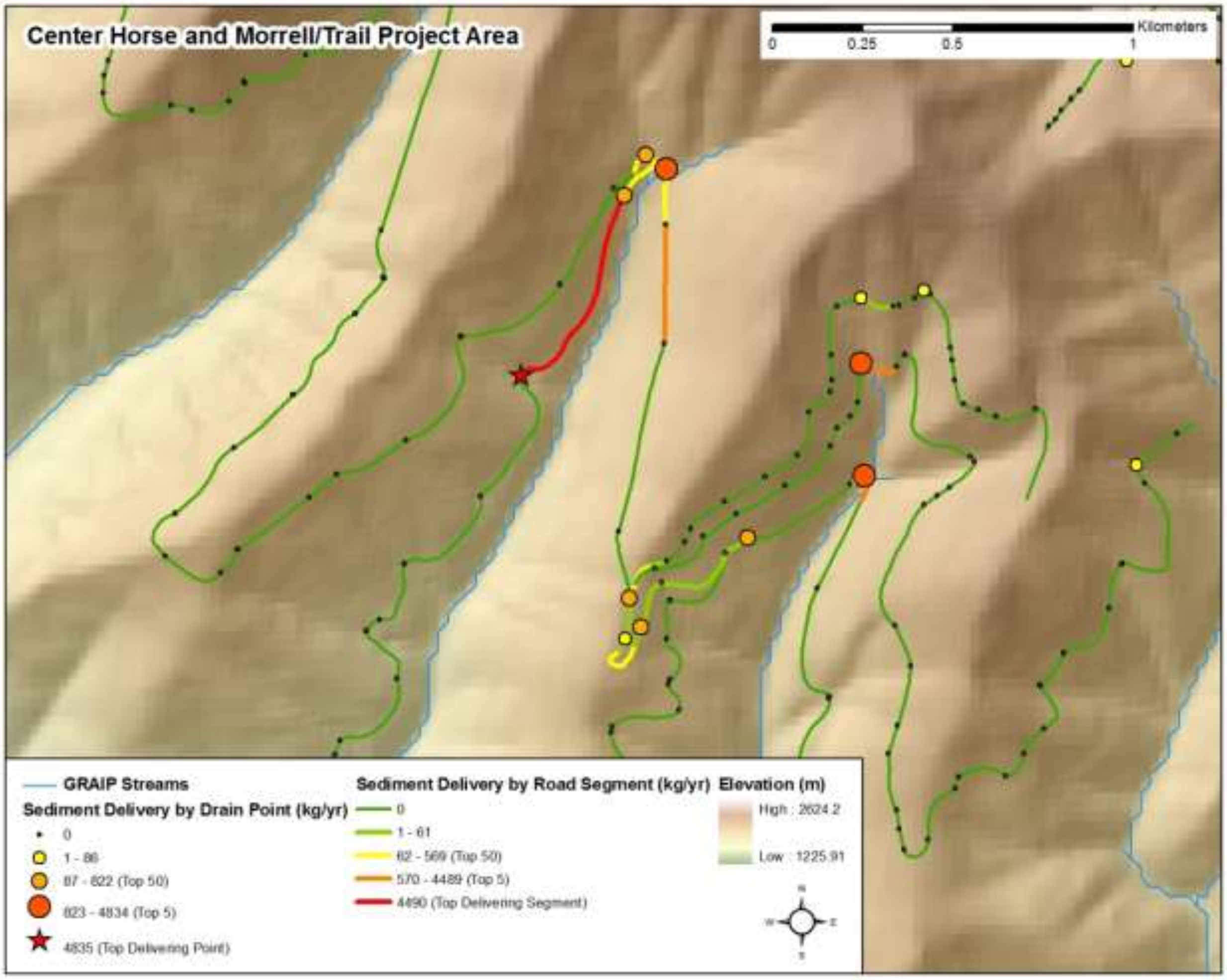


Figure 13. Fine sediment delivery to channels by road segment and drain point in the upper Little Shanley and Black Canyon Creeks area. The road lines are colored to indicate the mass of fine sediment delivered to channels.

Poorman Creek

There were 2190 drain points observed in the Poorman Creek area, 97 of which delivered sediment to stream channels (Table 5). Model predictions indicate that these points delivered an estimated 11.5 Mg/yr, or 5% of the 247 Mg/yr generated on the road surfaces and ditches (Figure 14). Non-engineered drains and stream crossings delivered the most sediment (4.4 Mg/yr and 4.0 Mg/yr, respectively; Figure 15). A map of the road surface sediment delivery and the accumulated sediment delivered through each drain point is shown for the central part of the Poorman Creek area (Figure 16).

***Table 5**. Summary of sediment production and delivery at drain points in the Poorman Creek area.*

Drain Type	**Count**	**Σ Sediment Production (kg/yr)**	**Σ Sediment Delivery (kg/yr)**	**% Sediment Delivery**	**Length Connected (m)**	**% Length Connected**
Broad Based Dip	412	70,320	2280	3%	930	2%
Diffuse Drain	417	47,010	160	0.3%	100	0.2%
Ditch Relief Culvert	56	7960	670	8%	1550	18%
Lead Off Ditch	8	710	0	0%	0	0%
Non-Engineered Drain	693	77,330	4420	6%	1600	4%
Stream Crossing	53	3960	3960	100%	3900	100%
Sump	2	80	0	0%	0	0%
Water bar	549	40,060	20	0.04%	30	0.1%
Discharge at Stream Crossings*	**75**	**7260**	**5600**	**77%**	**4580**	**87%**
All Drains	**2190**	**247,420**	**11,500**	**5%**	**8110**	**5%**

** includes stream crossings and any other drain point within 10 m of stream crossings*

There was 5.6 Mg/yr of delivery that occurred within 10 m of a stream crossing. This is 49% of all sediment delivery and 77% of all sediment produced within 10 m of a stream crossing (compared to the 5% delivery rate for all sediment).

The fraction of sediment produced and delivered from the road system can also be evaluated in the context of road length. Of the 174 km (108 mi) of total inventoried road length, 8.1 km (5.0 mi, 5%) deliver sediment to streams (Table 2).

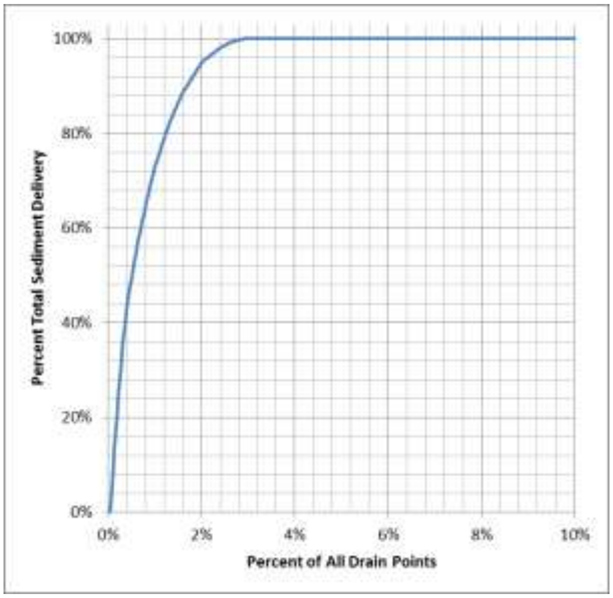


Figure 14. Percent total sediment delivered to streams by percent of drain points. 3% of all drain points deliver 100% of the delivered sediment.

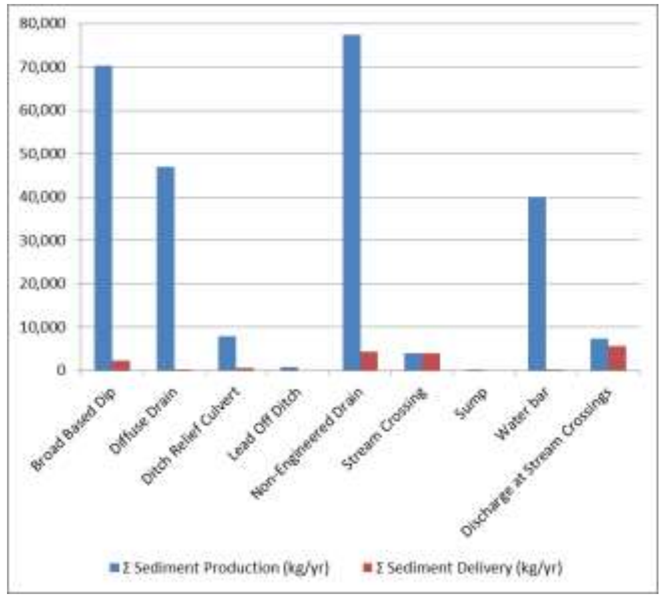


Figure 15. Sediment production and delivery by drain point type.

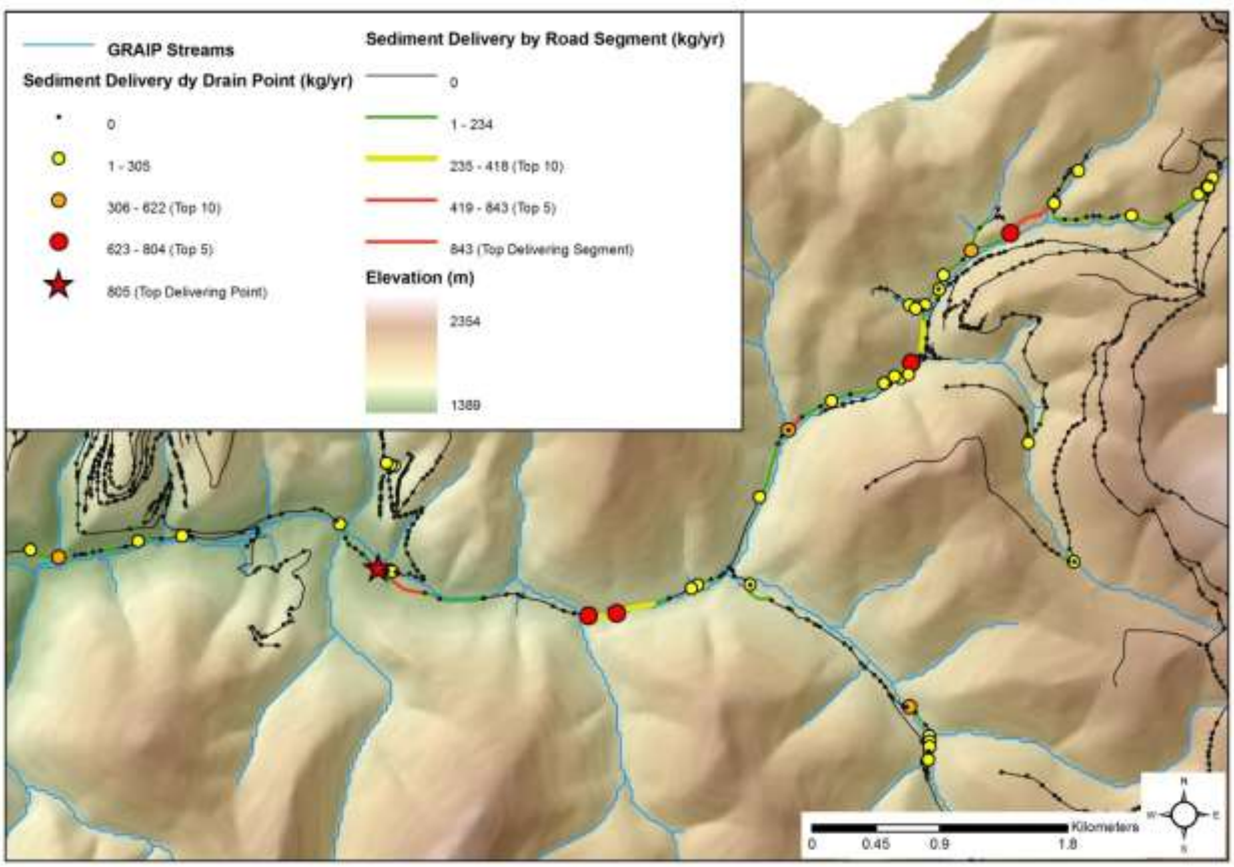


Figure 16. Fine sediment delivery to channels by road segment and drain point in central roaded portion of the Cold Creek area. The road lines are colored to indicate the mass of fine sediment delivered to channels.

Cold Creek

There were 3584 drain points observed in the Cold Creek area, 205 of which delivered sediment to stream channels (Table 6). Model predictions indicate that these points delivered an estimated 9.8 Mg/yr, or 4% of the 162 Mg/yr generated on the road surfaces and ditches (Figure 17). Broad based dips and stream crossings delivered the most (3.3 Mg/yr and 3.8 Mg/yr, respectively; Figure 18). A map of the road surface sediment delivery and the accumulated sediment delivered through each drain point is shown for the central part of the Cold Creek area (Figure 19).

Table 6. *Summary of sediment production and delivery at drain points in the Cold Creek area.*

Drain Type	Count	Σ Sediment Production (kg/yr)	Σ Sediment Delivery (kg/yr)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	1050	64,750	3350	5%	1320	2%
Diffuse Drain	670	30,070	0	0%	0	0%
Ditch Relief Culvert	266	12,750	1780	14%	2240	13%
Lead Off Ditch	139	5000	200	4%	360	5%
Non-Engineered Drain	1097	377,340	300	1%	360	1%
Stream Crossing	115	3840	3840	100%	4320	100%
Sump	1	110	0	0%	0	0%
Water Bar	246	7590	350	5%	110	1%
Discharge at Stream Crossings*	**180**	**8760**	**6570**	**75%**	**5210**	**75%**
All Drains	**3584**	**161,840**	**9810**	**6%**	**8720**	**4%**

** includes stream crossings and any other drain point within 10 m of stream crossings*

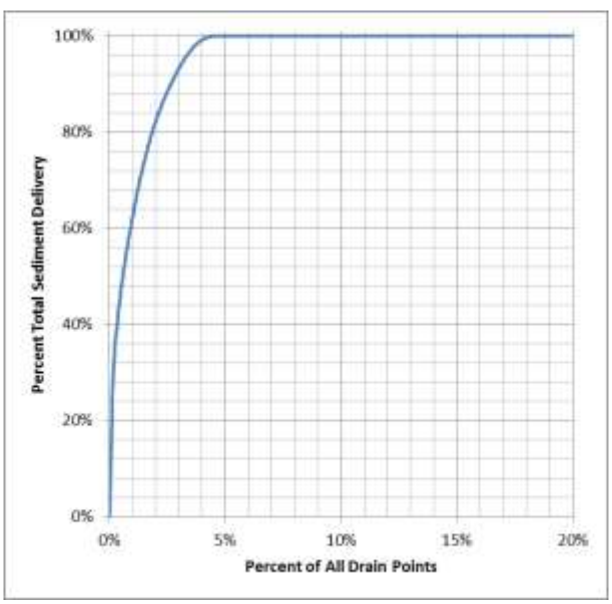


Figure 17. Percent total sediment delivered to streams by percent of drain points. 6% of all drain points deliver 100% of the delivered sediment.

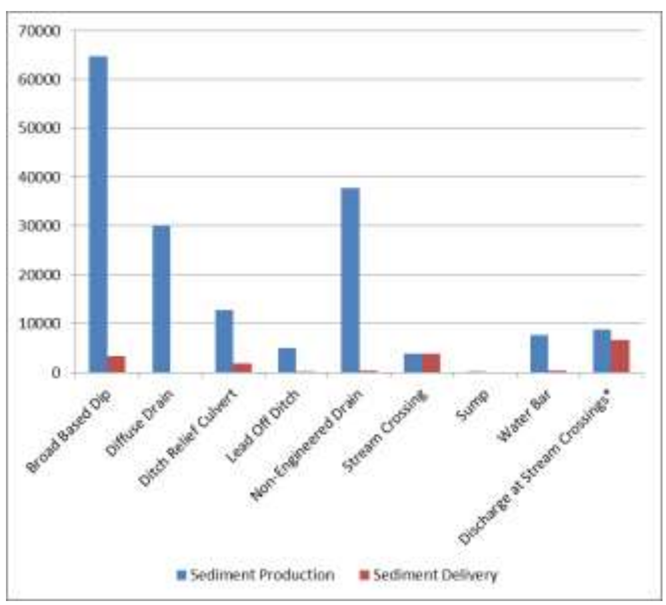


Figure 18. Sediment production and delivery by drain point type.

There was 6.6 Mg/yr of delivery that occurred within 10 m of a stream crossing. This is 67% of all sediment delivery and 75% of all sediment produced within 10 m of a stream crossing (compared to the 4% delivery rate for all sediment).

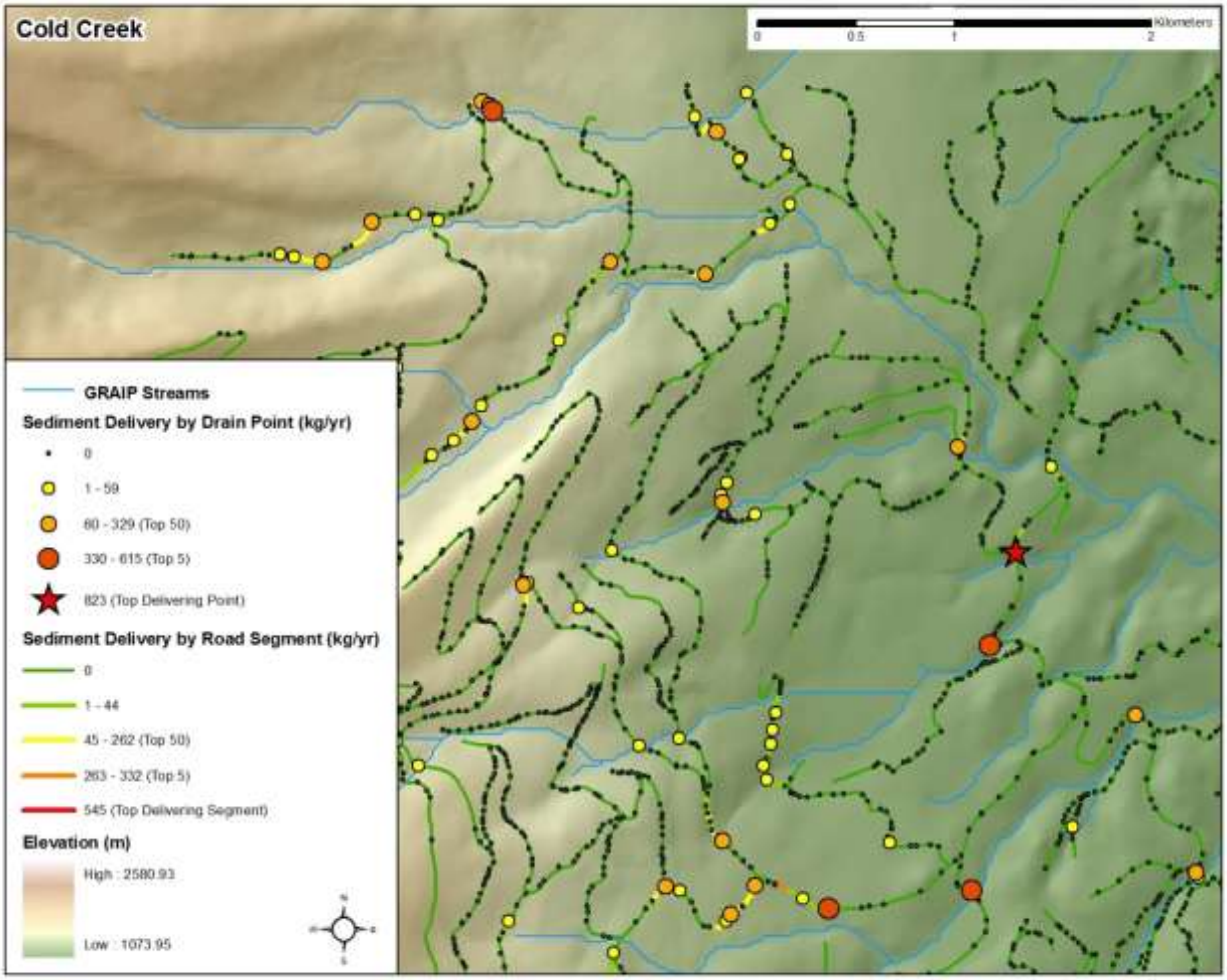


Figure 19. Fine sediment delivery to channels by road segment and drain point in the central roaded portion of the Cold Creek area. The road lines are colored to indicate the mass of fine sediment delivered to channels.

The fraction of sediment produced and delivered from the road system can also be evaluated in the context of road length. Of the 198 km (123 mi) of total inventoried road length, 8.7 km (5.4 mi, 4%) deliver sediment to streams (Table 3).

4.3 Downstream Sediment Accumulation

Road surface derived fine sediment enters the stream network below connected drain points. Road-related sediment accumulates in streams and is routed through the network. GRAIP calculates two measures of road sediment for each stream segment. The first measure, sediment accumulation (Figures 20, 23, and 26, below), is the mass of road-related sediment that passes through each stream segment per year. In the absence of detailed information on sediment routing, the assumption is that road surface-related fine sediment has a residence time of less than one year. The second measure, specific sediment accumulation (Figures 21, 24, and 26, below), is the mass of road-related sediment normalized by the contributing area. In this metric, area is used as a proxy for discharge, allowing us to compare the sediment impacts to channel segments with differing contributing areas.

Observed annual sediment yields for nearby areas (Table 7) range from 2.8 Mg/km^2/yr to 122.6 Mg/km^2/yr. Time-scales and data types varied. Not including the outlying data from Gibson Reservoir, the measured average sediment yield for nearby areas was 9.2 Mg/km^2/yr, similar to short-term rates for the northern Rocky Mountains as reported by Kirchner (2001).

Table 7. *Observed annual sediment yields for nearby areas. Sampling methods and time scales vary.*

Location	Citation	Length of Record	Type of Data	Specific Sediment (Mg/km^2/yr)
North Fork Blackfoot River, MT	Lolo National Forest 2009	18 years	Suspended sediment	2.8
Blackfoot River at Bonner, MT	USGS 2012; Lambing and Sando 2008	15 of 22 years	Suspended sediment	7.5
Nevada Creek Reservoir, MT	USDA 1978	36 years	Reservoir core samples	7.7
Lower Willow Creek Reservoir, MT	USDA 1978	11 years	Reservoir core samples	11.9
Flathead Lake, MT	Hoffman et al. 2006	7600 years	Seismic survey	16.3
Gibson Reservoir, MT	USDA 1978	43 years	Reservoir core samples	122.6
Average, no outlier				**9.2**

Center Horse Morrell-Trail Project Area

Road surface-related sediment at the mouth of the various creeks within the Center Horse and Morrell-Trail project area ranged from 0.03 Mg/yr (Lost Creek) to 11.6 Mg/yr (Cottonwood Creek; Figure 20; Table 8). Specific sediment ranged from 0.01 Mg/km^2/yr (North Fork Cottonwood Creek) to 1.80 Mg/km^2/yr (Little Shanley Creek). Using the total road surface sediment delivered and the drainage area for the whole Center Horse and Morrell/Trail project area, the specific sediment was 0.10 Mg/km^2/yr (Figure 21).

Including the sediment from road-related landslides (not including cutslope failures), gullies, and fill erosion at drain points (see Sections 4.4, 4.5, and 4.7), in addition to that from the road surface, the total annual road sediment accumulation at the mouth of the various creeks within the Center Horse and Morrell-Trail project area ranged from 0.03 Mg/yr (Lost Creek) to 20.5 Mg/yr (Cottonwood Creek). Specific sediment with mass wasting sediment ranged from 0.01 $Mg/km^2/yr$ (North Fork Cottonwood Creek) to 1.80 $Mg/km^2/yr$ (Little Shanley Creek) with large increases in some other areas (Cottonwood, Shanley, Spring, and Blind Canyon Creeks). Using the total sediment including mass wasting delivered and the drainage area for the whole Center Horse and Morrell/Trail project area, the specific sediment was 0.21 $Mg/km^2/yr$ (Figure 22).

Table 8. *Project area streams and sediment accumulation and specific sediment accumulation at the stream mouth, calculated using only road surface-related sediment and all road sediment sources (landslides, gullies, and fill erosion at drain points).*

Stream Name	Road Surface Sediment at Mouth (Mg/yr)	Specific Road Surface Sediment at Mouth ($Mg/km^2/yr$)	All Road Sediment at Mouth (Mg/yr)	All Specific Road Sediment at Mouth ($Mg/km^2/yr$)
Shanley Creek	0.8	0.06	3.0	0.21
Lost Creek	0.03	0.03	0.03	0.03
Dry Cottonwood Creek	0.3	0.05	0.3	0.05
Black Canyon Creek	2.4	0.43	2.4	0.43
Cottonwood Creek	11.6	0.19	20.5	0.33
Spring Creek	2.2	0.17	11.0	0.88
Little Shanley Creek	7.3	1.80	7.3	1.80
North Fork Cottonwood Creek	0.3	0.01	0.3	0.01
Morrell Creek	3.6	0.05	3.9	0.06
Trail Creek	1.6	0.03	4.1	0.08
Swamp Creek	0.3	0.03	0.4	0.04
Blind Canyon Creek	0.9	0.04	3.3	0.14
Center Horse and Morrell/Trail Project Area	**21.4**	**0.10**	**45.2**	**0.21**

At the stream reach scale, road sediment impacts may be more pronounced due to high local delivery rates from gullies, landslides, road fill or surface erosion, and due to limitations on available transport energy. Reaches in lower Spring, Black Canyon, Shanley, and Little Shanley Creeks may be in this group (Figure 22).

Road-related sediment both with and without mass wasting ranged from about 0.1% to about 20% of the estimated average annual observed sediment yield for this geographic region. Using the total sediment delivered and the drainage area for the whole Center Horse and Morrell/Trail project area, the specific sediment was 1% of the estimated average annual observed sediment yield with road-surface sediment only, and 2% of the estimated average annual observed sediment yield including mass wasting sediment.

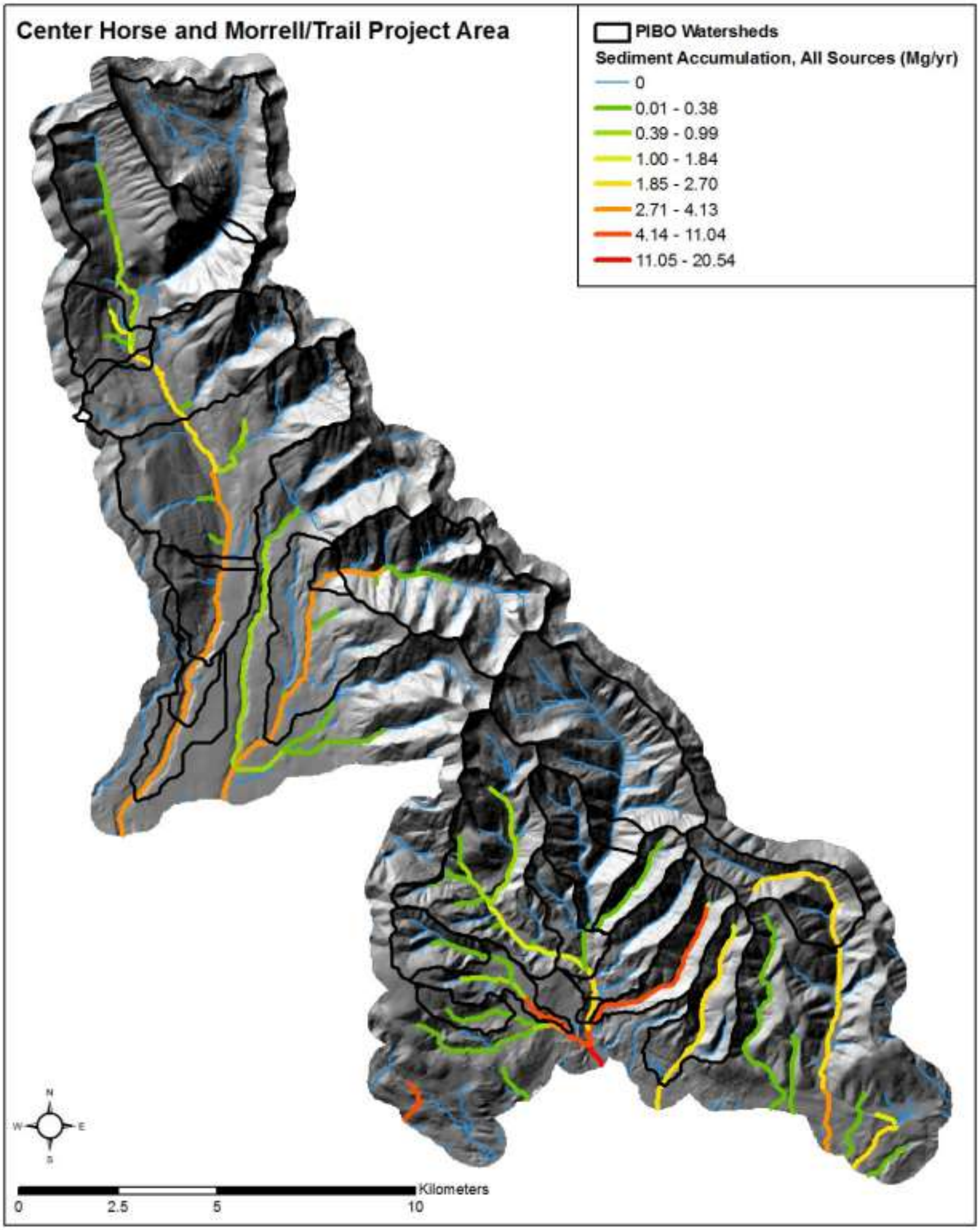


Figure 20. Sediment accumulation from all road-related sediment sources (road surface, gullies, landslides, and fill erosion) in the Center Horse and Morrell/Trail project area.

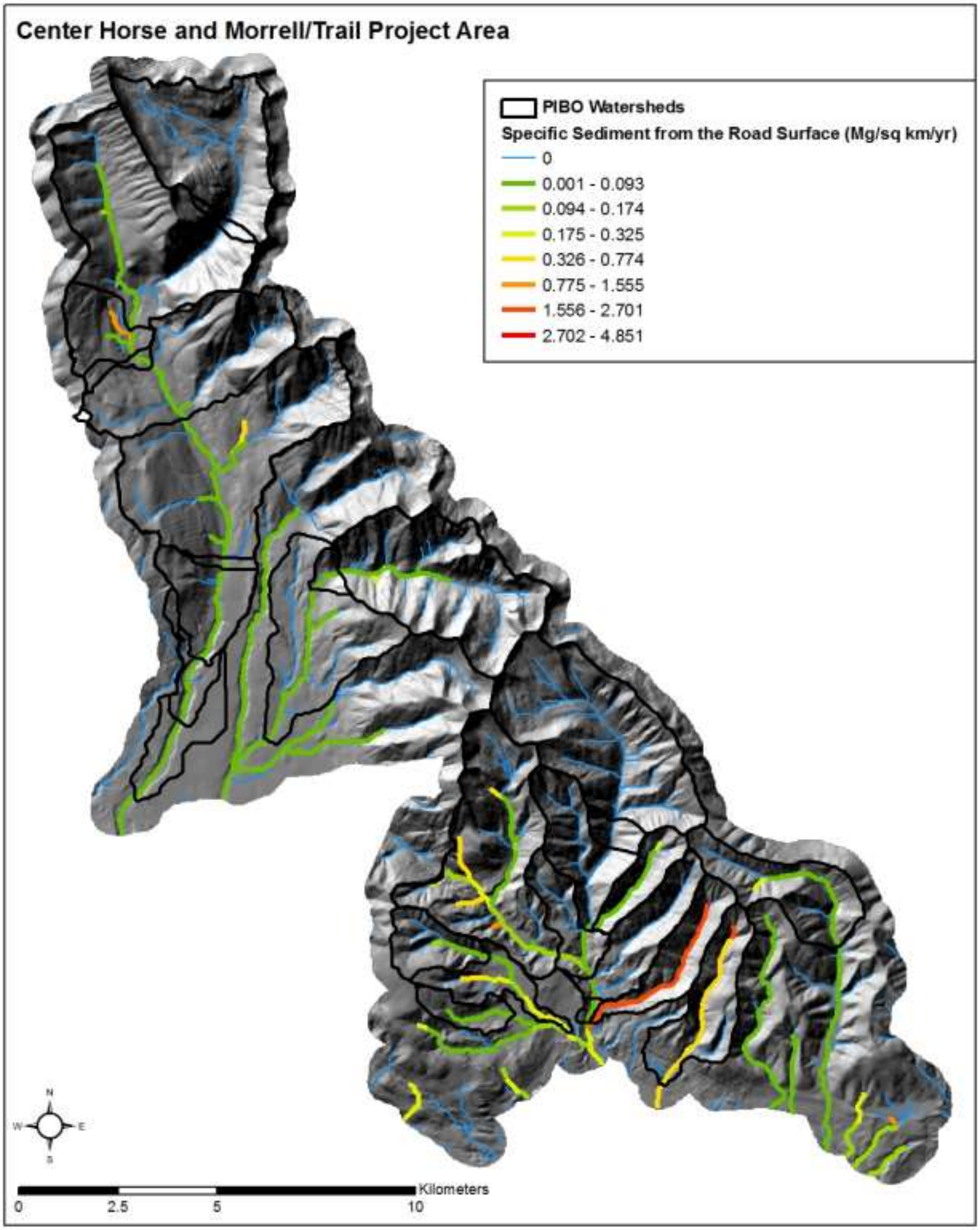


Figure 21. Specific sediment from road surface sediment in the Center Horse and Morrell/Trail project area.

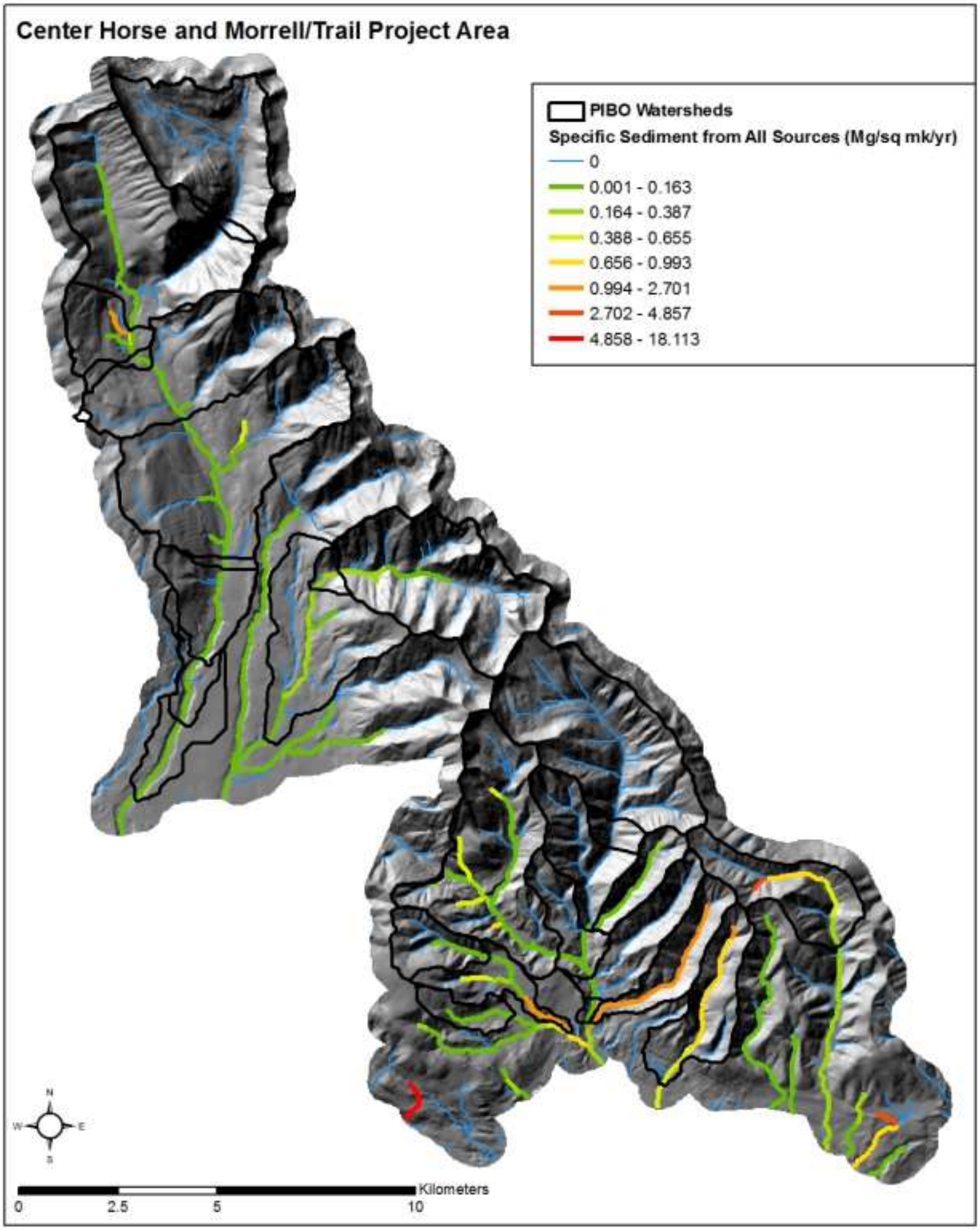


Figure 22. Specific sediment from all road-related sediment sources (road surface, gullies, landslides, and fill erosion) in the Center Horse and Morrell/Trail project area.

Poorman Creek

Road surface-related sediment at the mouth of the two named creeks within the Poorman Creek area ranged from 0.1 Mg/yr (Canyon Creek) to 0.8 Mg/yr (South Fork Poorman Creek; Figure 23; Table 9). Specific sediment ranged from 0.04 Mg/km^2/yr (Canyon Creek) to 0.05 Mg/km2/yr (South Fork Poorman Creek). Using the total road surface sediment delivered and the drainage area for the whole Poorman Creek area, the specific sediment was 0.11 Mg/km^2/yr (Figure 24).

Table 9. *Project area streams and sediment accumulation and specific sediment accumulation at the stream mouth, calculated using only road surface-related sediment and all road sediment sources (landslides, gullies, and fill erosion at drain points).*

Stream Name	Road Surface Sediment at Mouth (Mg/yr)	Specific Road Surface Sediment at Mouth (Mg/km^2/yr)	All Road Sediment at Mouth (Mg/yr)	All Specific Road Sediment at Mouth (Mg/km^2/yr)
South Fork Poorman Creek	0.8	0.05	1.1	0.03
Canyon Creek	0.1	0.04	0.1	0.04
Poorman Creek (Project Area)	**11.5**	**0.11**	**19.6**	**0.19**

Including the sediment from road-related landslides (not including cutslope failures), gullies, and fill erosion at drain points (see Sections 4.4, 4.5, and 4.7), in addition to that from the road surface, the total annual road sediment accumulation at the mouth of Poorman Creek was 19.6 Mg/yr. Specific sediment with mass wasting sediment for the entire Poorman Creek area was 0.19 Mg/km^2/yr (Figure 25).

At the stream reach scale, road sediment impacts may be more pronounced due to high local delivery rates from gullies, landslides, road fill or surface erosion, and due to limitations on available transport energy. Reaches in upper Poorman Creek may be in this group (Figure 25).

Road-related sediment both with and without mass wasting ranges from about 0.4% to about 0.5% of the estimated average annual observed sediment yield for this geographic region. Using the total sediment delivered and the drainage area for the whole Poorman Creek area, the specific sediment is 1% of the estimated average annual observed sediment yield with road-surface sediment only, and 2% of the estimated average annual observed sediment yield including mass wasting sediment.

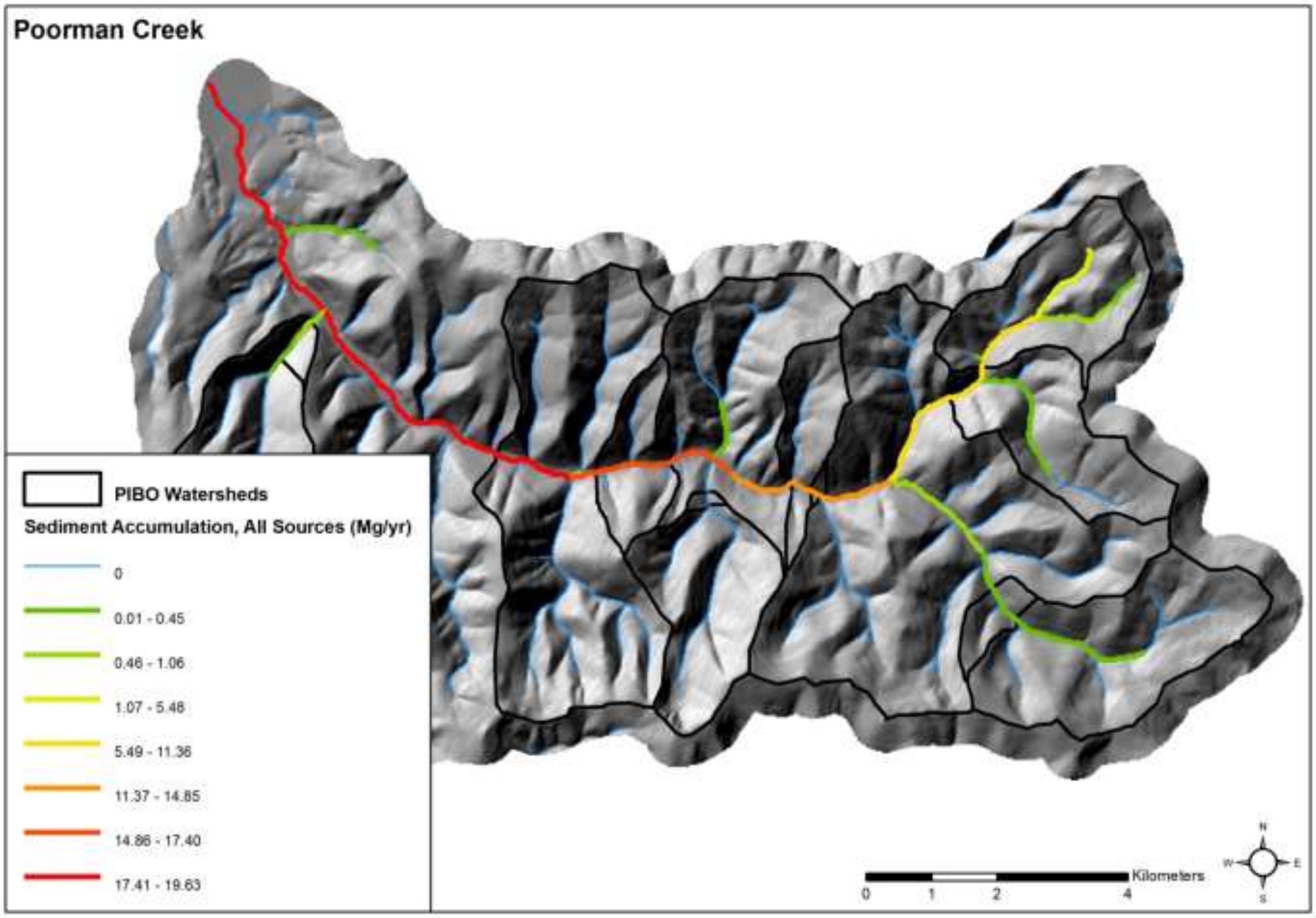
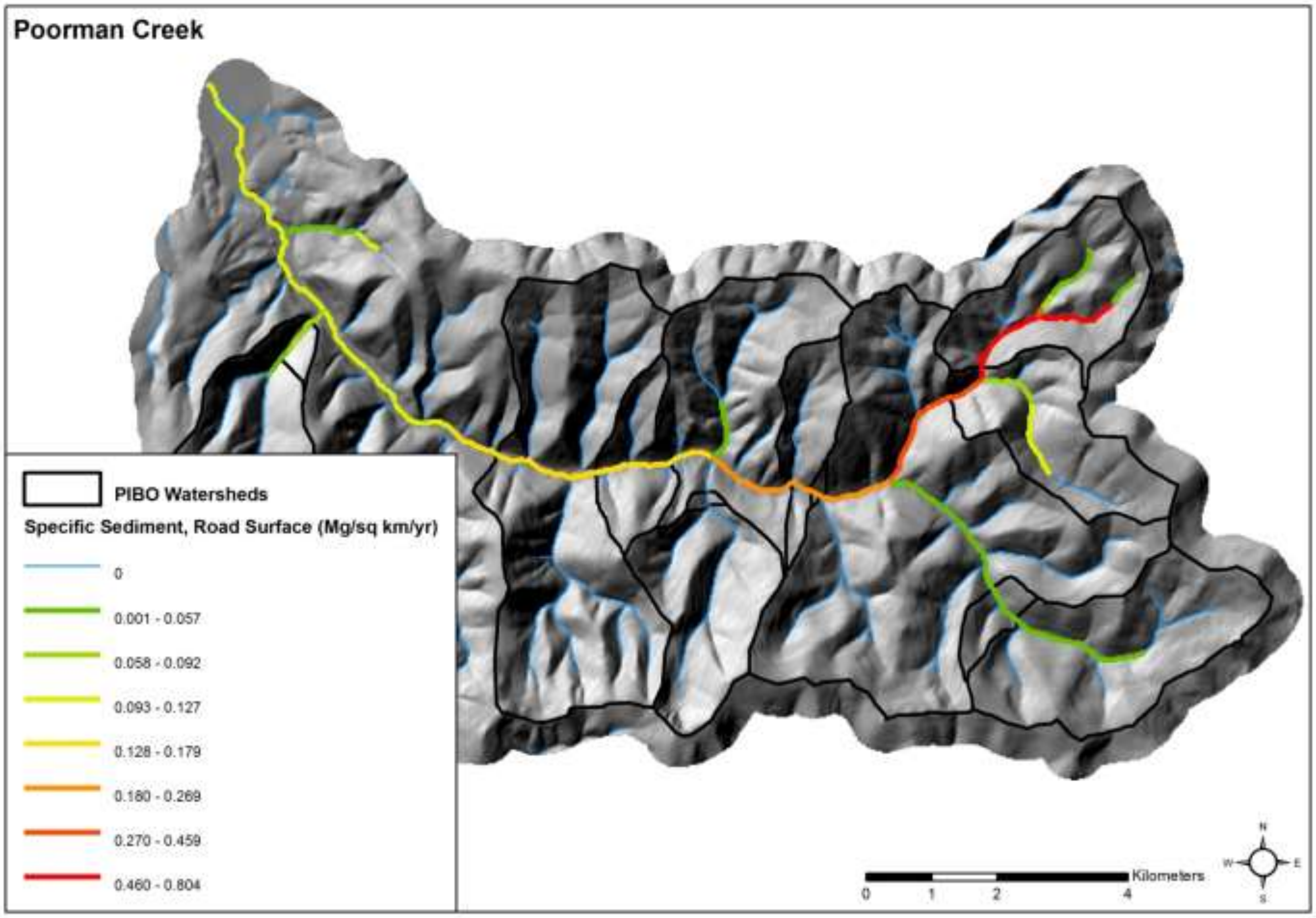


Figure 23. Sediment accumulation from all road-related sediment sources (road surface, gullies, landslides, and fill erosion) in the Poorman Creek area.


Poorman Creek
PIBO Watersheds
Specific Sediment, Road Surface (Mg/sq km/yr)
0
0.001 - 0.057
0.058 - 0.092
0.093 - 0.127
0.128 - 0.179
0.180 - 0.269
0.270 - 0.459
0.460 - 0.804
Kilometers
0
1
2
4
N
W
E
S

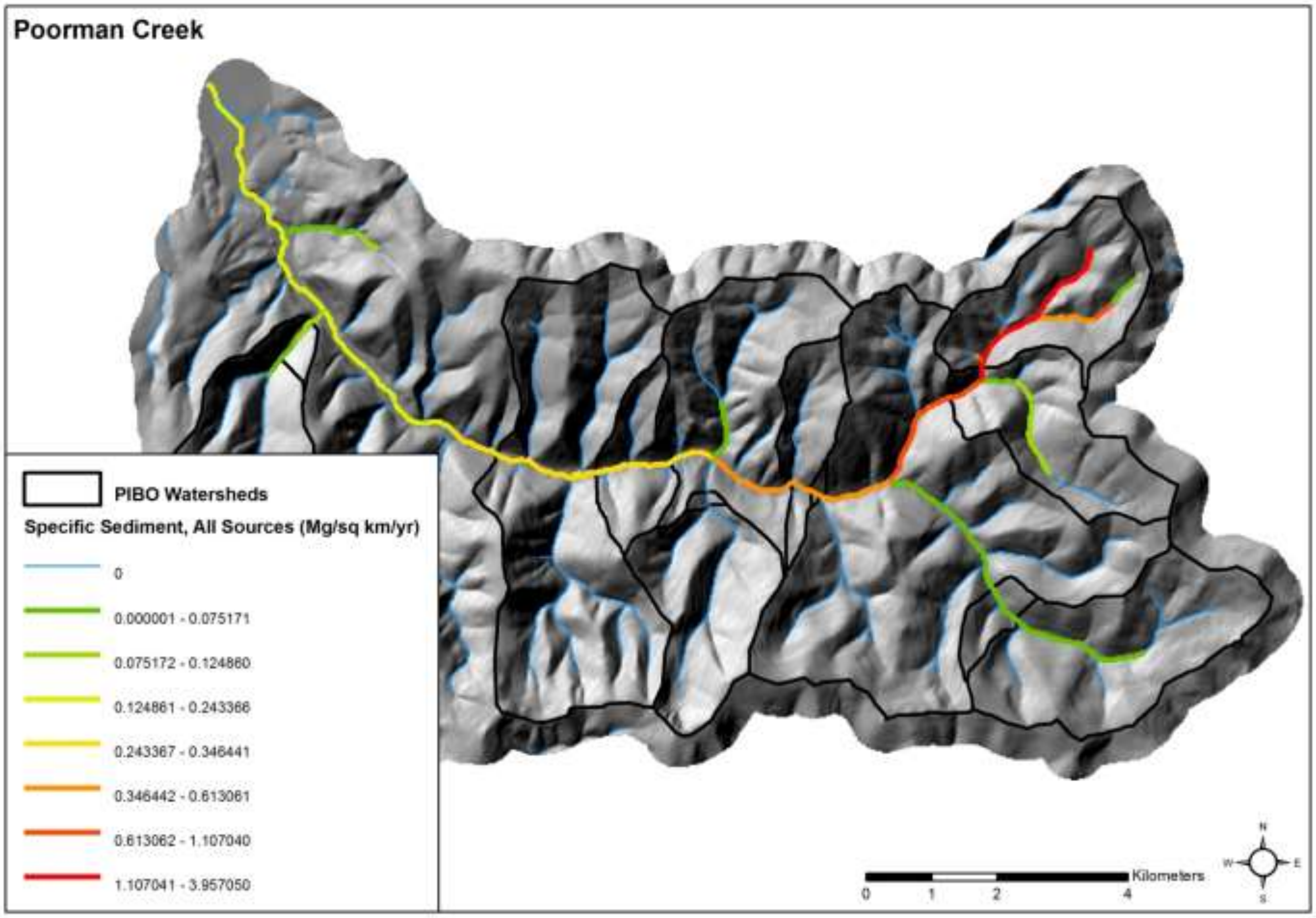


Figure 25. Specific sediment from all road-related sediment sources (road surface, gullies, landslides, and fill erosion) in the Poorman Creek area.

Cold Creek

Road surface-related sediment at the mouth of the two forks of Cold Creek ranged from 0.4 Mg/yr (North Fork Cold Creek) to 3.8 Mg/yr (South Fork Cold Creek; Figure 26; Table 10). Specific sediment ranged from 0.04 Mg/km2/yr (North Fork Cold Creek) to 0.14 Mg/km2/yr (South Fork Cold Creek). Using the total road surface sediment delivered and the drainage area for the whole Cold Creek area, the specific sediment was 0.10 Mg/km2/yr (Figure 27). There were no instances of delivering gullies or landslides, and only two instances of delivering fill erosion, totaling roughly 0.02 Mg/yr, so mass wasting was not routed downstream in Cold Creek.

Table 10. *Project area streams and sediment accumulation and specific sediment accumulation at the stream mouth, calculated using only road surface-related sediment. There was no mass wasting that was observed to deliver sediment to the stream in Cold Creek.*

Name	Road Surface Sediment at Mouth (Mg/yr)	Specific Road Surface Sediment at Mouth (Mg/km2/yr)	Additional Sediment from Mass Wasting at Mouth (Mg/yr)
South Fork Cold Creek	3.8	0.14	0
North Fork Cold Creek	0.4	0.04	0
Cold Creek (Main Stem)	8.7	0.09	0
Cold Creek Project Area	**9.8**	**0.10**	**0**

At the stream reach scale, road sediment impacts may be more pronounced due to high local delivery rates, road surface erosion, and due to limitations on available transport energy. Reaches in the South Fork Cold Creek may be in this group (Figure 27).

Road-related sediment ranged from about 0.4% to about 1.5% of the estimated average annual observed sediment yield for this geographic region. Using the total sediment delivered and the drainage area for the whole Cold Creek area, the specific sediment was 1% of the estimated average annual observed sediment yield.

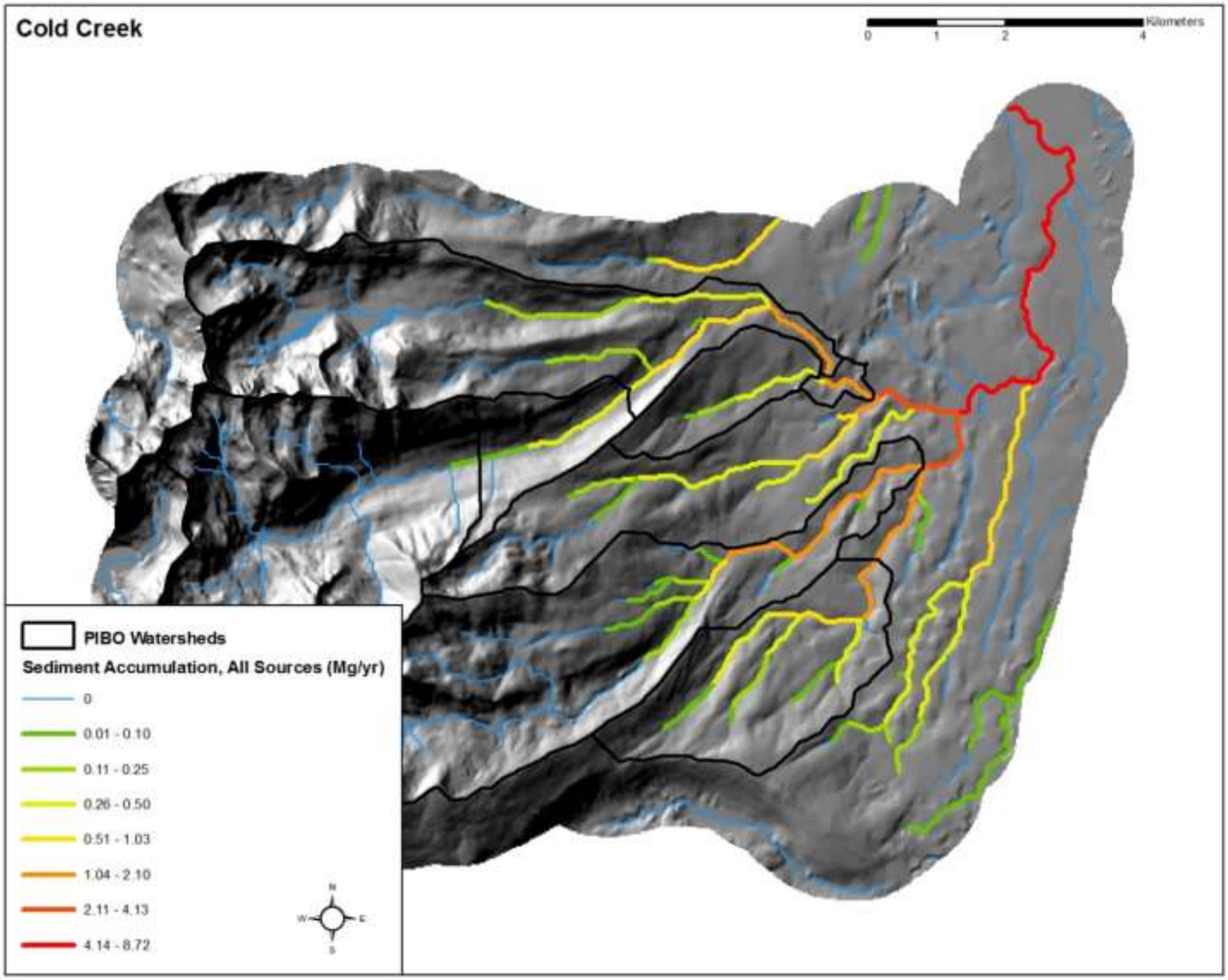


Figure 26. Sediment accumulation from the road surface in the Cold Creek area. There were no instances of mass wasting that were observed to deliver sediment to streams in Cold Creek.

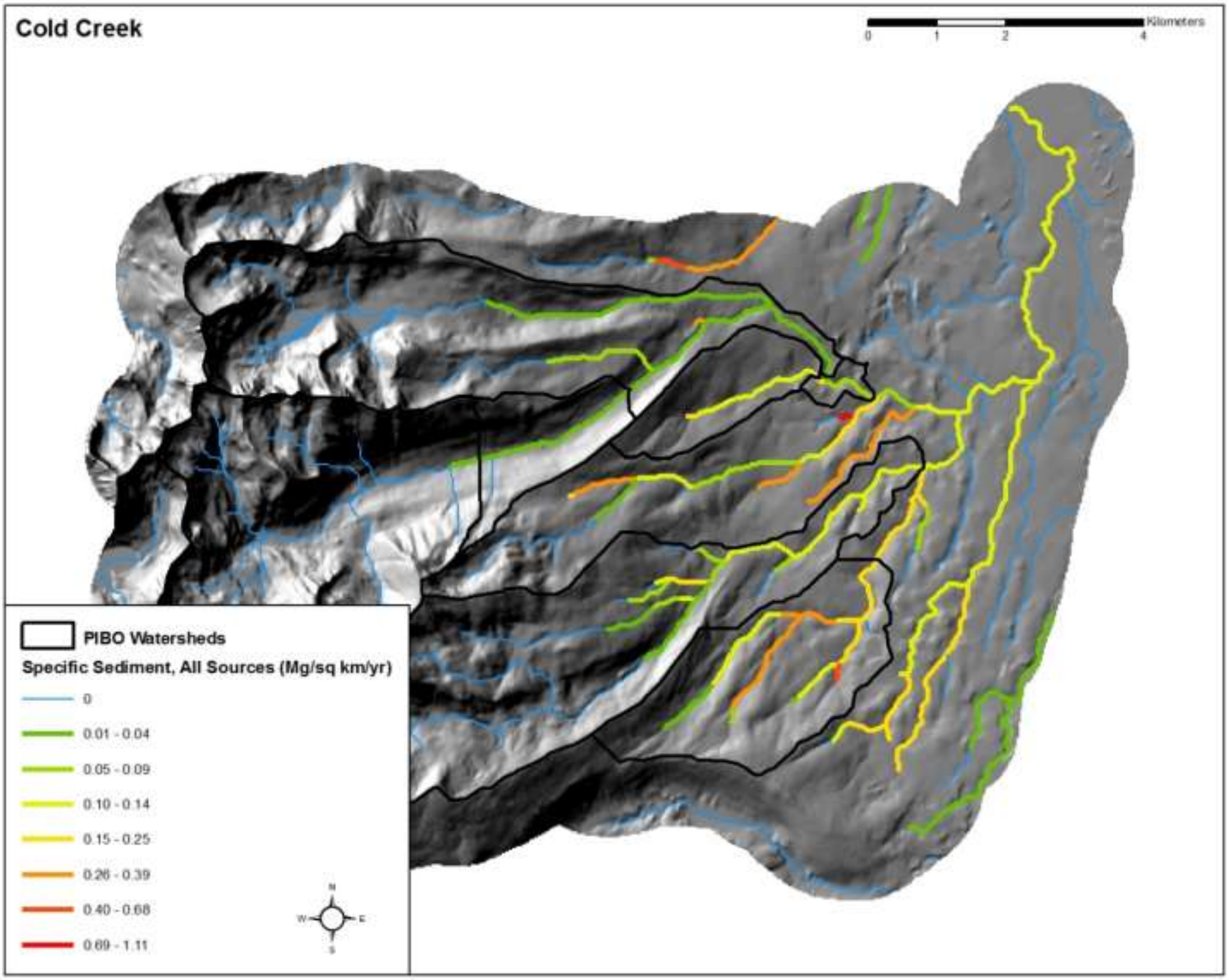


Figure 27. Specific sediment from road surface sediment in the Cold Creek area.

4.4 Landslides

At each landslide location, the type, location, and volume are observed. Landslides can be determined to be connected to the channel network if an associated drain point above the landslide is connected to the channel network, if an associated road surface flow path that would be expected to intercept the landslide sediment is connected to the network, or if the landslide is observed in the field to be connected to the network. In most cases, shallow landslides initiate during large storm events when soils become saturated, and deliver sediment to the channel over a limited time frame. This represents a pulsed as opposed to chronic sediment input to the streams. Delivered landslide masses are distributed over a 20 year time span in order to compare their approximate magnitude with that of the road surface fine sediment (a chronic sediment source). Twenty years is used because, in most places, that is roughly the maximum age of a feature still easily observable in the field. In any given year, the amount of sediment delivered to streams from landslides is likely to be higher or lower than the rate we calculate.

The risk of shallow landslide initiation is predicted using SINMAP 2.0 (Pack at al. 2005, http://hydrology.neng.usu.edu/sinmap2/), modified to account for contributions of road surface runoff, and locally calibrated to known locations of landslides (where available). SINMAP has its basis in the infinite plane slope stability model and produces raster grids that illustrate slope stability based on hillslope and specific catchment area at each DEM grid cell. Un-roaded and roaded risk grids are subjected to a series of mathematical operations that result in grids that show the important changes to landslide risk due to the presence of the roads. These change grids are compared to the natural landslide risk grid to show how the roads affect slope stability in the context of the background risks (i.e. the risks without the influence of road drainage). Important grid cell changes are those un-roaded to roaded differences that show a risk change from stable to unstable, or the areas that were unstable without roads and became less stable after road construction.

Center Horse Morrell-Trail Project Area

Existing Landslides

The Center Horse and Morrell/Trail project area has a low incidence of road-related shallow landsliding. Most road miles are located on the shallow slopes of the glaciated valley bottoms. Landslide volume was estimated for all landslides visible from the road greater than a minimum threshold of six feet in slope length and slope width. The inventory recorded 18 landslides (Table 11), totaling 1319 m^3 (1726 yd^3). There were nine landslides estimated to be less than five years of age, three between five and ten years old, and six landslides were between ten and 15 years old. There were ten that were related to the road in some way; road-related landslides totaled 307 m^3 (402 yd^3). Including non-road related landslides, there were nine cutslope failures (257 m^3, 336 yd^3), four hillslope failures (614 m^3, 803 yd^3), and five fillslope failures (449 m^3, 587 yd^3). Figure 28 shows the locations of the observed landslides in the Spring Creek area of the Center Horse and Morrell/Trail project area.

There were two landslides (11%) found to be stream connected; one road related fillslope failure and one non-road related cutslope failure. The cutslope failure may not be fully connected due to the common removal of eroded cutslope material during road maintenance and uncertainty surrounding timing and discharge of intercepting flow paths. The stream in which the fillslope failure discharged may lead to a lake.

Using a bulk density for road fill of 1.6 Mg/m^3 (Madej 2001), the total mass of sediment generated was expected to be 2111 Mg, with 176 Mg delivering to streams, not including the cutslope failure. This is about 10% of all landslide-generated mass (Table 11). Over a 20-year period, about 8.8 Mg/yr (again without the cutslope failure) have been delivered to streams. This is roughly half the rate of the annual road surface fine sediment delivery. It would take about eight years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from landslides. Estimates here do not account for partial delivery of landslide sediments (i.e. not all sediment from a road related landslide is likely to be delivered, even if some of the sediment is), so actual volumes may be lower.

Table 11. *Number and types of observed landslides, as well as masses and volumes of sediment generated and delivered to the stream channel network in the Center Horse and Morrell/Trail project area.*

Location *Road Related*	**Count**	**Volume (yd^3)**	**Volume (m^3)**	**Mass Produced (Mg)**	**Mass Delivered (Mg)**	**Average Delivery Rate Over 20 Years (Mg/yr)**
Cutslope	**9**	**336**	**257**	**411**	**109**	**5.4**
Not Road Related	*3*	*156*	*119*	*190*	*109*	*5.4*
Road Related	*6*	*180*	*138*	*221*	*0*	*0*
Fillslope	**5**	**587**	**449**	**718**	**176**	**8.8**
Not Road Related	*3*	*421*	*322*	*515*	*0*	*0*
Road Related	*2*	*166*	*127*	*203*	*176*	*8.8*
Hillslope	**4**	**803**	**614**	**982**	**0**	**0**
Not Road Related	*2*	*747*	*571*	*914*	*0*	*0*
Road Related	*2*	*55*	*42*	*68*	*0*	*0*
Totals, Not Considering Cutslope Failures				**1700**	**176**	**8.8**
Totals	**18**	**1726**	**1319**	**2111**	**284**	**14.2**
Not Road Related	*8*	*1324*	*1012*	*1620*	*109*	*5.4*
Road Related	*10*	*402*	*307*	*491*	*176*	*8.8*

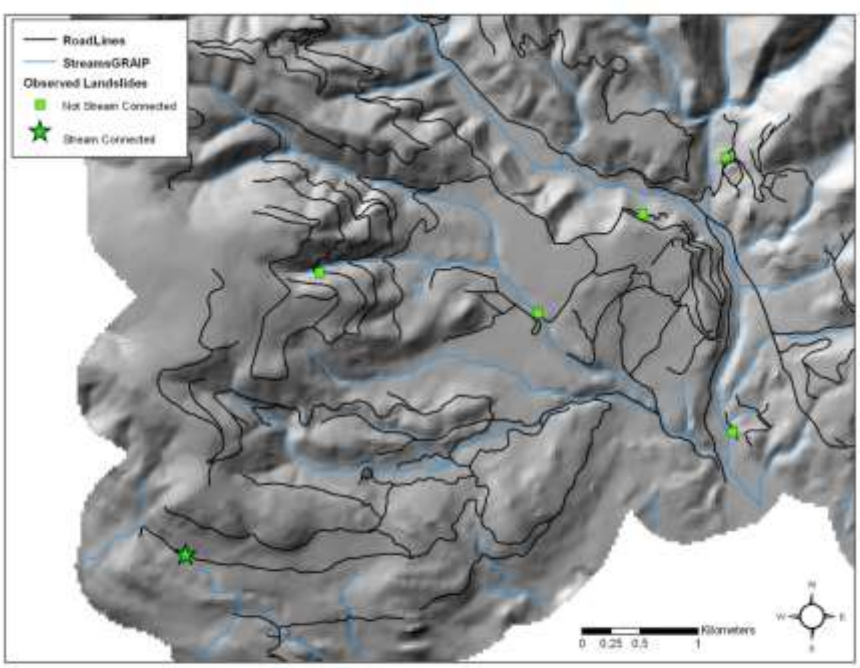


Figure 28. Observed landslides in the Spring Creek area of the Center Horse and Morrell/Trail project area.

Changes to Landslide Risk Due to Roads

SIMNAP calibration was completed using eight known locations of landslides in the local area obtained from forest personnel (S. Hendrickson, personal communication 2013). Figures 29 and 30 illustrate the risk and change in risk in the area. SINMAP was calibrated and run initially to determine the intrinsic stability of the slopes over which the road traverses and to identify locations that are at a high risk of failure without the road (Figure 29).

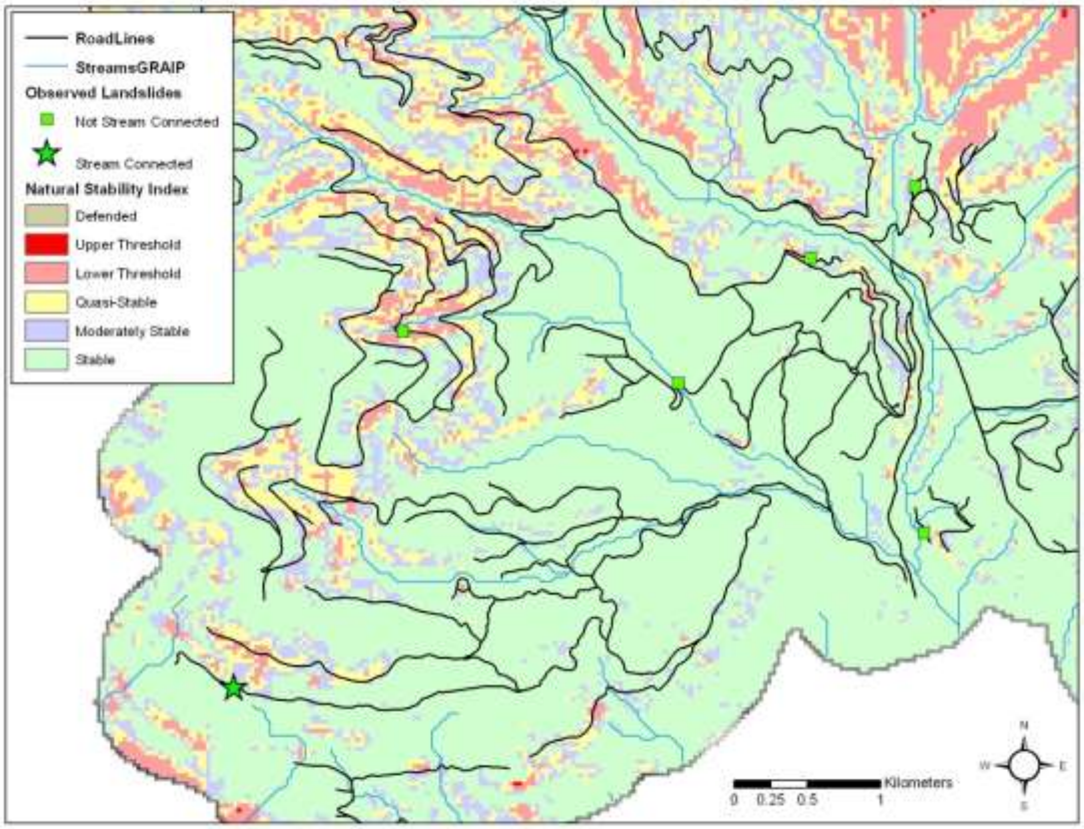


Figure 29. Natural slope stability in the Spring Creek drainage of the Center Horse and Morrell/Trail project area. The yellow, blue, and green cells are generally considered to be stable, while the pink, red, and dark tan cells are generally considered to be unstable. The star indicates a stream-connected landslide in a creek that discharges into a lake.

A second calibrated stability index run was performed to address the effects of road water contribution to drain points. In Figure 30, the areas in the Spring Creek drainage in the southern part of the project area where the road changed the risk from the stable category (stable, moderately stable, quasi-stable from Figure 29, above) to the unstable category (lower threshold, upper threshold, defended) are shown in red. These are areas where road drainage was installed over naturally stable slopes, and the added water moved the area into the unstable category. The orange cells are areas where the risk increased (became less stable) after road construction, and the terrain was unstable prior to road construction. This is due to the installation of road drainage over naturally unstable slopes. Risk may not extend as far downslope as is shown.

Figure 30 also shows the locations of observed landslides. Over the whole area, nine of the 18 landslides (50%) occurred on destabilized slopes. As shown and described above, some of these points are fillslope or cutslope failures, and may not correlate well with the SINMAP risk which is designed to predict hillslope risks rather than risks within the road prism. Additionally, there were only eight calibration landslide points; a good calibration dataset should include at least 50 points. Given these considerations, there is a reasonably high level of correlation between observed and expected landslide locations.

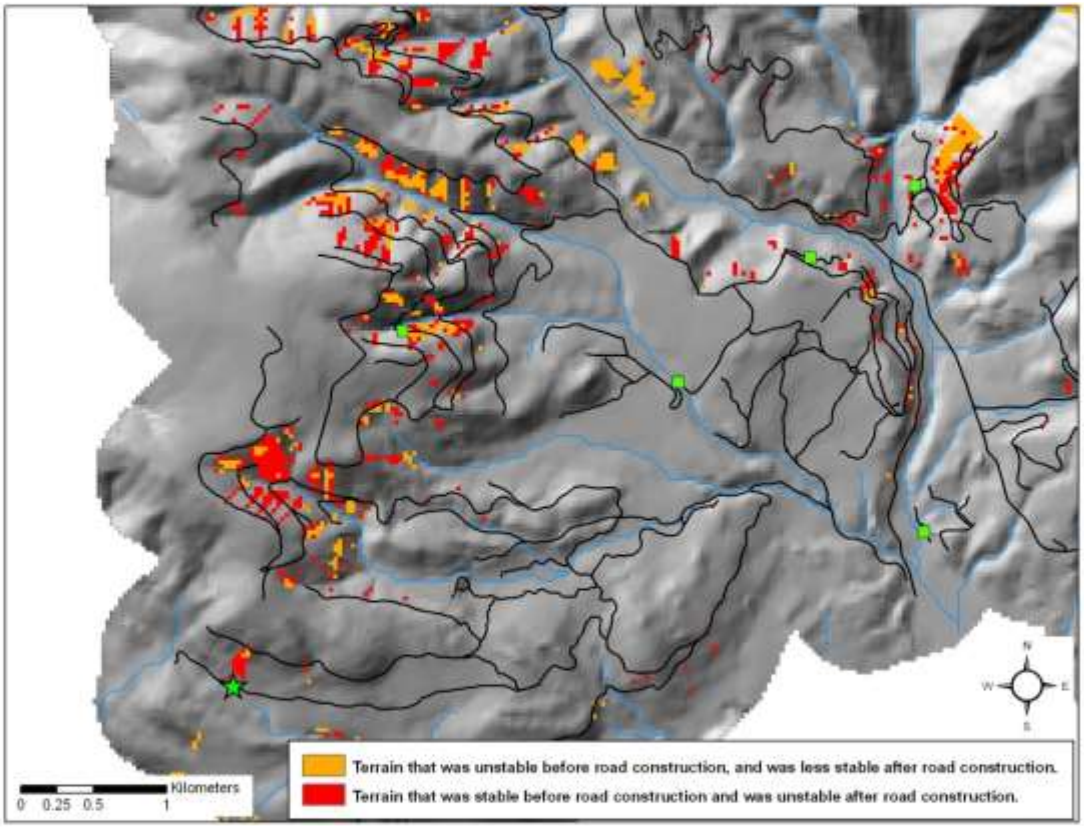


Figure 30. Changes in slope stability risk in the Spring Creek drainage of the Center Horse and Morrell/Trail project area. The red and orange areas are where the risk increased.

Of the 216 km^2 (83 mi^2) that comprise the Center Horse and Morrell/Trail project area, 2.6 km^2 (1 mi^2, 1%) was stable before road construction and is now unstable, and 3.7 km^2 (1.4 mi^2, 2%) was unstable before road construction and is now less stable due to road drainage (Table 12). This is a total of 6.3 km^2 (2.4 mi^2, 3%) of the watershed that has experienced an increase in landslide risk due to road hydrology. This can be compared to 7.8% of the North Fork Siuslaw River watershed in western Oregon that experienced an increase in landslide risk due to roads, and has a high incidence of road related shallow landsliding.

Table 12. *Landslide risk changes in the Center Horse and Morrell/Trail project area by category and area.*

Total Area of Watershed (m^2)	215,620,000	100%
Area Stable Before Roads, Now Unstable (m^2)	2,646,600	1%
Area Unstable Before Roads, Now Less Stable (m^2)	3,686,400	2%
Total Area Affected by Roads (m^2)	6,336,000	3%

Poorman Creek

Existing Landslides

The Poorman Creek area has a low incidence of road-related shallow landsliding. Hillslopes in Poorman Creek are generally shallow. Landslide volume was estimated for all landslides visible from the road greater than a minimum threshold of six feet in slope length and slope width. The inventory recorded five landslides (Table 13), totaling 252 m^3 (329 yd^3). Three landslides were estimated to be less than five years of age, and two landslides were between ten and 15 years old. All five were related to the road in some way. There were three cutslope failures (95 m^3, 124 yd^3), one hillslope failure (153 m^3, 200 yd^3), and one fillslope failure (4 m^3, 5 yd^3). Figure 31 shows the locations of the observed landslides in the Poorman Creek area.

Table 13. *Number and types of observed landslides, as well as masses and volumes of sediment generated and delivered to the stream channel network in the Poorman Creek area.*

Location*	Count	Volume (yd^3)	Volume (m^3)	Mass Produced (Mg)	Mass Delivered (Mg)	Average Delivery Rate Over 20 Years (Mg/yr)
Cutslope	3	124	95	152	91	4.5
Fillslope	1	5	4	6	0	0
Hillslope	1	200	153	245	0	0
Total	**5**	**329**	**252**	**403**	**91**	**4.5**

** all observed landslides were road related*

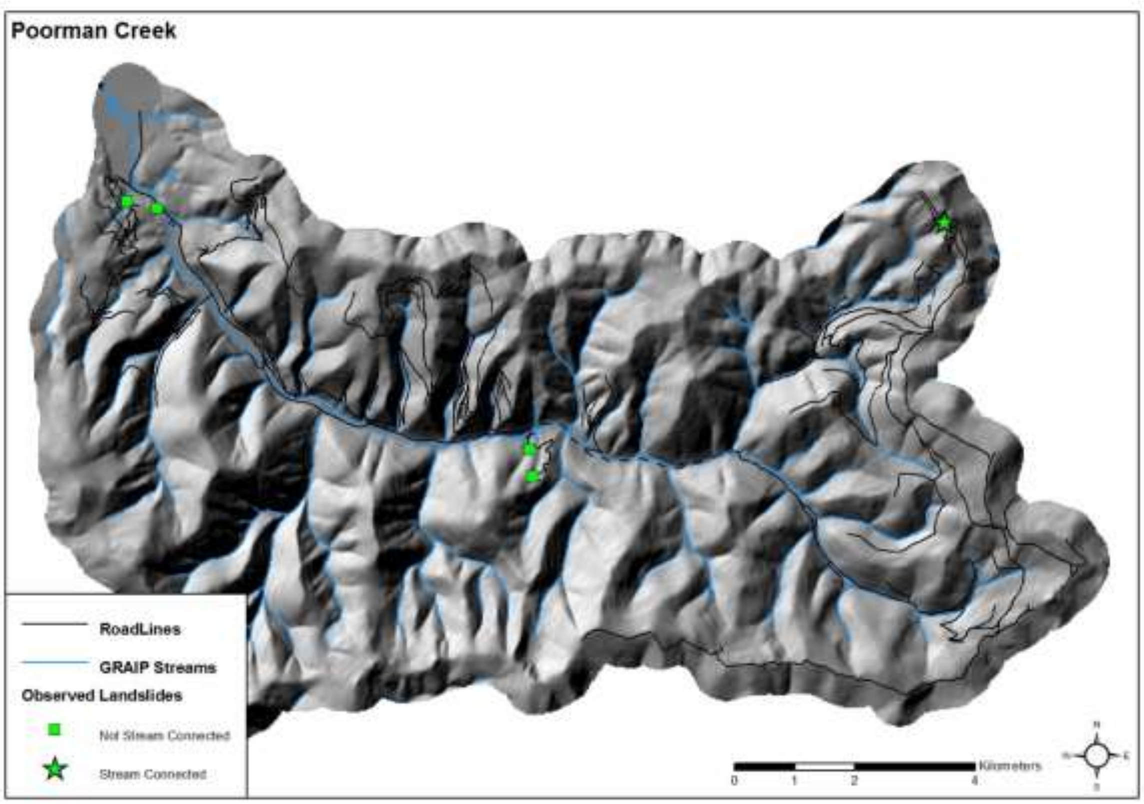


Figure 31. Observed landslides in the Poorman Creek area. The dotted line was collected in 2014.

There was one landslide that was found to be stream connected. This cutslope failure occurred directly above a culvert, and the culvert was connected to a stream. Though it is likely that some sediment from this failure moved across the road and was not delivered, or was removed by maintenance equipment, observations suggest that most of the sediment entered the culvert and therefore delivered to the stream.

Using a bulk density for road fill of 1.6 Mg/m^3 (Madej 2001), the total mass of sediment generated was expected to be 403 Mg, with 91 Mg delivering to streams. This is about 20% of all landslide-generated mass (Table 13). Over a 20-year period, about 4.5 Mg/yr have been delivered to streams. This is roughly half the annual road surface fine sediment delivery rate. It would take about 8 years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from landslides. Estimates here do not account for partial delivery of landslide sediments (i.e. not all sediment from a road related landslide is likely to be delivered, even if some of the sediment is), so actual volumes may be lower.

Changes to Landslide Risk Due To Roads

SIMNAP calibration was completed using the same eight known locations of landslides in the Center Horse and Morrell/Trail project area obtained from forest personnel (S. Hendrickson, personal communication 2013). Figures 32 and 33 illustrate the risk and change in risk in the area. SINMAP was calibrated and run initially to determine the intrinsic stability of the slopes over which the road traverses and to identify locations that are at a high risk of failure without the road (Figure 32).

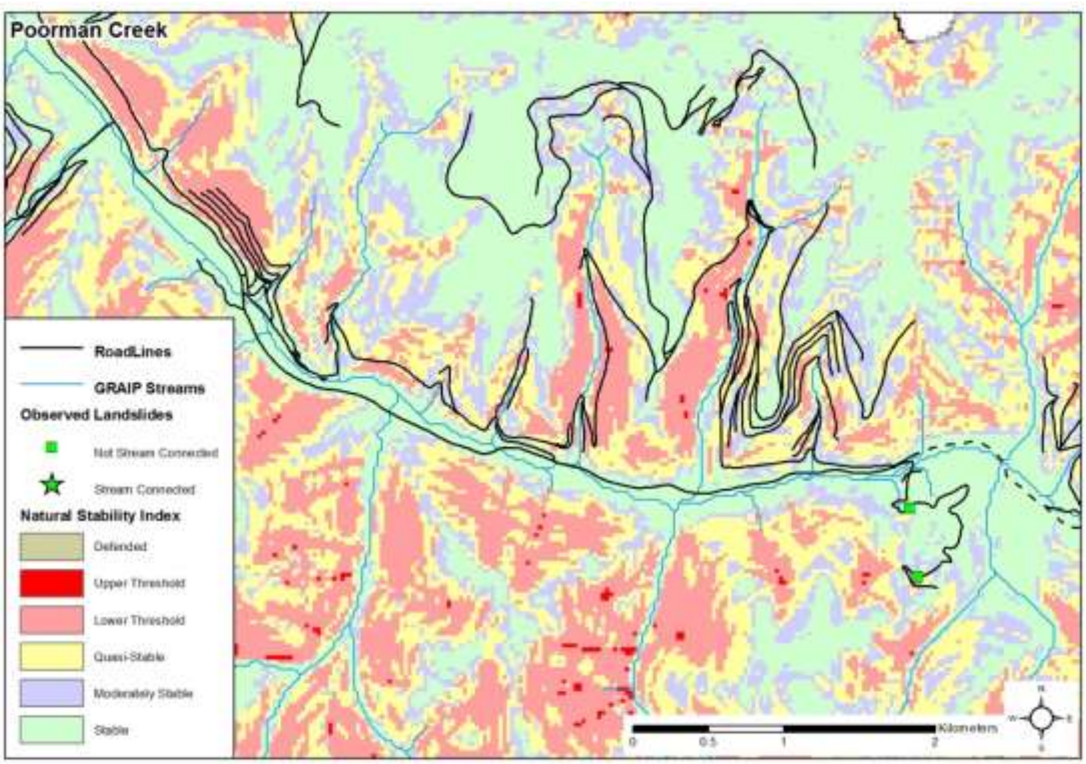


Figure 32. Natural slope stability in the central part of the Poorman Creek area. The yellow, blue, and green cells are generally considered to be stable, while the pink, red, and dark tan cells are generally considered to be unstable. The dotted line was collected in 2014.

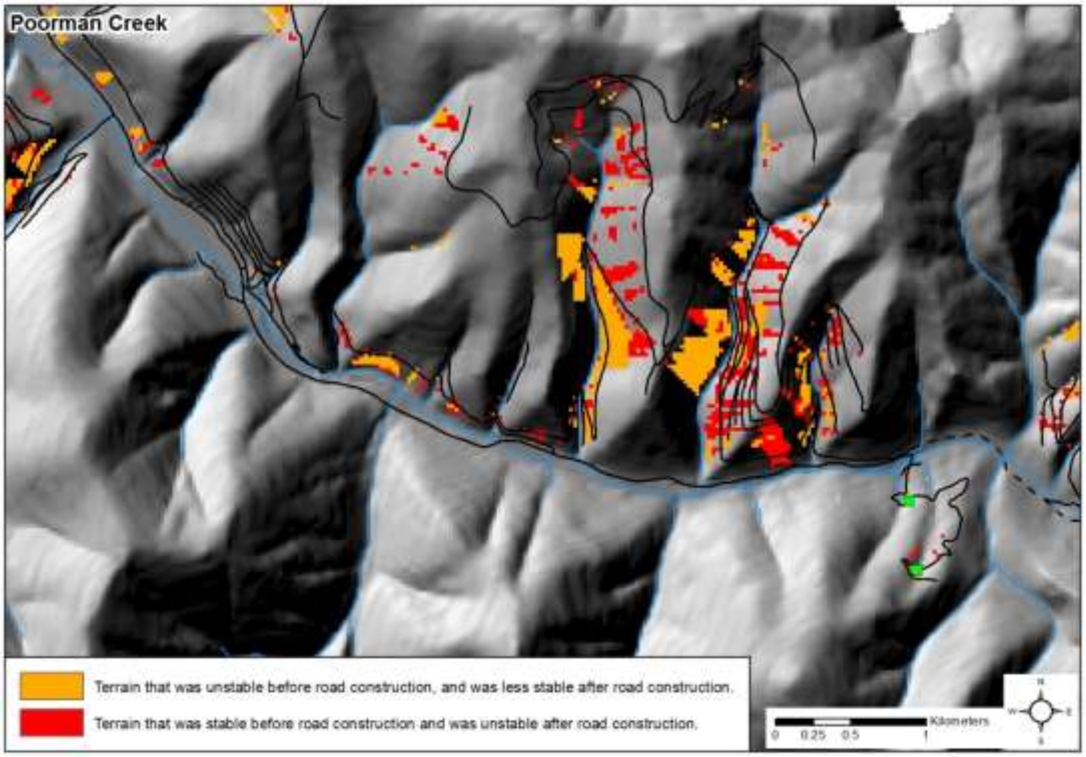


Figure 33. Changes in slope stability risk in the central part of the Poorman Creek area. The red and orange areas are where the risk increased. The dotted line was collected in 2014.

A second calibrated stability index run was performed to address the effects of road water contribution to drain points. In Figure 33, the areas in the central portion of the Poorman Creek area where the road changed the risk from the stable category (stable, moderately stable, quasi-stable from Figure 32, above) to the unstable category (lower threshold, upper threshold, defended) are shown in red. These are areas where road drainage was installed over naturally stable slopes, and the added water moved the area into the unstable category. The orange cells are areas where the risk increased (became less stable) after road construction, and the terrain was unstable prior to road construction. This is due to the installation of road drainage over naturally unstable slopes. Risk may not extend as far downslope as is shown.

Figure 33 also shows the locations of observed landslides. Over the whole area, the only landslide that occurred over a destabilized slope was the hillslope failure. Fillslope and cutslope failures may not correlate well with the SINMAP risk which is designed to predict hillslope risks rather than risks within the road prism. Additionally, there were only eight calibration landslide points, and they were located in somewhat dissimilar geology in a relatively spatially distant locale; a good calibration dataset should include at least 50 points and be within a nearby area of similar soils and geology. Given these considerations, it is reasonable to expect poor correlation between observed and expected landslide locations.

Of the 130 km^2 (50 mi^2) that comprise the Poorman Creek area, 1.4 km^2 (0.5 mi^2, 1%) was stable before road construction and is now unstable, and 1.5 km^2 (0.6 mi^2, 1%) was unstable before road construction and is now less stable due to road drainage (Table 12). This is a total of 2.9 km^2 (1.1 mi^2, 2%) of the watershed that has experienced an increase in landslide risk due to road hydrology. This can be compared to 7.8% of the North Fork Siuslaw River watershed in western Oregon that experienced an increase in landslide risk due to roads, and has a high incidence of road related shallow landsliding.

Table 14. *Landslide risk changes in the Poorman Creek area by category and area.*

Total Area of Watershed (m^2)	130,484,000	100%
Area Stable Before Roads, Now Unstable (m^2)	1,351,100	1%
Area Unstable Before Roads, Now Less Stable (m^2)	1,519,560	1%
Total Area Affected by Roads (m^2)	2,870,670	2%

Cold Creek

Existing Landslides

The Cold Creek area has a low incidence of road-related shallow landsliding (Figure 34). Most road miles are located on the shallow slopes of the glaciated valley bottom. Landslide volume was estimated for all landslides visible from the road greater than a minimum threshold of six feet in slope length and slope width. The inventory recorded nine landslides (Table 15), totaling 175 m^3 (229 yd^3). Two landslides were estimated to be less than five years of age, one landslide was estimated to be between five and ten years old, and six landslides were between ten and 15 years old or older. There were eight that were related to the road in some way; road-related landslides totaled 141 m^3 (184 yd^3). Including the non-road related landslide, there were five cutslope failures (80 m^3, 105 yd^3, and four fillslope failures (94 m^3, 123 yd^3).

Figure 34 shows the locations of each of the observed landslides in the Cold Creek area. No landslides were found to be connected to the stream network. Using a bulk density for road fill of 1.6 Mg/m^3 (Madej 2001), the total mass of sediment generated was expected to be 280 Mg (Table 15).

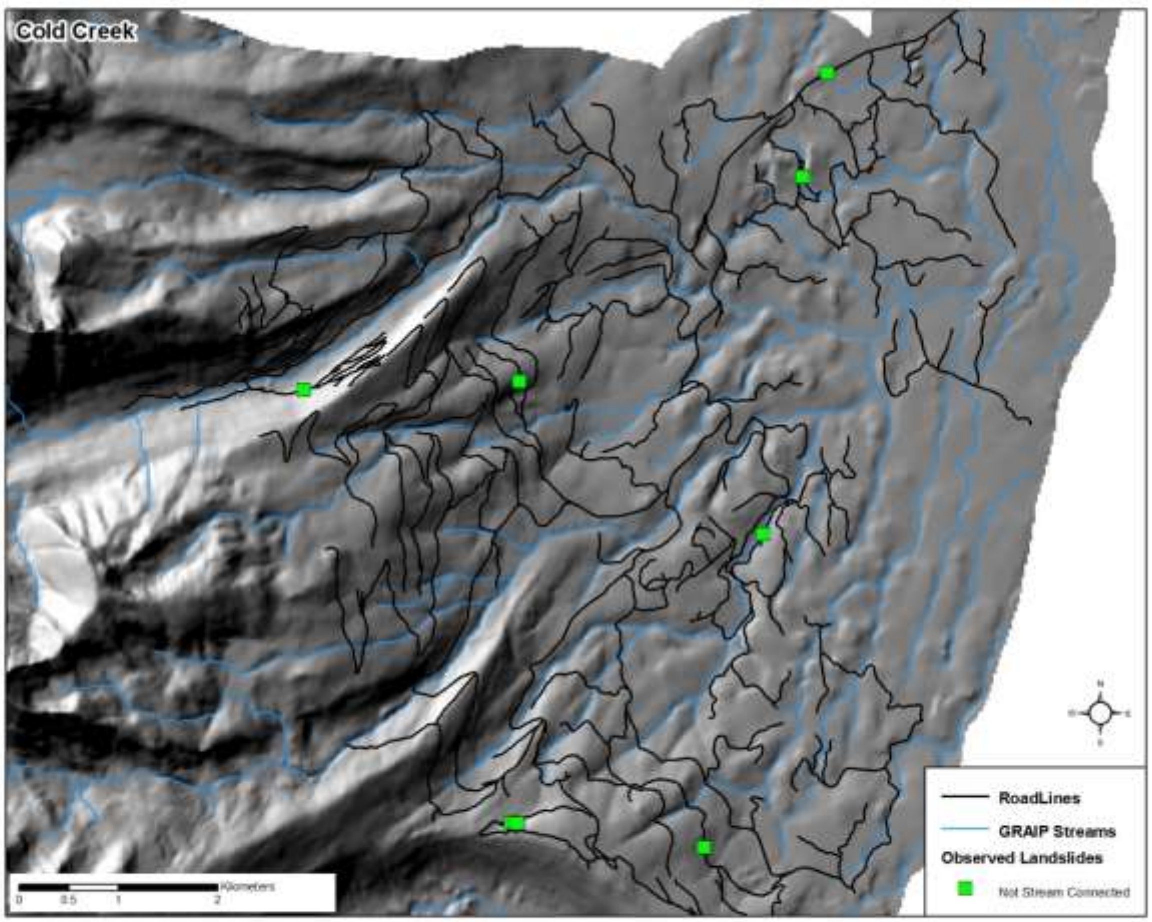


Figure 34. Observed landslides in the Cold Creek area.

Table 15. *Number and types of observed landslides, as well as masses and volumes of sediment generated in the Cold Creek area.*

Location *Road Related*	Count	Volume (yd3)	Volume (m3)	Mass Produced (Mg)	Mass Delivered (Mg)
Cutslope	**5**	**105**	**80**	**129**	**0**
Road Related	*5*	*105*	*80*	*129*	*0*
Fillslope	**4**	**123**	**94**	**151**	**0**
Not Road Related	*1*	*44*	*34*	*54*	*0*
Road Related	*3*	*79*	*60*	*97*	*0*
Totals, Not Considering Cutslope Failures				**151**	**0**
Totals	**9**	**229**	**175**	**280**	**0**
Not Road Related	*1*	*44*	*34*	*54*	*0*
Road Related	*8*	*184*	*141*	*225*	*0*

Changes to Landslide Risk Due To Roads

SIMNAP calibration was completed using the same eight known locations of landslides in the Center Horse and Morrell/Trail project area obtained from forest personnel (S. Hendrickson, personal communication 2013). Figures 35 and 36 illustrate the risk and change in risk in the area. SINMAP was

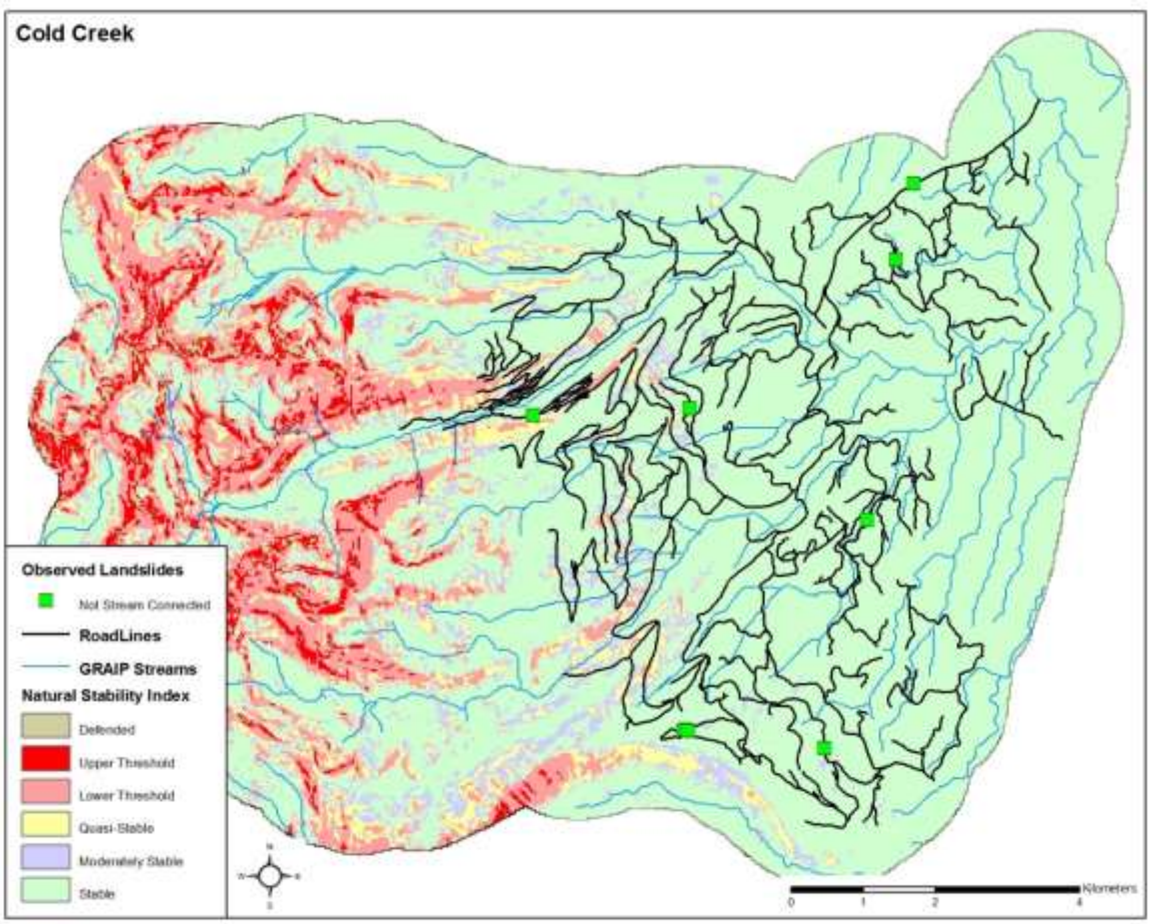


Figure 35. Natural slope stability in the Cold Creek area. The yellow, blue, and green cells are generally considered to be stable, while the pink, red, and dark tan cells are generally considered to be unstable.

calibrated and run initially to determine the intrinsic stability of the slopes over which the road traverses and to identify locations that are at a high risk of failure without the road (Figure 35).

A second calibrated stability index run was performed to address the effects of road water contribution to drain points. In Figure 36, the areas in the Cold Creek area where the road changed the risk from the stable category (stable, moderately stable, quasi-stable from Figure 35, above) to the unstable category (lower threshold, upper threshold, defended) are shown in red. These are areas where road drainage was installed over naturally stable slopes, and the added water moved the area into the unstable category. The orange cells are areas where the risk increased (became less stable) after road construction, and the terrain was unstable prior to road construction. This is due to the installation of road drainage over naturally unstable slopes. Risk may not extend as far downslope as is shown. The areas of elevated risk may be limited to the upper part of the road network, where valley walls are steeper. Most of the road network in the Cold Creek area is in the lower part of the watershed, where hillslopes are generally very shallow.

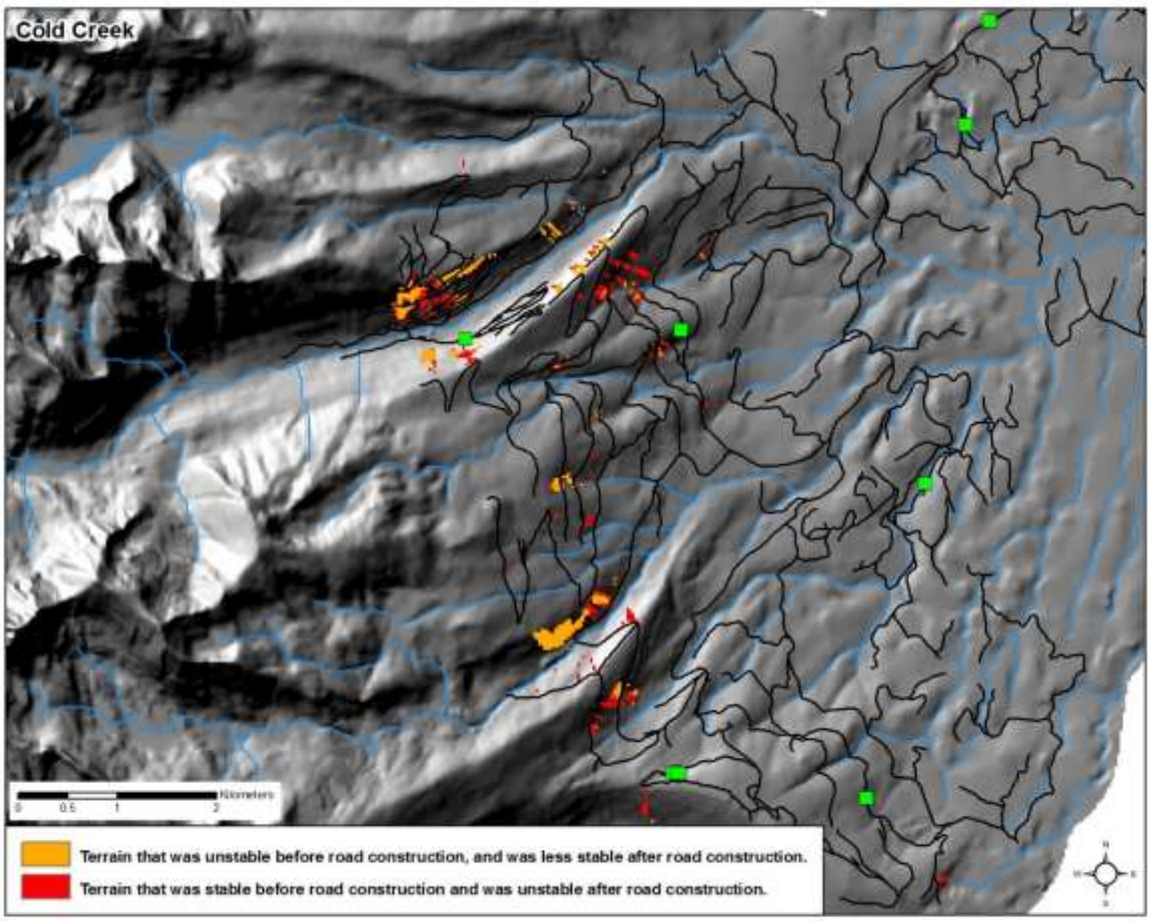


Figure 36. Changes in slope stability risk in the central part of the Cold Creek area. The red and orange areas are where the risk increased.

Figure 36 also shows the locations of observed landslides. Over the whole area, the only landslide that occurred over a destabilized slope was a cutslope failure. There were no observed hillslope failures, and fillslope and cutslope failures may not correlate well with the SINMAP risk which is designed to predict hillslope risks rather than risks within the road prism. Additionally, there were only eight calibration landslide points, and they were located in a relatively spatially distant locale; a good calibration dataset should include at least 50 points and be nearby to the area of interest. Given these considerations, it is reasonable to expect poor correlation between observed and expected landslide locations.

Of the 101 km^2 (39 mi^2) that comprise the Cold Creek area, 0.3 km^2 (0.1 mi^2, 0.3%) was stable before road construction and is now unstable, and 0.3 km^2 (0.1 mi^2, 0.3%) was unstable before road construction and is now less stable due to road drainage (Table 16). This is a total of 0.6 km^2 (0.3 mi^2, 0.6%) of the watershed that has experienced an increase in landslide risk due to road hydrology. This can be compared to 7.8% of the North Fork Siuslaw River watershed in western Oregon that experienced an increase in landslide risk due to roads, and has a high incidence of road related shallow landsliding.

Table 16. *Landslide risk changes in the Cold Creek area by category and area.*

Total Area of Watershed (m^2)	100,642,000	100%
Area Stable Before Roads, Now Unstable (m^2)	308,900	0.3%
Area Unstable Before Roads, Now Less Stable (m^2)	338,000	0.3%
Total Area Affected by Roads (m^2)	646,900	0.6%

4.5 Gullies and Gully Initiation Risk

Gullying at drain points below roads can be a substantial source of sediment to stream channels. At each gully location we measured or estimated the volume of the gully, and observed properties such as its location, any other contributing factors such as groundwater interception, and whether or not it was associated in any way with the road. To distinguish between road-related gullies and natural incipient channel heads, we mapped features as a gully if they occurred below the road drain points, but were absent on the uphill side of the road. A gully was defined as a linear erosional feature at least ten feet long and six inches deep. Gullies can be determined to be connected to the stream channel network if an associated drain point that discharges through the gully is connected to the channel. This mass is both pulsed (as the gully initiates) and chronic (as continued erosion by road surface-derived water), but it is not known what proportion belongs to each category. Delivered gully masses are distributed over a 20 year time span in order to compare their magnitude with that of the road surface fine sediment (a chronic sediment source). Twenty years is used because, in most places, that is roughly the maximum age of a feature still easily observable in the field. In any given year, the amount of sediment delivered to streams from gullies is likely to be higher or lower than the rate we calculate.

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 drain point.

$$ESI = L \times S^2$$

L is the contributing road length at the drain point (m)
S is the slope of the hillslope below the drain point (%)

Calculated ESI values are compared to a calibrated critical ESI threshold (ESI_{crit}) to identify areas with a high risk of gully formation (i.e., where $ESI > ESI_{crit}$). Calibrations are completed using a logistical regression technique (local fit, locfit) in the R statistical computing environment and a length-slope plot of the drain points with and without gullies (Figure 38, below). An easy way to conceptualize this is to think of these distributions as densities. That is, while the density of non-gully drain points decreases as ESI gets larger, the density of gullied points increases relative to the non-gullied drain points. For more information on ESI in GRAIP, see Cissel et al. (2012), specifically, pages 105-109 and page 126.

Diffuse drain points, stream crossings, and drain points that do not have an associated road surface flow path (i.e. orphan drain points, Appendix A) are not included in the ESI analysis, because these types of drain points do not behave in such a way that the ESI is a useful metric. Diffuse points represent a road segment that does not concentrate flow, and so does not pose a gully risk. Streams have their own, and often non-road related, controls on their propensity to incise, and so cannot be treated the same as other drain points. Orphan drain points have a contributing length of zero, and so have an ESI of zero, which throws off a meaningful average.

Center Horse Morrell-Trail Project Area

Existing Gullies

The Center Horse and Morrell/Trail project area has a medium to low incidence of road related gullies. There were 33 gullies observed during the course of the survey, with a total volume of 208 m^3 (272 yd^3, Table 17). There were 13 gullies that occurred only on the hillslope (44 m^3, 58 yd^3), four that occurred only on the fillslope (2 m^3, 3 yd^3), and ten that occurred on both the fillslope and hillslope below a drain point (131 m^3, 172 yd^3). All 33 gullies occurred in wet swales. Three gullies were no longer actively eroding, while 30 were actively eroding. Figure 37 shows the locations of the gullies in the western portion of the Center Horse area, as well as gully initiation risk information (see below).

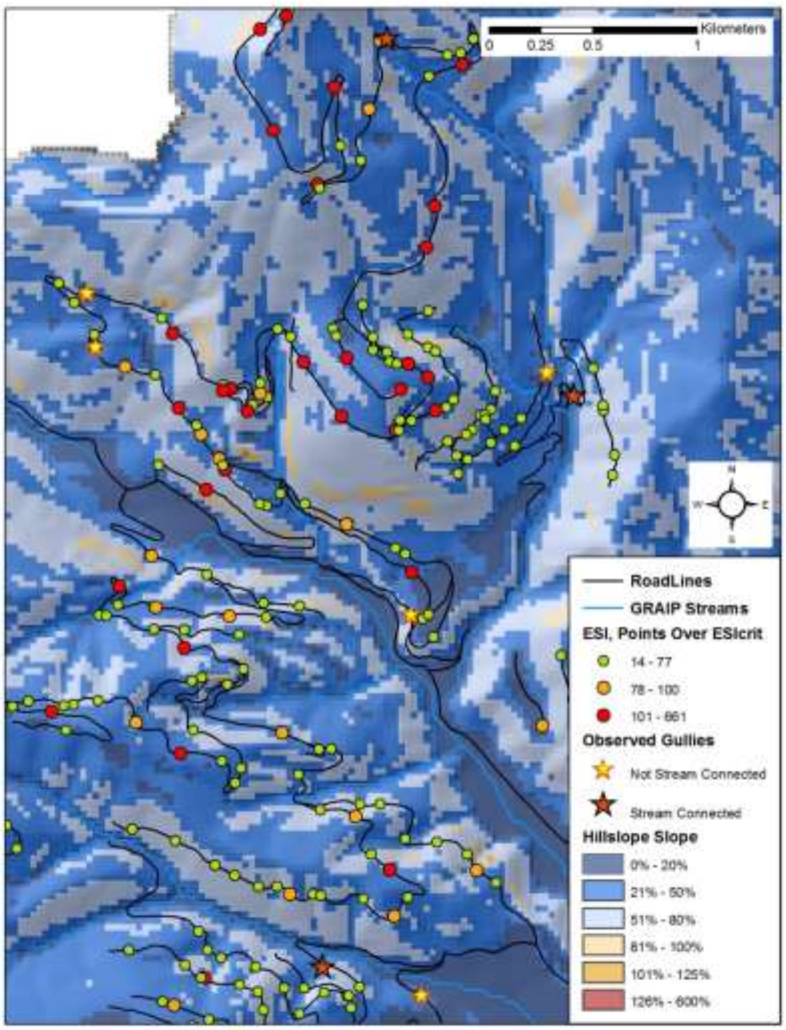


Figure 37. Locations of observed gullies and ESI risk at drain points, western portion of the Center Horse area.

There were ten gullies (30%) that were determined to be connected to the channel. Using a bulk density for road fill of 1.6 Mg/m^3 (Madej 2001), the mass of sediment generated at all connected gullies was 217 Mg (Table 18). This was 65% of the mass generated at all gullies. Over a 20 year period, 11 Mg/yr of sediment was delivered to stream channels, or roughly half of the rate of road surface fine sediment delivered to stream channels annually. It would take about ten years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from gullies. Actual annual sediment delivery from gullies is likely higher or lower than these estimates in any given year.

Table 17. *Inventoried gullies in the Center Horse and Morrell/Trail project area.*

Location of Gully / *Activity of Gully*	Count	Volume (yd^3)	Volume (m^3)	Number That Occur in Wet Swale	Average Delivery Rate Over 20 Years (Mg/yr)
Above Road	**6**	**39**	**30**	**6**	**0**
Not Active	*1*	*1.8*	*1.4*	*1*	*0*
Still Eroding	*5*	*38*	*29*	*5*	*0*
Fillslope	**4**	**2.7**	**2.1**	**4**	**9**
Not Active	*2*	*1.3*	*1.0*	*2*	*9*
Still Eroding	*2*	*1.4*	*1.1*	*2*	*0*
Hillslope	**13**	**58**	**44**	**13**	**0**
Still Eroding	*13*	*58*	*44*	*13*	*0*
Fill and Hill	**10**	**172**	**131**	**10**	**2**
Still Eroding	*10*	*172*	*131*	*10*	*2*
Totals	**33**	**272**	**208**	**33**	**11**

Table 18. *Sediment masses produced and delivered by active gullies in the Center Horse and Morrell/Trail project area.*

	Mass Produced (Mg)	Mass Delivered (Mg)	% Sediment Delivery	Average Delivery Rate Over 20 Years (Mg/yr)
Fillslope	3	0	0%	0
Hillslope	71	45	64%	2
Fillslope and Hillslope	210	172	82%	9
Totals	**332**	**217**	**65%**	**11**

Gully Initiation Risk

The ESI_{crit} was empirically derived for the Center Horse and Morrell/Trail project area using inventoried gullies, and is the ESI value above which the risk of gully formation increases significantly (Figure 38). Here, ESI_{crit} = 14, as the risk of gully formation roughly doubles above that value (Table 19). There was one orphan drain point with a gully, and seven gullies without an associated drain point.

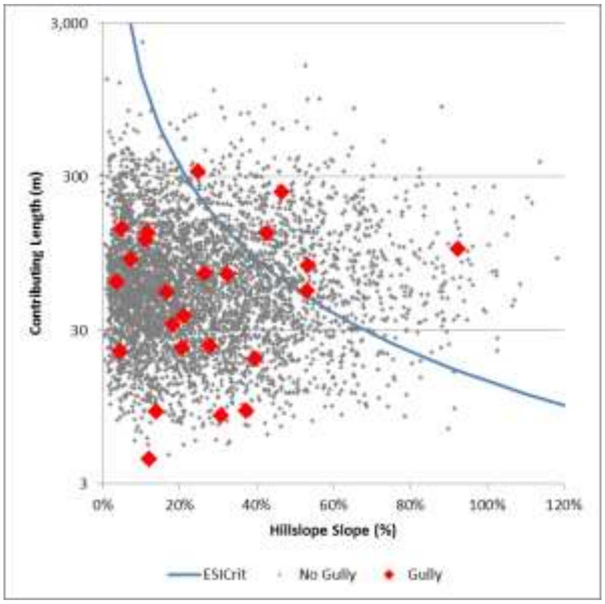


Figure 38. Length-slope plot that shows the distribution of gullied and non-gullied drain points. Notice that there are more non-gullied points towards the center of the graph. As the ESI gets larger (upper right part of the distribution), there are fewer non-gullied points, but there are relatively more gullied points. Above the blue ESI_{crit} = 14 line, there is a 1.0% chance of a point being gullied, while below the ESI_{crit} line, there is a 0.5% chance.

The average ESI across the Center Horse and Morrell/Trail project area was 9, with an average contributing road length of 85 m (280 ft, Table 20). There were 587 (16%) non-diffuse non-stream crossing non-orphan drain points where ESI exceeded ESI_{crit}, leaving 3126 drain points (84%) with an ESI value below the threshold. Of the drain points with gullies, six (26%) had an ESI value in excess of ESI_{crit}. This leaves 17 gullied drain points (74%) with an ESI that fell under the critical threshold. The gully rate for all points above ESI_{crit} was 1.0%, and it was 0.5% for points below ESIcrit (Table 19). Drain points that had gullies drained 1.8 km (1.1 mi) of road length. The average ESI of drain points with gullies was 11, while the average ESI of drain points without gullies was 9. The average contributing length at drain points with gullies was 77 m (250 ft), and similarly 85 m (280 ft) at drain points without gullies. Figure 37 shows the distribution of gully risk in the western portion of the Center Horse area.

Table 19. *Distribution of drain points by ESI value, Center Horse and Morrell/Trail project area.* ESI_{crit} *= 14. Eight observed gullies did not have an associated drain point or occurred below an orphan drain point, and so are not counted.*

	< ESIcrit	> ESIcrit		
ESI Value	**< 14**	**14 - 50**	**50 - 100**	**> 100**
# Sites With Gullies	17	4	2	0
# Sites Without Gullies	3109	440	106	35
% of Total With Gullies	74%	17%	9%	0%
% of Total Without Gullies	84%	12%	3%	1%
Gully Rate (# Gullied / # Total in %)	0.5%	1.0%		

Table 20. *Further distribution information of drain points by ESI value.*

	Contributing Length (m)		Average ESI	Where ESI > ESIcrit		Total Number
	Total	**Average**		**Total**	**Percent**	
Drain Points With Gullies	1770	77	11	6	26%	23
Drain Points Without Gullies	315,070	85	9	581	16%	3690
All Drain Points	316,840	85	9	587	16%	3713

Poorman Creek

Existing Gullies

The Poorman Creek area has a low incidence of road related gullies. There were four gullies observed during the course of the survey, with a total volume of 151 m^3 (197 yd^3, Table 21). There were two gullies that occurred only on the hillslope (150 m^3, 196 yd^3), and two that occurred only on the fillslope (0.7 m^3, 0.9 yd^3). No gullies occurred in wet swales. The gullies located on the hillslope were no longer actively eroding, while both gullies that occurred on the fillslope were actively eroding. Figure 39 shows the locations of the gullies in the central portion of the Poorman Creek area, as well as gully initiation

Table 21. *Inventoried gullies in the Poorman Creek area.*

Location of Gully / *Activity of Gully*	Count	Volume (yd^3)	Volume (m^3)	Number That Occur in Wet Swale	Average Delivery Rate Over 20 Years (Mg/yr)
Fill and Hill	**1**	**0.3**	**0.2**	**0**	**0.02**
Still Eroding	*1*	*0.3*	*0.2*	*0*	*0.02*
Fillslope	**4**	**9**	**7**	**0**	**0.2**
Still Eroding	*4*	*9*	*7*	*0*	*0.2*
Hillslope	**2**	**196**	**150**	**0**	**0**
Not Active	*2*	*196*	*150*	*0*	*0*
Totals	**7**	**206**	**157**	**0**	**0.2**

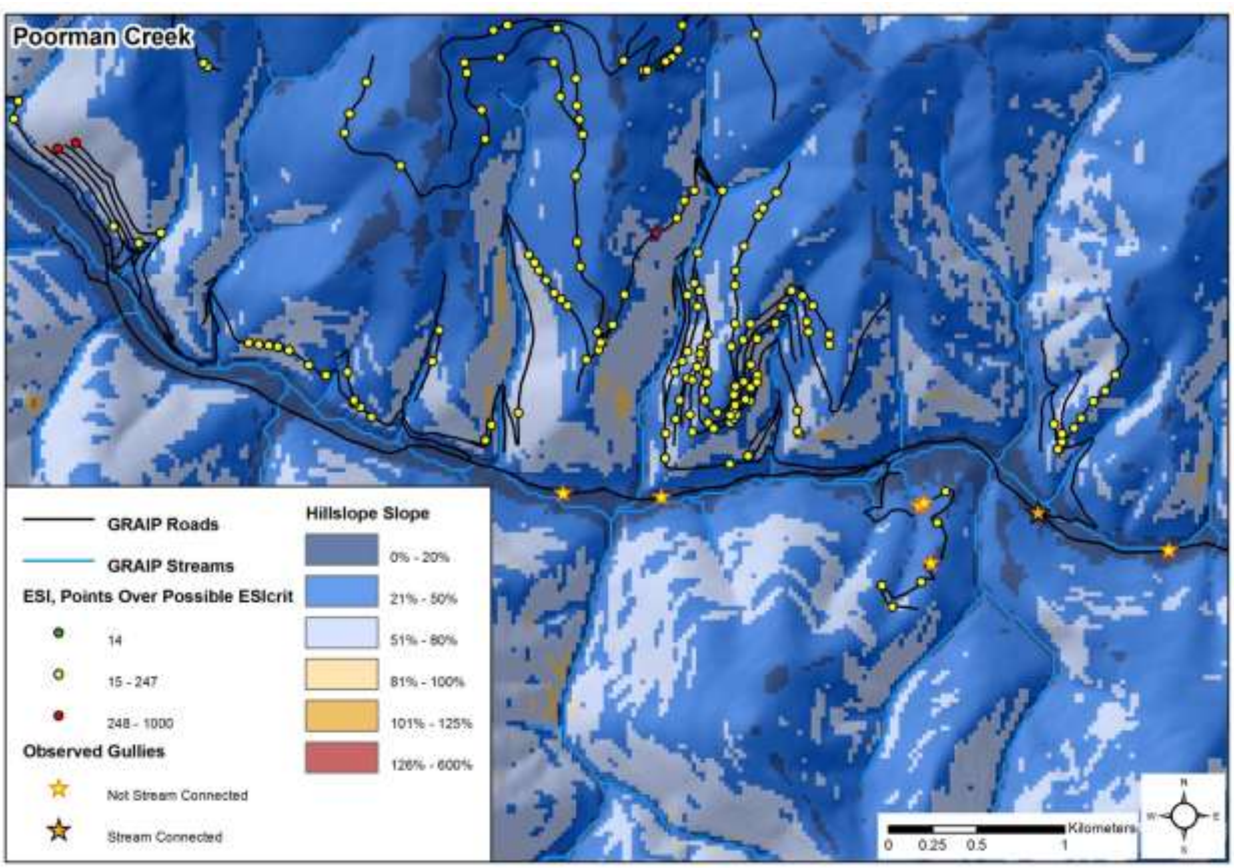


Figure 39. Locations of observed gullies and ESI risk at drain points, central portion of the Poorman Creek area.

risk information (see below). No gullies were determined to be connected to the channel. Using a bulk density for road fill of 1.6 Mg/m^3 (Madej 2001), the mass of sediment generated at all gullies was 241 Mg.

There were two gullies (29%) that were determined to be connected to the channel. Using a bulk density for road fill of 1.6 Mg/m^3 (Madej 2001), the mass of sediment generated at all connected gullies was 4 Mg (Table 22). This was 2% of the mass generated at all gullies. Over a 20 year period, 0.2 Mg/yr of sediment was delivered to stream channels, which is insignificant compared to the rate of road surface fine sediment delivered to stream channels annually. It would take less than one year for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from gullies. Actual annual sediment delivery from gullies is likely higher or lower than these estimates in any given year.

Table 22. *Sediment masses produced and delivered by active gullies in the Poorman Creek area.*

	Mass Produced (Mg)	Mass Delivered (Mg)	% Sediment Delivery	Average Delivery Rate Over 20 Years (Mg/yr)
Fillslope	11	4	31%	0.2
Hillslope	240	0	0%	0
Fillslope and Hillslope	0.3	0.3	100%	0.02
Totals	**252**	**4**	**2%**	**0.2**

Gully Initiation Risk

In the Poorman Creek area, there were too few gullies to determine an ESI_{crit}, suggesting that the gully initiation risks here may be very low. The average ESI across the Poorman Creek area was 8, with an average contributing road length of 79 m (259 ft, Table 23). Drain points that had gullies drained 1.2 km (0.8 mi) of road length. Figure 39 shows the distribution of gully risk in the central portion of the Poorman Creek area.

Table 23. *Drain point and ESI statistics for the Poorman Creek area*

	Contributing Length (m)		Average ESI	Total Number
	Total	Average		
Drain Points With Gullies	1222	204	5	6
Drain Points Without Gullies	172864	79	8	2184
All Drain Points	174086	79	8	2190

Cold Creek

Existing Gullies

The Cold Creek area has a low incidence of road related gullies. There were three gullies observed during the course of the survey, with a total volume of 5 m^3 (7 yd^3, Table 24). There were two gullies that occurred only on the hillslope (4 m^3, 5 yd^3), and two that occurred only on the fillslope (2 m^3, 2 yd^3). No gullies occurred in wet swales. All gullies were actively eroding. Figure 40 shows the locations of the gullies in the Cold Creek area, as well as gully initiation risk information (see below). No gullies were determined to be connected to the channel. Using a bulk density for road fill of 1.6 Mg/m^3 (Madej 2001), the mass of sediment generated at all gullies was 9 Mg.

Table 24. *Inventoried gullies in the Cold Creek area.*

Location of Gully / *Activity of Gully*	**Count**	**Volume (yd3)**	**Volume (m3)**	**Mass Produced (Mg)**	**% Sediment Delivery**	**Number That Occur in Wet Swale**
Fillslope	**1**	**2**	**2**	**2**	**0%**	**0**
Still Eroding	*1*	*2*	*2*	*2*	*0%*	*0*
Hillslope	**2**	**5**	**4**	**6**	**0%**	**0**
Still Eroding	*2*	*5*	*4*	*6*	*0%*	*0*
Totals	**3**	**7**	**5**	**9**	**0%**	**0**

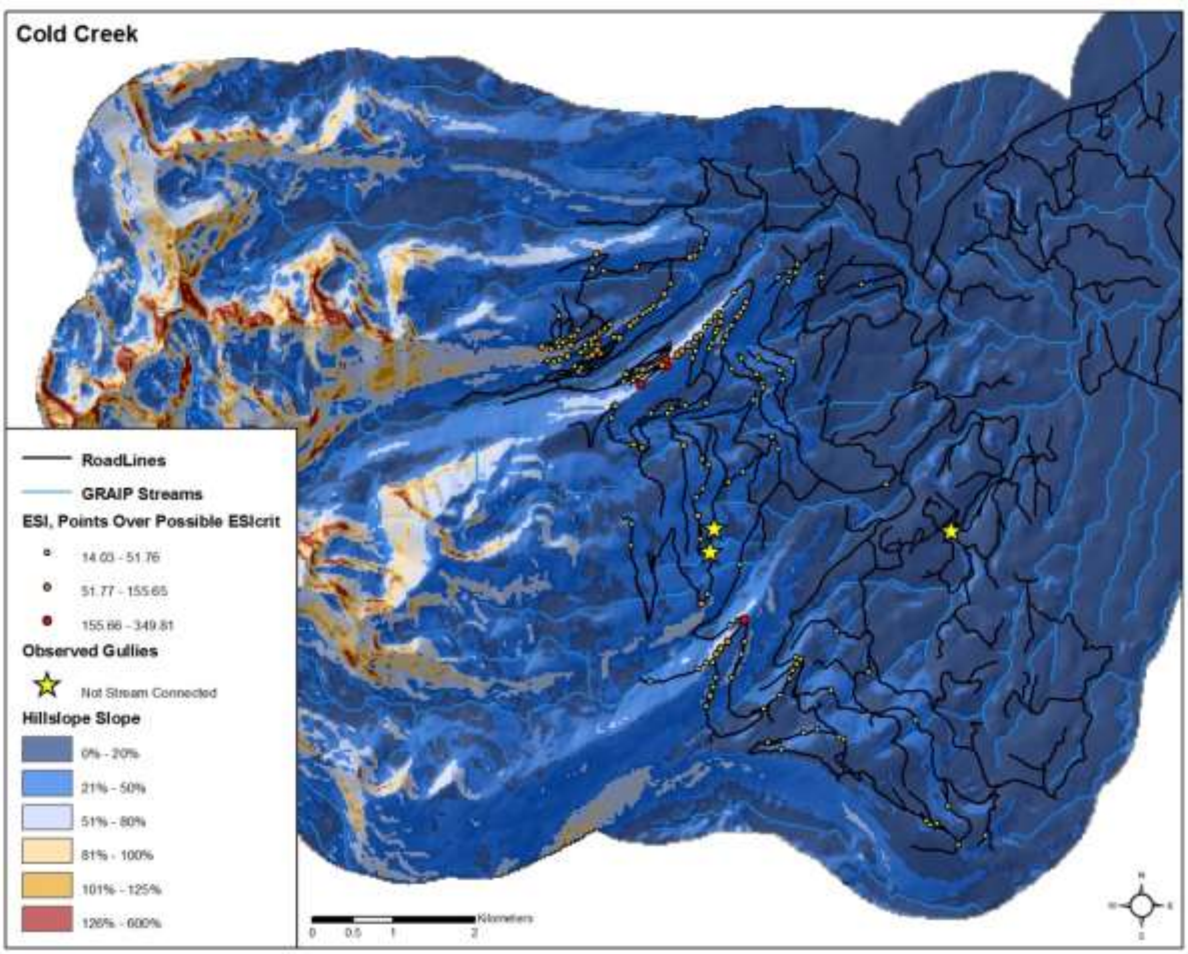


Figure 40. Locations of observed gullies and ESI risk at drain points, central portion of the Cold Creek area.

Gully Initiation Risk

In the Cold Creek area, there were too few gullies to determine an ESI_{crit}, suggesting that the gully initiation risks here may be very low. The average ESI across the Cold Creek area was 4, with an average contributing road length of 55 m (180 ft, Table 25). Drain points that had gullies drained 0.2 km (0.1 mi) of road length. Figure 40 shows the distribution of gully risk in the Cold Creek area.

Table 25. *Drain point and ESI statistics for the Cold Creek area.*

	Contributing Length (m)		Average ESI	Total Number
	Total	Average		
Drain Points With Gullies	157	52	4.3	3
Drain Points Without Gullies	197,699	55	4.0	3581
All Drain Points	197,856	55	4.0	3584

4.6 Stream Crossing Failure Risk

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

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

Another consequence of concern at failed stream crossings is the diversion of stream flow onto road surfaces and unchanneled hillslopes. Once a crossing becomes occluded and begins to act as a dam, failure can occur in one of 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 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. 1997, Best et al. 1995). In these situations, volumes of sediment far exceeding those at the crossing can be at risk. GRAIP addresses this issue by classifying the potential for stream crossings to divert streamflow down the adjacent road as: no potential, potential to divert in one direction, or potential to divert in two directions.

The highest risk crossings in these areas have high SBI and diversion potential in one or both directions. These are generally the crossings that should be addressed first.

Center Horse Morrell-Trail Project Area

Field crews recorded 150 stream crossings in the Center Horse and Morrell/Trail project area. Only the 116 crossings with a culvert were included in the SBI calculations. The 34 crossings that did not have a culvert were bridges (seven crossings), were natural fords (23), or were excavated crossings (four), and were not included. Risk of pipe plugging is not a factor at these crossings.

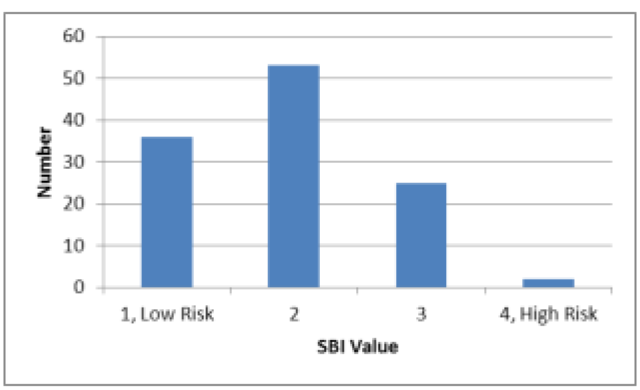
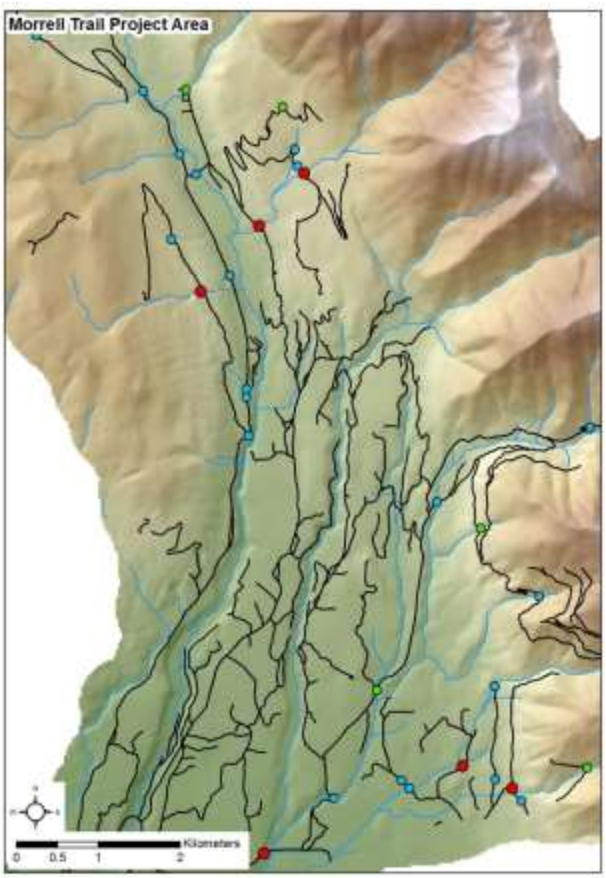


Figure 41. Distribution of SBI values for the Center Horse and Morrell/Trail project area.

The SBI values for the Center Horse and Morrell/Trail project area had an average of 1.9 for the 116 stream crossings. There were two stream crossings with an SBI of 4, 25 crossings with an SBI of 3, 53 crossings with an SBI of 2, and 36 crossings with an SBI of 1 (Figure 41). Of the crossings with values of three and four, 24 of 27 had a pipe diameter to channel width ratio of 0.5 or less (small pipe, large stream), and 14 had a pipe that was 1/3 or less than the width of the stream, and seven pipes were partially or totally blocked. Six crossings with an SBI of 2 had a pipe that was half the width of the channel.

The total fill volume at risk for all the stream crossings was 6844 m^3 (8951 yd^3). Fill volumes ranged from 5 m^3 (7 yd^3) to 875 m^3 (1144 yd^3), and had a mean volume of 60 m^3 (78 yd^3). This is similar to previous findings for the middle Blackfoot River at 38 stream crossings, which had an average of 116 tons of fill per crossing (Montana Department of Environmental Quality 2008). Overtopping-type fill failure will not occur at bridges, so no fill volume risk was calculated at these locations. In the Center Horse and Morrell/Trail project area, 55 of 146 stream crossings (38%) had the potential to divert streamflow down the road in one or more directions. Bridges also had no diversion potential.



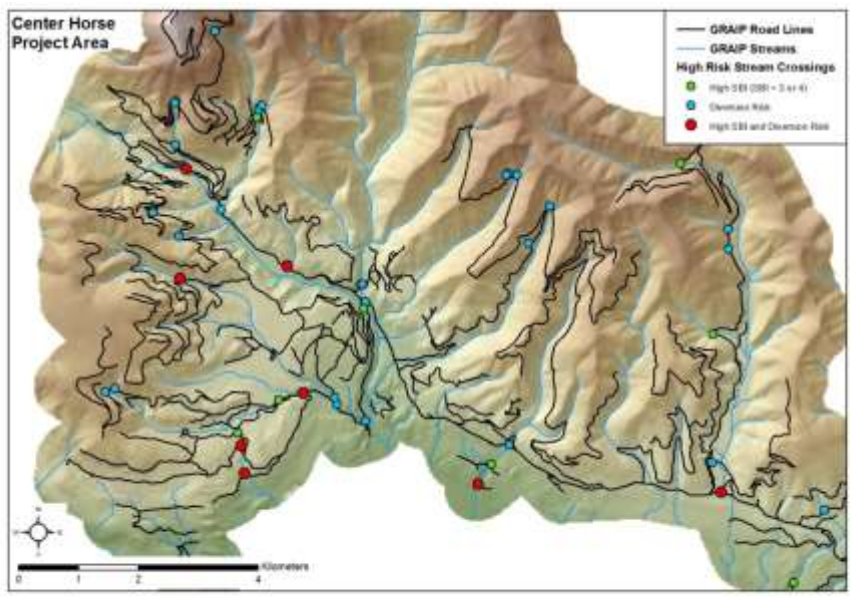


Figure 42. The stream crossings with the highest risk of plugging and the most severe consequences of failure in the Center Horse and Morrell/Trail project area.

There were 14 crossings with an SBI of 3 or 4 and diversion potential (Figure 42). There was a total of 824 m^3 (1077 yd^3) of fill at risk at these points. Two have more than 100 m^3 of fill at risk, and four had some major issue (e.g. observed overtopping) or were at imminent risk of a major issue (e.g. partial blockage or sediment plume moving downstream to the pipe). These crossings should have the highest priority for risk reduction treatments. The 13 crossings with a high SBI but no diversion had 1028 m^3

(1345 yd^3) of fill at risk, and the 47 crossings with diversion but a low SBI had 1835 m^3 (2400 yd^3) of fill at risk.

Several stream crossings were observed to have overtopped or diverted flow in the course of the survey. Two crossings, along road 4353 (Morrell Creek) and road 602 (Shanley Creek), were plugged by sediment, but the water from both diversions infiltrated before connecting to a stream. These crossings had SBIs of 1 and 2. One crossing, along road 17506 (Blind Canyon Creek), was plugged by sediment and connected, but had minimal erosion and had an SBI of 2. Two crossings, along road 16654 (connecting Morrell Creek roads with Trail Creek roads) and along road 4359 (minor Morrell Creek tributary), were plugged by sediment and delivered to a stream, but had minimal erosion. These crossings had SBI values of 3 and 4 (orange dots on Figure 42). One diversion, along road 56079 (Spring Creek, Figure 43), was plugged by wood and diverted roughly 100 m down the road. The resulting erosion of the road surface delivered about 910 ft^3 (25.6 m^3, 41.0 Mg) to Spring Creek (accounted for in the fill erosion piece, Section 4.7). That particular crossing pipe had an SBI value of 3 (orange dot on Figure 42). The diversion was repaired by a passing fire crew.

Figure 43. Spring Creek diversion that delivered 41 Mg of sediment to the stream.

Poorman Creek

Field crews recorded 53 stream crossings in the Poorman Creek area. Only the 29 crossings with a culvert were included in the SBI calculations. The 24 crossings that did not have a culvert were bridges (eight crossings) or were natural fords (16) and were not included. Risk of pipe plugging is not a factor at these crossings.

The SBI values for the Poorman Creek area had an average of 1.7 for the 29 stream crossings. There were no stream crossings with an SBI of 4, five crossings with an SBI of 3, nine crossings with an SBI of 2, and 15 crossings with an SBI of 1 (Figure 44). All five of the crossings with values of three had a pipe diameter to channel width ratio of 0.4 or less (small pipe, large stream), and two had a pipe that was 1/3 or less than the width of the stream. Two crossings with an SBI of 2 had a pipe that was half the width of the channel.

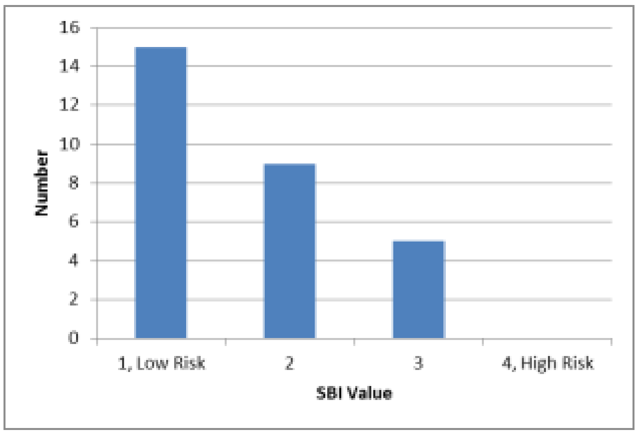


Figure 44. Distribution of SBI values for the Poorman Creek area.

The total fill volume at risk for all the stream crossings was 1399 m^3 (1830 yd^3). Fill volumes ranged from 6 m^3 (8 yd^3) to 318 m^3 (416 yd^3), and had a mean volume of 48 m^3 (63 yd^3). This is similar to previous findings for the middle Blackfoot River at 38 stream crossings, which had an average of 116 tons of fill per crossing (Montana Department of Environmental Quality 2008). Overtopping-type fill failure will not occur at bridges, so no fill volume risk was calculated at these locations. In the Poorman Creek area, eight of 53 stream crossings (15%), including three natural fords, had the potential to divert streamflow down the road in one or more directions. Bridges also had no diversion potential.

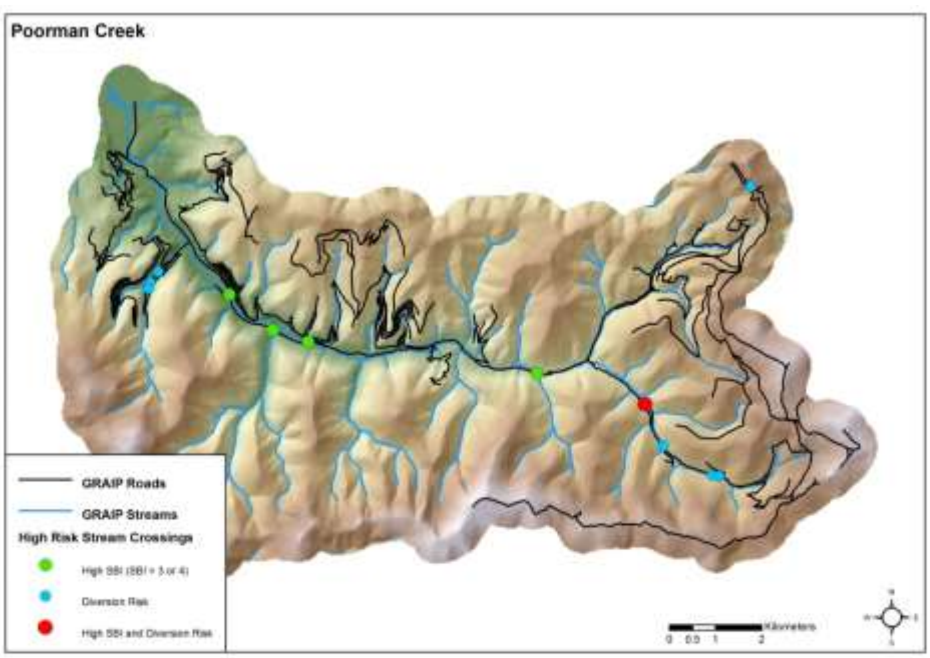


Figure 45. The stream crossings with the highest risk of plugging and the most severe consequences of failure in the Poorman Creek area.

There was one crossing with an SBI of 3 and diversion potential (Figure 45). There was a total of 21 m^3 (27 yd^3) of fill at risk at this point. There were no problems already apparent at this location. The three crossings with a high SBI but no diversion had 582 m^3 (761 yd^3) of fill at risk, and the seven crossings with diversion but a low SBI had 142 m^3 (186 yd^3) of fill at risk.

There were two natural ford type crossings in the western portion of the Poorman Creek area on road 1842-A2 that were observed to divert flow down the road, though no major erosion was observed at the time of the survey (Figure 46).

Figure 46. Stream diversion at a natural ford in the western portion of the Poorman Creek area. No major erosion was observed.

Cold Creek

Field crews recorded 115 stream crossings in the Cold Creek area. Only the 71 crossings with a culvert were included in the SBI calculations. The 42 crossings that did not have a culvert were bridges (six crossings), natural fords (36) or log culverts (two) and were not included. Risk of pipe plugging is not a factor at bridges and fords, and log culverts are generally considered to be blocked by design.

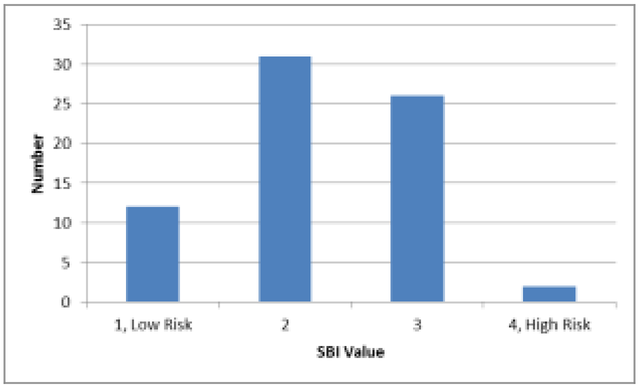


Figure 47. Distribution of SBI values for the Cold Creek area.

The SBI values for the Cold Creek area had an average of 2.3 for the 71 stream crossings. There were two stream crossings with an SBI of 4, 26 crossings with an SBI of 3, 31 crossings with an SBI of 2, and 12 crossings with an SBI of 1 (Figure 47). Of the 26 crossings with an SBI of 3, 17 had a pipe diameter to channel width ratio of 0.5 or less (small pipe, large stream), and five had a pipe that was 1/3 or less than the width of the stream. Nine crossings with an SBI of 2 had a pipe that was half the width of the channel.

The total fill volume at risk for all the stream crossings was 2095 m^3 (2740 yd^3). Fill volumes ranged from 4 m^3 (5 yd^3) to 268 m^3 (351 yd^3), and had a mean volume of 31 m^3 (41 yd^3). This is similar to previous findings for the nearby middle Blackfoot River at 38 stream crossings, which had an average of 116 tons

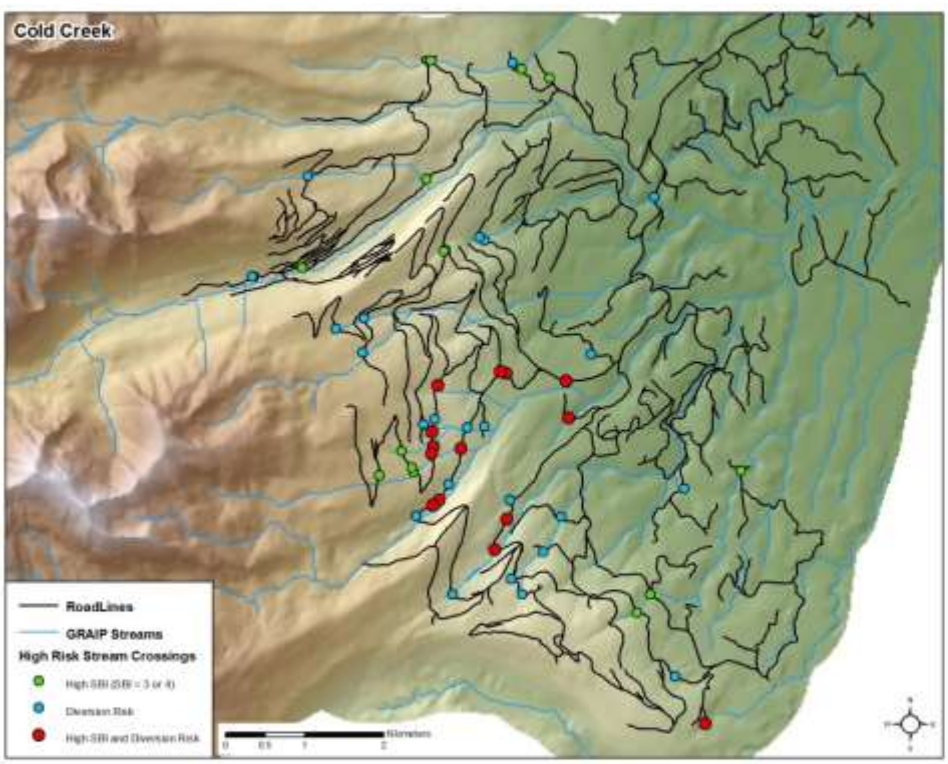


Figure 48. The stream crossings with the highest risk of plugging and the most severe consequences of failure in the Cold Creek area.

of fill per crossing (Montana Department of Environmental Quality 2008). Overtopping-type fill failure will not occur at bridges, so no fill volume risk was calculated at these locations. In the Cold Creek area, 39 of all 115 stream crossings (34%), had the potential to divert streamflow down the road in one or more directions.

There were 14 crossings with an SBI of 3 or 4 and diversion potential (Figure 48). There was a total of 332 m^3 (434 yd^3) of fill at risk at this points. Of those 14 crossings, half received the stream flow from the ditch, though this appeared to be intentional (streams were intercepted by the ditch and discharged through the next culvert down road 90509). No other problems were already apparent at these locations. The 14 crossings with a high SBI but no diversion had 427 m^3 (558 yd^3) of fill at risk, and the 25 crossings with diversion but a low SBI had 234 m^3 (306 yd^3) of fill at risk.

4.7 Drain Point Condition and Fill Erosion

The GRAIP inventory involves an assessment of the condition of each drain point and a determination of how well it is performing its intended function. Problems with drain point condition are pre-defined for each drain type. Broad based dips are considered to be in poor condition if they are insufficiently outsloped and pond water on the road. Culverts are defined to be in poor condition if they have more than 20% occlusion of the inlet by sediment, substantial inlet crushing, significant rust, or flow around the pipe. Lead off ditches are considered problematic if they have excess deposition or gullying. Non-engineered features are almost always a problem due to a blocked ditch, a gully, or a broken outside berm, but are not considered problematic if they occur due to an outsloped road and do not have any fill erosion. Stream crossings culverts are considered a problem if they are blocked by sediment or wood, crushed or rusted significantly, incising, scouring, losing much water from flow around the pipe, or have a high SBI with diversion potential (see Section 4.6 for more detail on SBI and diversion). 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.

If a drain point is observed to have fill erosion, the volume is estimated. Fill erosion can be determined to be connected to the stream channel network if its associated drain point is connected to the channel. This mass of sediment may be pulsed (if the fill failure happens at once), chronic (if the fill gradually erodes), or pulsed and then chronic (initial failure, followed by more gradual erosion); it is unknown what proportion of this mass belongs to each category. Delivered masses of fill erosion are distributed over a 20 year time span in order to compare their magnitude with that of the road surface fine sediment (a chronic sediment source). Twenty years is used because, in most places, that is roughly the maximum age of a feature still easily observable in the field. In any given year, the amount of sediment delivered to streams from gullies is likely to be higher or lower than the rate we calculate.

Table 26. *Drain point condition problems and fill erosion below drain points, Center Horse and Morrell/Trail project area.*

Drain Type	Count	Problems		Fill Erosion	
		Number	% of Total	Number	% of Total
Broad Based Dip	1413	387	27%	6	0.4%
Diffuse Drain	931	0	0%	13	1%
Ditch Relief Culvert	392	155	40%	11	3%
Excavated Stream Crossing	4	0	0%	0	0%
Lead Off Ditch	135	1	0.7%	0	0%
Non-Engineered Drain	1102	113	10%	28	3%
Stream Crossing	146	44	30%	4	3%
Sump	24	11	46%	0	0%
Water Bar	914	100	11%	21	2%
All Drains	**5061**	**811**	**16%**	**83**	**2%**

Center Horse Morrell-Trail Project Area

Within the Center Horse and Morrell/Trail project area, 16% of all drain points (811 of 5061) had one or more problem of some type (Table 26; Figures 49 and 50). Sumps had the highest rate of problems (11 of 24, 46%), followed by ditch relief culverts (155 of 392, 40%), stream crossings (44 of 146, 30%), and broad based dips (387 of 1413, 27%). Diffuse road segments (931 features total) and excavated stream crossings (four features total) did not have any problems. Water bars had problems at 100 of 914 locations (11%) and non-engineered drains had problems at 113 of 1102 locations (10%).

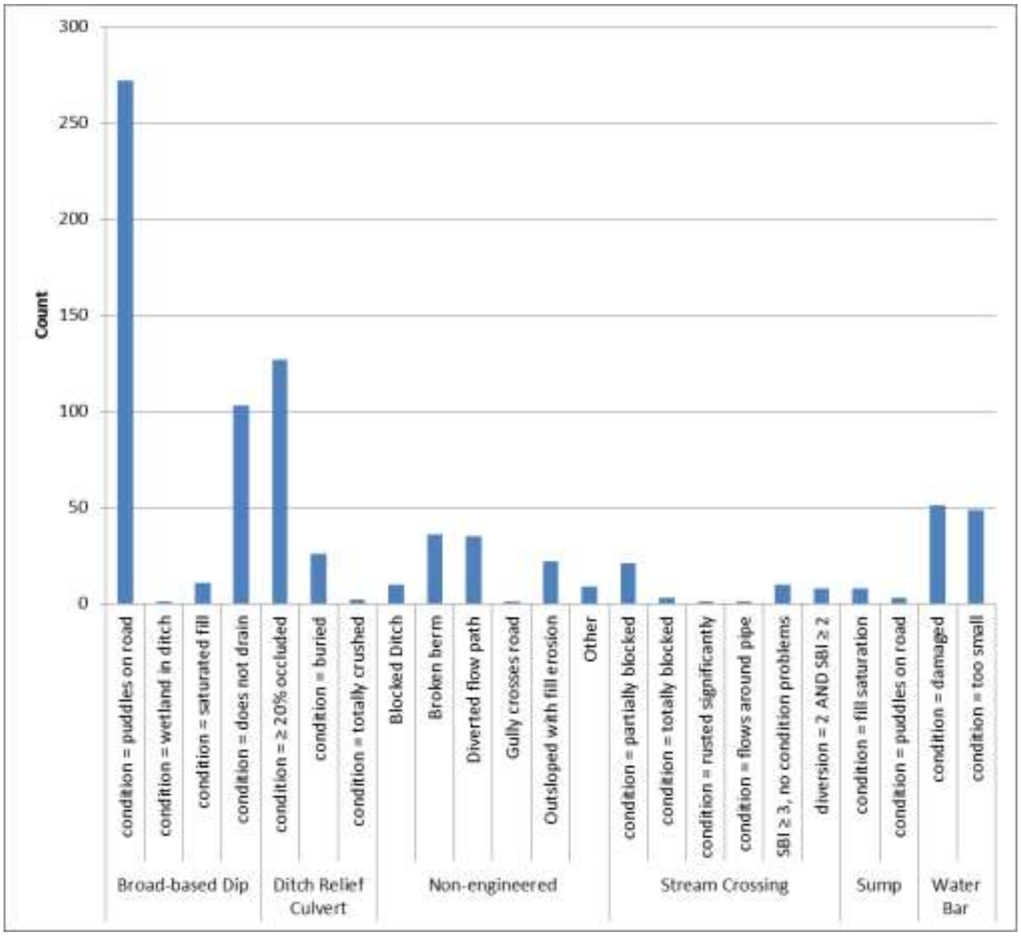


Figure 49. Specific drain point problems by drain type in the Center Horse and Morrell/Trail project area.

Fill erosion was present at 2% of all drain points, totaling 85 m^3 (3000 ft^3; Table 27). Fill erosion was most common at non-engineered drains, with 28 of 1102 (3%) eroding 23 m^3 (820 ft^3). Water bars had fill erosion at 21 of 914 locations (2%; 8 m^3; 280 ft^3); diffuse drains at 13 of 931 locations (1%; 2 m^3; 80 ft^3); and ditch relief culverts at 11 of 392 locations (3%; 4 m^3; 150 ft^3). Stream crossings had the most mass of fill erosion of 44 m^3 (1550 ft^3) eroded from four crossings. More than half of this mass was from the Spring Creek flow diversion. Using the same bulk density as above, fill erosion at drain points that were connected to the stream channel network totaled 87 Mg, most of which occurred at stream crossings (70 Mg) and non-engineered drains (13 Mg). This was 64% of the sediment produced by fill erosion at drain points. Over a 20 year period, 4.4 Mg/yr of sediment were delivered to stream channels, or roughly one quarter of the rate of road surface fine sediment delivered to stream channels annually. It would take about four years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from fill erosion. Actual annual sediment delivery from fill erosion is likely higher or lower than these estimates in any given year, and when the largest failures occur, they are often repaired and quickly become difficult to record accurately.

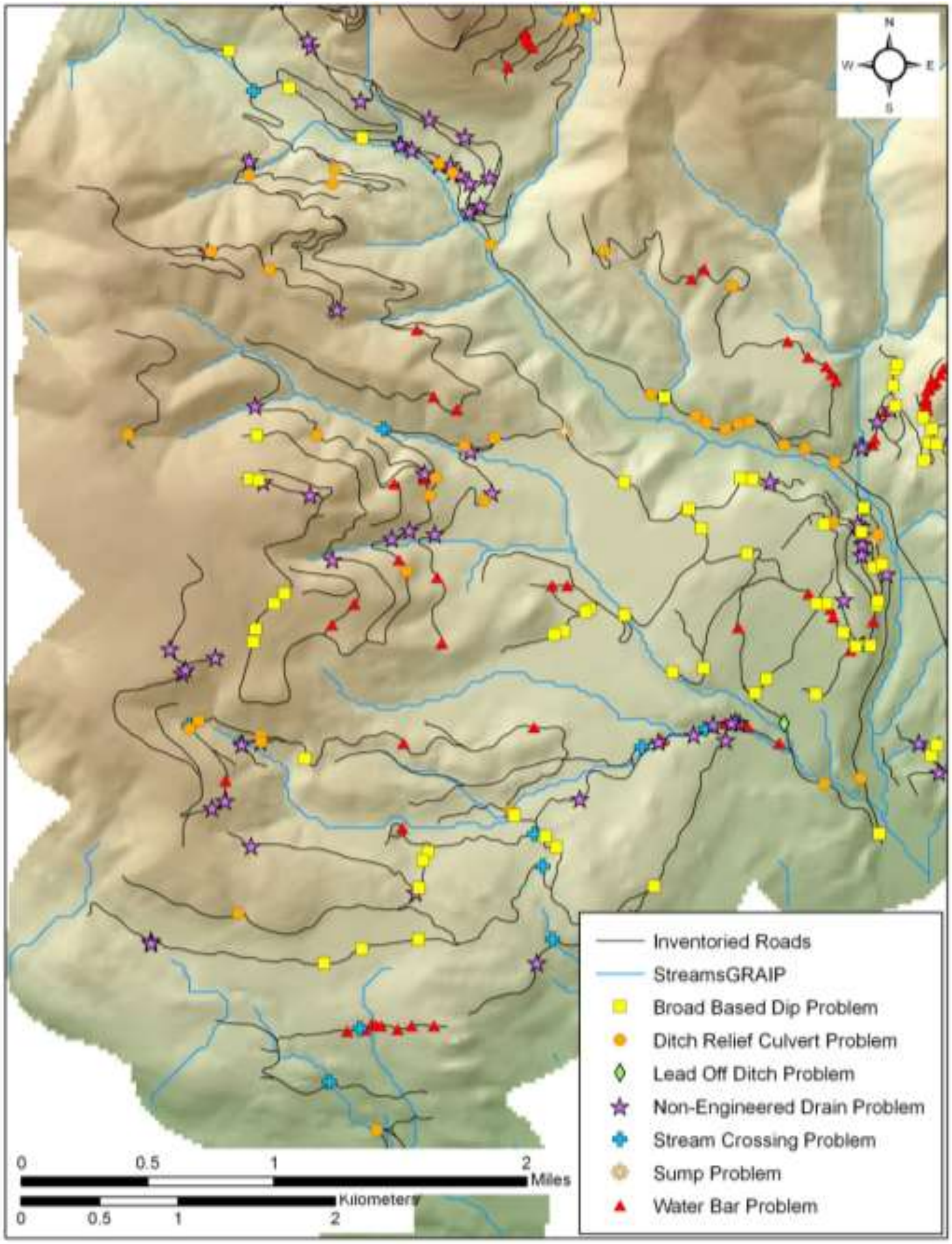


Figure 50. Drain point problems in the Spring Creek watershed.

Table 27. *Fill erosion below drain points, volumes and masses, Center Horse and Morrell/Trail project area.*

Drain Type	Count	Number With Fill Erosion	% of Total	Total Volume		Mass Sediment Produced (Mg)	Mass Sediment Delivered (Mg)	% Sediment Delivery	Average Delivery Rate Over 20 Years (Mg/yr)
				(m^3)	(ft^3)				
Broad Based Dip	1413	6	0.4%	4	140	6	2	30%	0.1
Diffuse Drain	931	13	1%	2	80	3	0	0%	0
Ditch Relief Culvert	392	11	3%	4	150	7	0.1	2%	0.01
Excavated Stream Crossing	4	0	0%	0	0	0	0	0%	0
Lead Off Ditch	135	0	0%	0	0	0	0	0%	0
Non-Engineered Drain	1102	28	3%	23	820	37	13	36%	1
Stream Crossing	146	4	3%	44	1550	70	70	100%	4
Sump	24	0	0%	0	0	0	0	0%	0
Water Bar	914	21	2%	8	280	13	2	15%	0.1
All Drains	**5061**	**83**	**2%**	**85**	**3000**	**136**	**87**	**64%**	**4**

Poorman Creek

Within the Poorman Creek area, 12% of all drain points (270 of 2190) had one or more problem of some type (Table 28; Figures 51 and 52). Ditch relief culverts had the highest rate of problems (18 of 56, 32%), followed by broad based dips (120 of 412, 29%); sumps had a rate of 50%, but there were only two

Table 28. *Drain point condition problems and fill erosion below drain points, Poorman Creek area.*

	Count	Problems		Fill Erosion	
		Number	% of Total	Number	% of Total
Broad Based Dip	412	120	29%	2	0.5%
Diffuse Drain	417	0	0%	1	0.2%
Ditch Relief Culvert	56	18	32%	1	2%
Lead Off Ditch	8	0	0%	0	0%
Non-Engineered Drain	693	63	9%	16	2%
Stream Crossing	53	7	13%	0	0%
Sump	2	1	50%	0	0%
Water bar	549	61	11%	2	0.4%
All Drains	**2190**	**270**	**12%**	**22**	**1%**

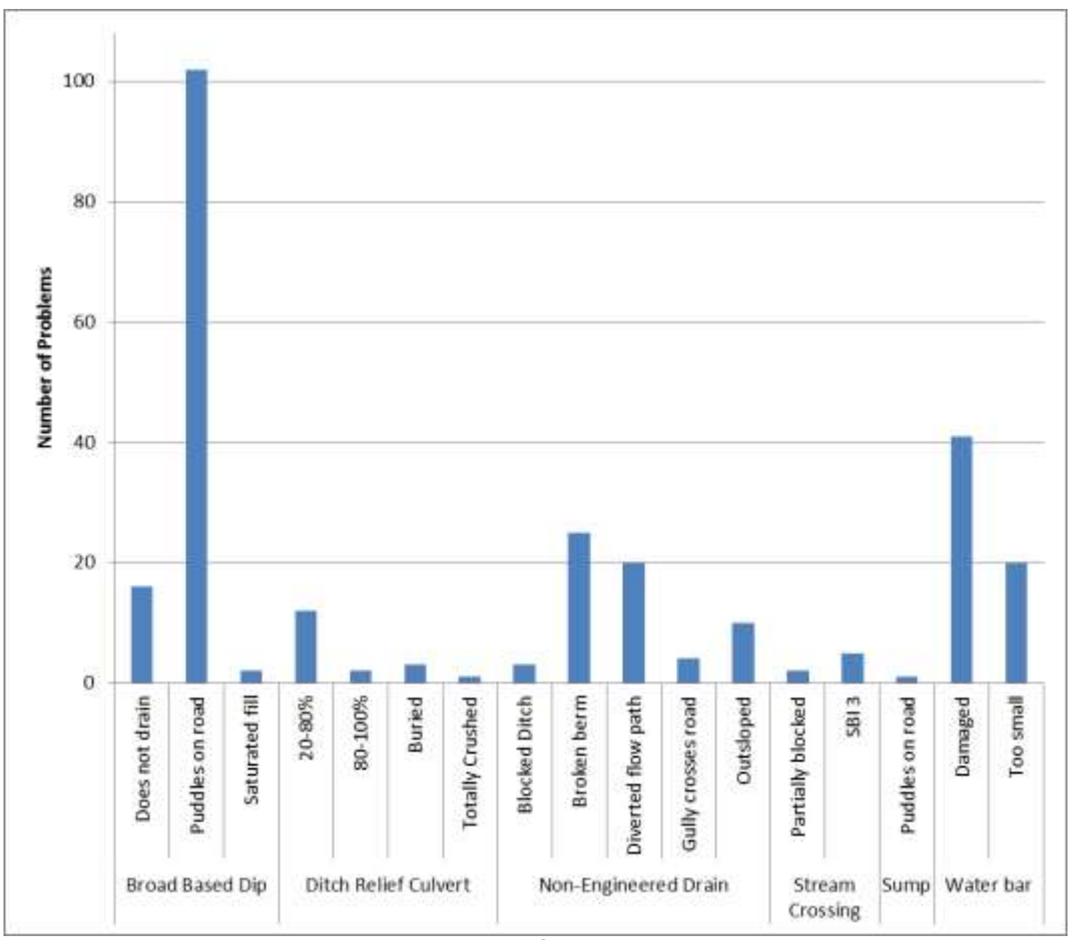


Figure 51. Specific drain point problems by drain type in the Poorman Creek area.

sumps recorded. Diffuse road segments (417 features total) and lead off ditches (eight features) did not have any problems. Stream crossings had problems at seven of 53 locations (13%), water bars had problems at 61 of 549 locations (11%) and non-engineered drains had problems at 63 of 693 locations (9%).

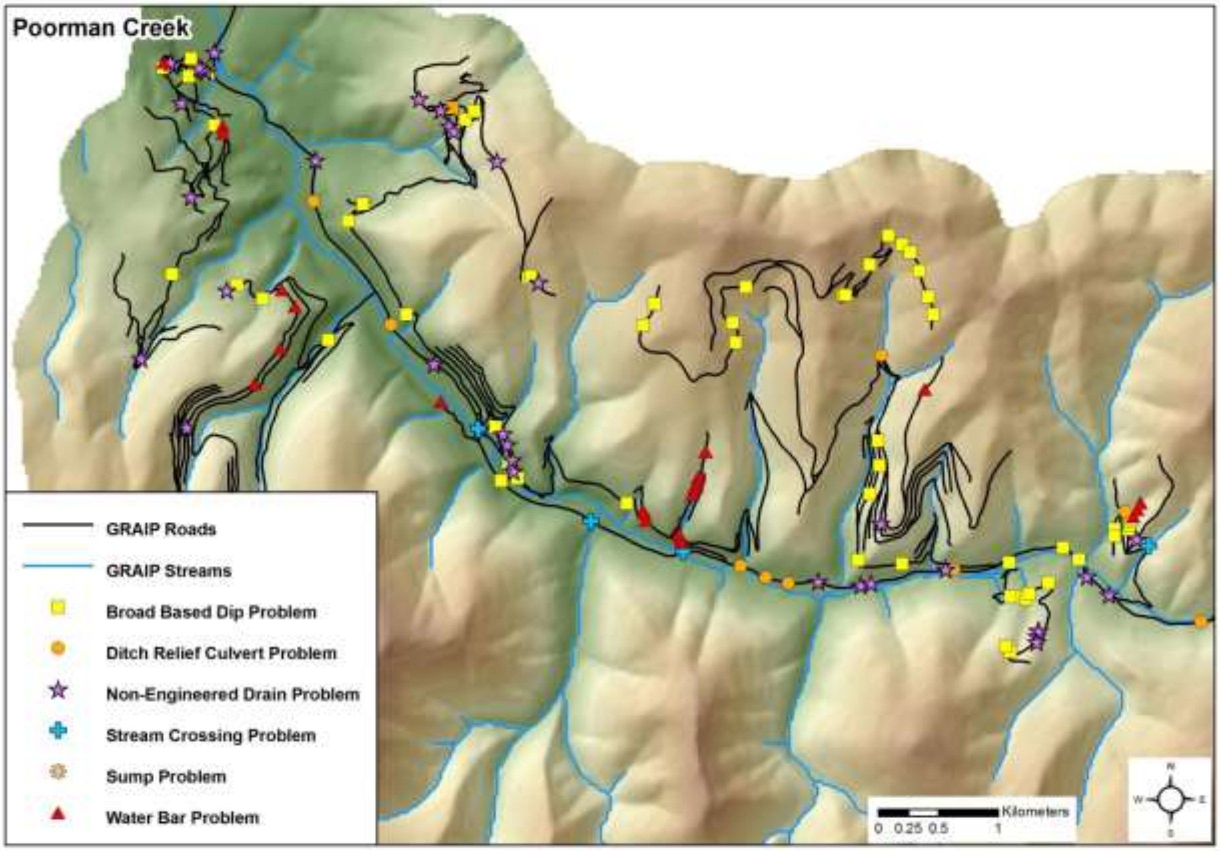


Figure 52. Drain point problems in the western half of the Poorman Creek area.

Table 29. *Fill erosion below drain points, volumes and masses, Poorman Creek area.*

Drain Type	Count	Number With Fill Erosion	% of Total	Total Volume		Mass Sediment Produced (Mg)	Mass Sediment Delivered (Mg)	% Sediment Delivery	Average Delivery Rate Over 20 Years (Mg/yr)
				(m³)	(ft³)				
Broad Based Dip	412	2	0.5%	1	50	2	0.5	20%	0.02
Diffuse Drain	417	1	0.2%	0.1	10	0.2	0	0%	0
Ditch Relief Culvert	56	1	2%	0.3	10	0.5	0	0%	0
Lead Off Ditch	8	0	0%	0	0	0	0	0%	0
Non-Engineered Drain	693	16	2%	8	300	13	3	22%	0.1
Stream Crossing	53	0	0%	0	0	0	0	0%	0
Sump	2	0	0%	0	0	0	0	0%	0
Water bar	549	2	0.4%	1	40	2	0	0%	0
All Drains	**2190**	**22**	**1%**	**11**	**400**	**18**	**3.4**	**19%**	**0.2**

Fill erosion was present at 1% of all drain points, totaling 11 m^3 (403 ft^3; Table 29). Fill erosion was most common at non-engineered drains, with 16 of 693 (2%) eroding 8 m^3 (296 ft^3). Water bars had fill erosion at two of 549 locations (0.4%; 1 m^3; 40 ft^3); broad based dips at two of 412 locations (0.5%; 1 m^3; 50 ft^3); and ditch relief culverts at 1 of 56 locations (2%; 0.3 m^3; 12 ft^3). Non-engineered drains had the most mass of fill erosion. Using the same bulk density as above, fill erosion at drain points that were connected to the stream channel network totaled 3.4 Mg, 3 Mg of which occurred at non-engineered drains. This was 19% of the sediment produced by fill erosion at drain points. Over a 20 year period, 0.2 Mg/yr of sediment were delivered to stream channels, which is negligible compared to other sources. Actual annual sediment delivery from fill erosion is likely higher or lower than these estimates in any given year, and when the largest failures occur, they are often repaired and quickly become difficult to record accurately.

Cold Creek

Within the Cold Creek area, 8% of all drain points (284 of 3584) had one or more problem of some type (Table 30; Figures 53 and 54). Stream crossings had the highest rate of problems (45 of 115, 39%), followed by ditch relief culverts (80 of 266, 30%). Diffuse road segments (670 features total), lead off

Table 30. *Drain point condition problems and fill erosion below drain points, Cold Creek area.*

Drain Type	Count	Problems		Fill Erosion	
		Number	% of Total	Number	% of Total
Broad Based Dip	1050	14	1%	18	2%
Diffuse Drain	670	0	0%	0	0%
Ditch Relief Culvert	266	80	30%	1	0.4%
Lead Off Ditch	139	0	0%	0	0%
Non-Engineered Drain	1097	127	12%	3	0.3%
Stream Crossing	115	45	39%	1	1%
Sump	1	0	0%	0	0%
Water Bar	246	18	7%	0	0%
All Drains	**3584**	**284**	**8%**	**23**	**1%**

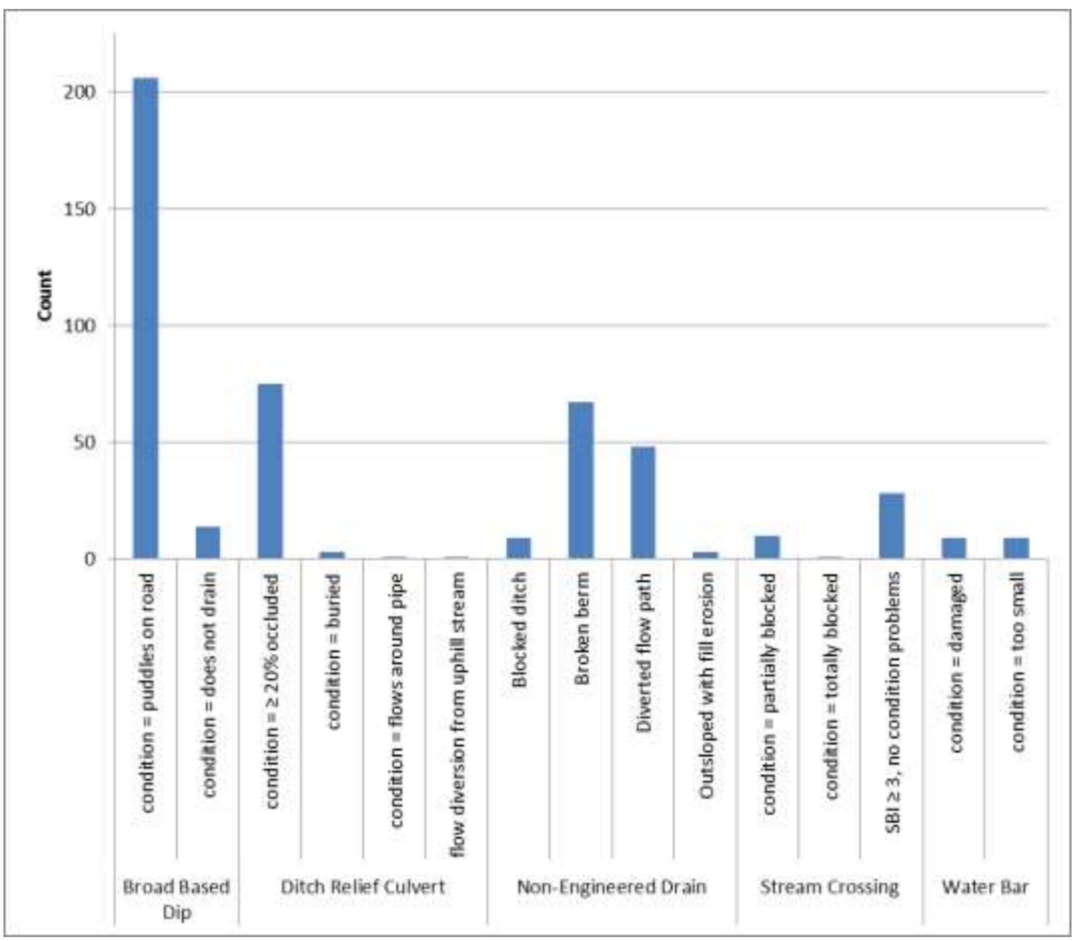


Figure 53. Specific drain point problems by drain type in the Cold Creek area.

ditches (139 features total), and sumps (one feature total) did not have any problems. Non-engineered drains had problems at 127 of 1097 locations (12%), water bars had problems at 18 of 246 locations (7%), and broad based dips had problems at 14 of 1050 locations (1%).

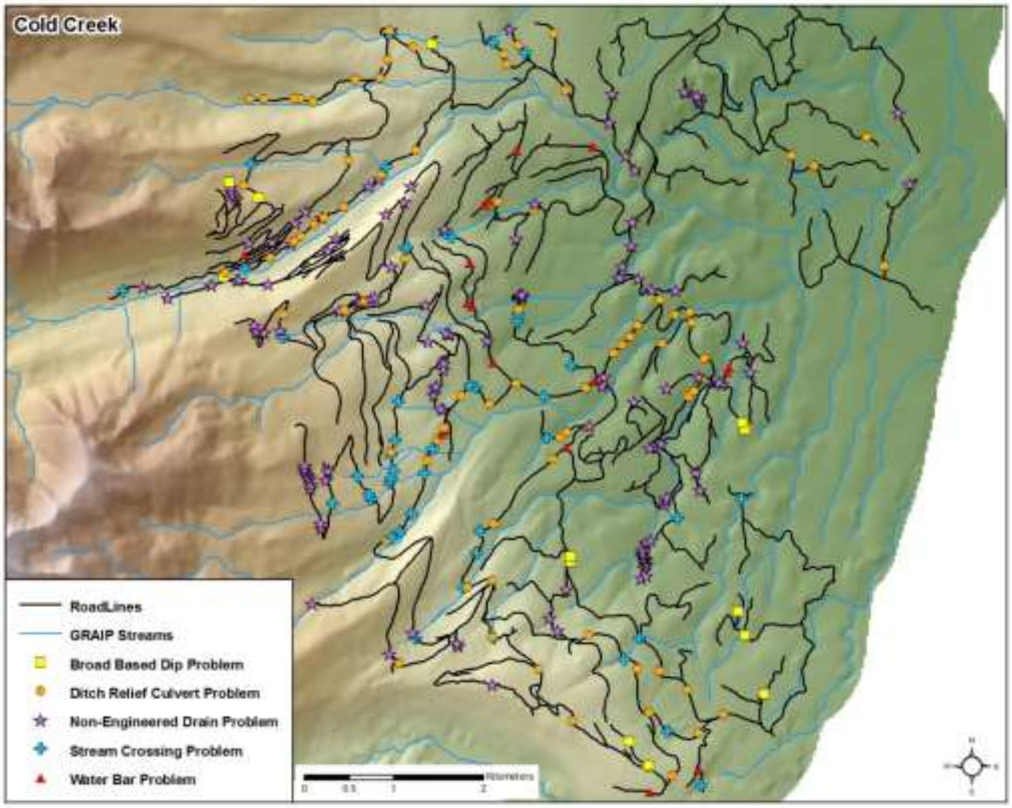


Figure 54. Drain point problems in the Cold Creek area.

Table 31. *Fill erosion below drain points, volumes and masses, Cold Creek area.*

Drain Type	Count	Number With Fill Erosion	% of Total	Total Volume (m3)	Total Volume (ft3)	Mass Sediment Produced (Mg)	Mass Sediment Delivered (Mg)	% Sediment Delivery	Average Delivery Rate Over 20 Years (Mg/yr)
Broad Based Dip	1050	18	2%	3	90	4	0	0%	0
Diffuse Drain	670	0	0%	0	0	0	0	0%	0
Ditch Relief Culvert	266	1	0.4%	0.03	1	0.05	0	0%	0
Lead Off Ditch	139	0	0%	0	0	0	0	0%	0
Non-Engineered Drain	1097	3	0.3%	0.4	20	1	0.2	33%	0.02
Stream Crossing	115	1	1%	0.2	10	0.3	0.3	100%	0.05
Sump	1	0	0%	0	0	0	0	0%	0
Water Bar	246	0	0%	0	0	0	0	0%	0
All Drains	**3584**	**23**	**1%**	**3**	**114**	**5**	**0.5**	**10%**	**0.005**

Fill erosion was present at 1% of all drain points, totaling 3 m^3 (110 ft^3; Table 31). Fill erosion was most common at broad based dips, with 18 of 1050 (2%) eroding 3 m^3 (90 ft^3). Non-engineered drains had fill erosion at 3 of 1097 locations (0.3%; 0.4 m^3; 20 ft^3); stream crossings at 1 of 115 locations (1%; 0.2 m^3; 10 ft^3); and ditch relief culverts at 1 of 266 locations (0.4%; 0.03 m^3; 1 ft^3). Broad based dips had the most mass of fill erosion. Using the same bulk density as above, fill erosion at drain points that were connected to the stream channel network totaled 0.5 Mg, which occurred at stream crossings (0.3 Mg) and non-engineered drains (0.2 Mg). This was 10% of the sediment produced by fill erosion at drain points. Over a 20 year period, 0.005 Mg/yr of sediment were delivered to stream channels, which is negligible compared to other sources. Actual annual sediment delivery from fill erosion is likely higher or lower than these estimates in any given year, and when the largest failures occur, they are often repaired and quickly become difficult to record accurately.

4.8 Risks by Maintenance Level

Sediment production and delivery, connected length of road, drain point problems, and fill erosion were analyzed by road maintenance level for the three areas. Gully and landslide risks were analyzed for the Center Horse and Morrell/ Trail project area. Poorman Creek and Cold Creek did not have enough gullies or landslides for this analysis. Road surface fine sediment delivery risks were hypothesized to be higher on roads that received more maintenance (Maintenance Levels 3 and 4), and lower on roads that received less maintenance (ML 1 and 2), due to the positive correlation of maintenance level with traffic. Mass wasting risks and other infrastructure problems were hypothesized to be higher on roads that received less maintenance (ML 1 and 2), as many of these issues may be preventable. Unclassified roads are usually small and seldom used, and are generally equivalent to ML 1 or 2. Appendix A shows these risks for each of the three areas and summarized for all three.

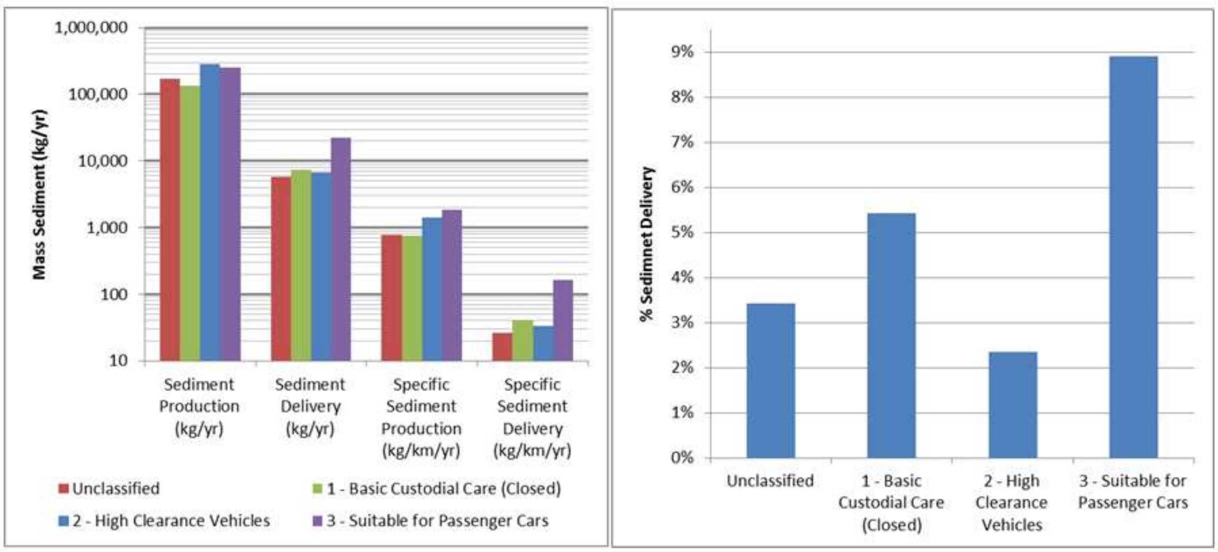


Figure 55. Sediment delivery risks for all three areas. Note that the logarithmic scale begins at 10. Only the Center Horse and Morrell/Trail project area had ML 4 roads, so these were omitted from these graphs. Specific sediment is normalized by road length in each ML category.

For all three areas, there was roughly twice as much total sediment delivery on the ML 3 roads as on any of the ML 1 or 2 or unclassified roads (Figure 55, note the logarithmic scale). Sediment production, as well, was higher on the higher maintenance level roads. Specific sediment delivery (delivery normalized by length of road in each ML category) was almost five times higher on the ML 3 roads than any of the ML 1 or 2 or unclassified roads. For sediment delivery as a percentage of production, each maintenance level was roughly equivalent, though the ML 3 roads had the highest percent, suggesting that the higher delivery on the higher maintenance levels was due to the higher production.

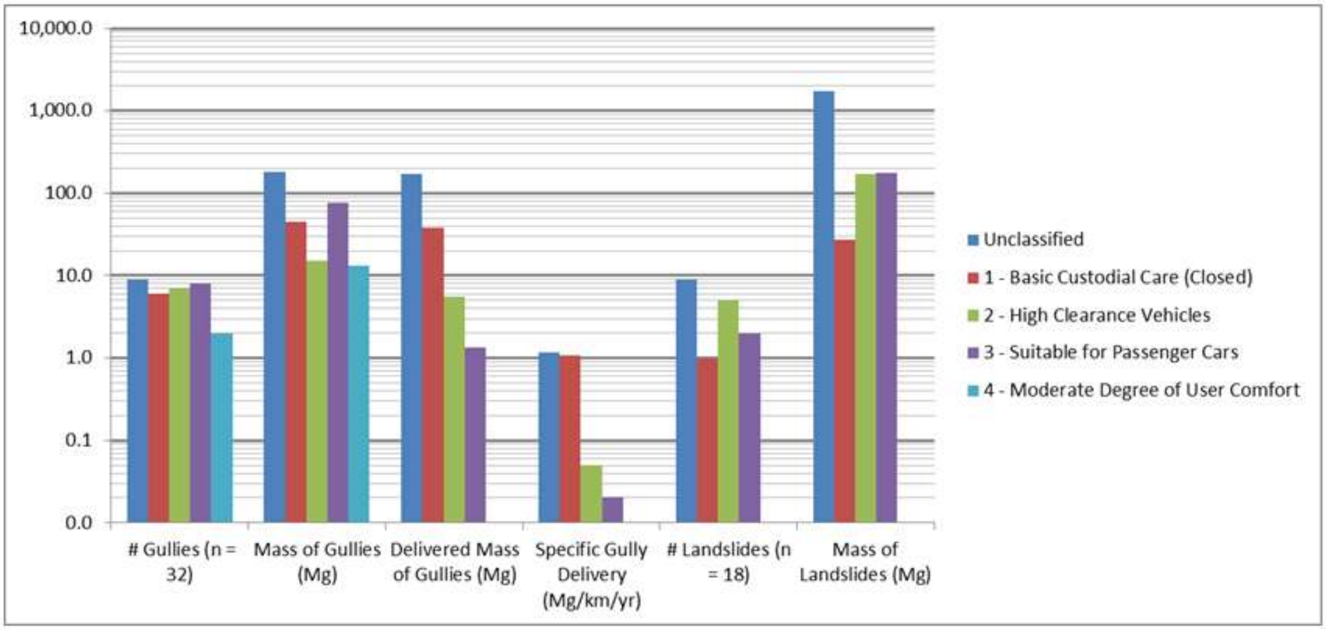


Figure 57. Gully and landslide risks for the Center Horse and Morrell/Trail project area. Note the logarithmic scale. The other two areas did not have enough gullies or landslides for this analysis.

In the Center Horse and Morrell/Trail project area, there were more landslides with more mass on the lower maintenance level roads than the higher (Figure 56). The number, mass, and delivered mass of gullies exhibited a similar pattern in this area. This pattern is stronger when the delivered mass from gullies is normalized by total road length in each ML category, with a roughly ten-fold difference between the unclassified and ML 1 roads and the ML 2, 3, and 4 roads. Fill erosion mass, delivered mass, specific delivered mass, and percent mass delivered were also higher on the lower maintenance level roads in all three areas (Figure 57). Regular maintenance may address the road problems that lead to mass wasting. An alternative hypothesis is that the higher maintenance level roads tend to cross less steep slopes in the valley bottom, which is less conducive to mass wasting. In the Center Horse and Morrell/Trail project area, the average slope that the ML 4 roads traversed was about half of the average slope that the ML 1, 2, and 3 roads traversed.

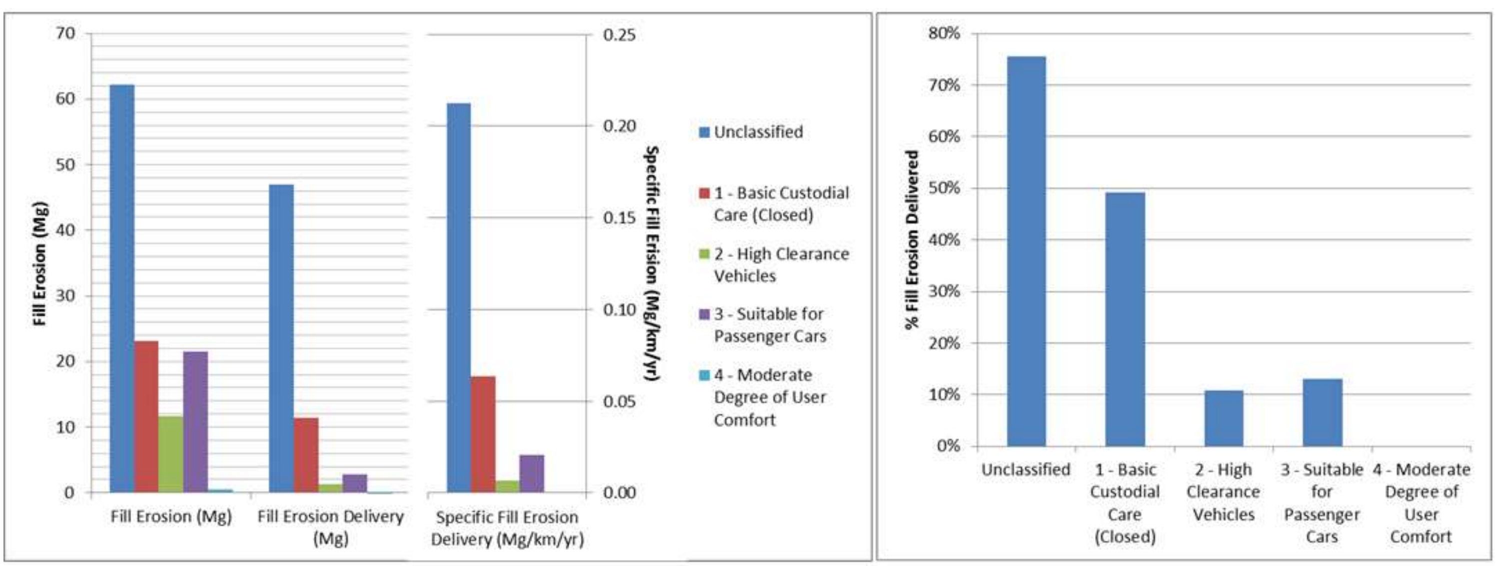


Figure 56. Fill erosion total mass and delivered mass for all three project areas. Note the change in axis scale for Specific Fill Erosion Delivery on the left graph.

Drain point problems did not fit the expected pattern, as although there were more drain points with problems on the lower maintenance level roads, the higher maintenance level roads had a higher percentage of drain points with problems (Figure 58). Heavier traffic may result in wear on infrastructure that outpaces the effects of neglect on the lower maintenance level roads, though given enough time, the effects of neglect may be larger. Additionally, different types of drain points preferentially occur on the different maintenance levels, and each type of drain point has a different overall problem rate.

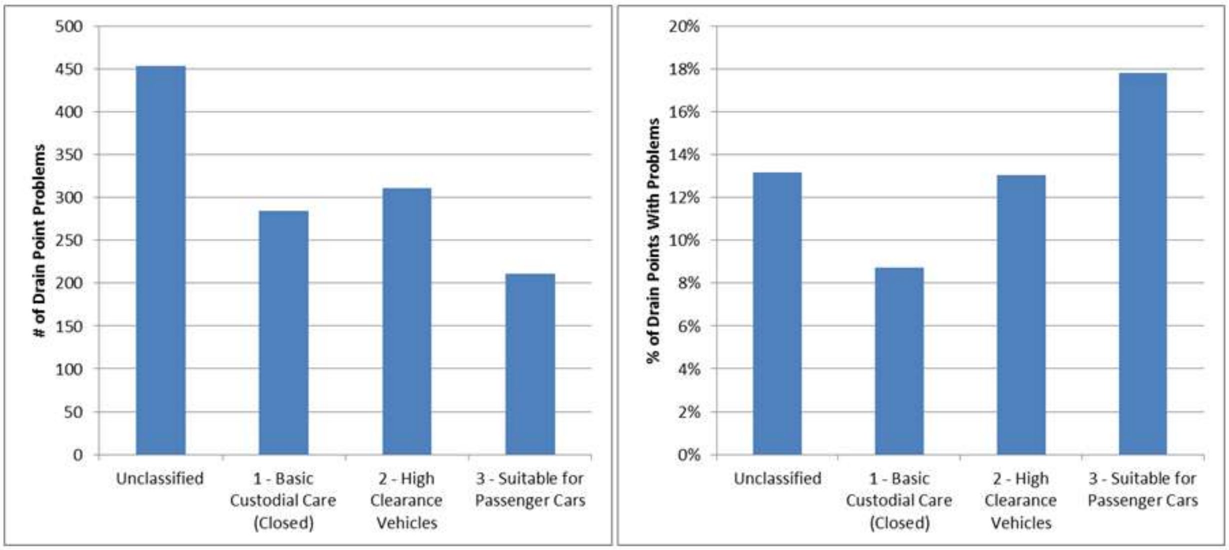


Figure 58. Drain point problems for all three project areas.

5.0 Jammer Road Inventory and Observations

Jammer roads are decades-old closely-spaced unsurfaced logging roads built to a low standard that contour along the hillslope roughly every 30 m (100 ft) of slope length. In the Center Horse and Morrell/Trail project area, there were 380 km (230 mi) of jammer roads concentrated in 20 to 25 complexes that encompass 0.25 mi^2 to 1 mi^2 each (Figure 59). This is about the same total length as there were regular, non-jammer roads.

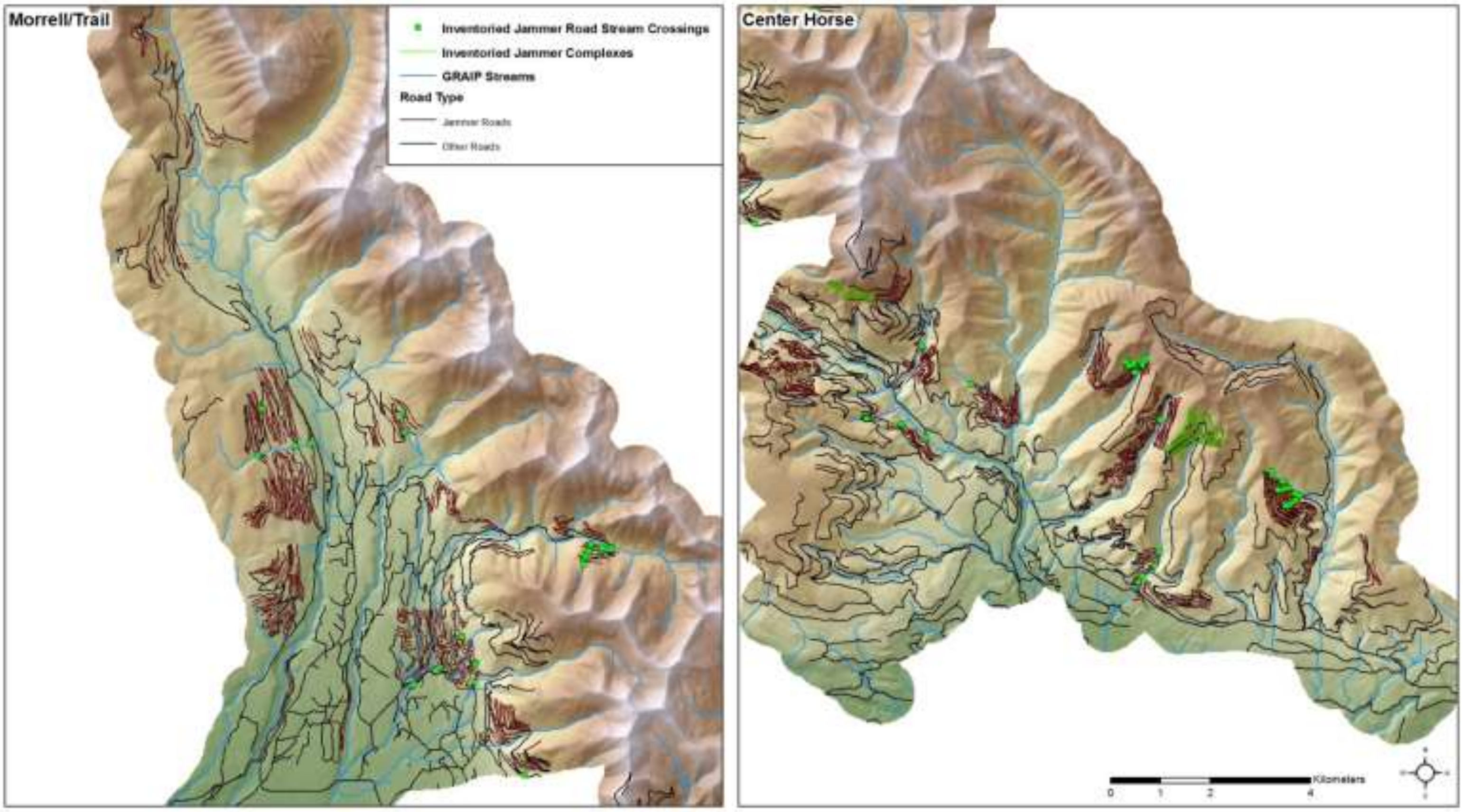


Figure 59. Jammer road locations in the Center Horse and Morrell/Trail project area, with the complete surveyed complexes and the stream crossings that we surveyed.

Though these roads were generally unmaintained since they were in use as logging roads, the risks they may pose to aquatic systems in the future were unknown. On the one hand, most of these roads were heavily vegetated and initially appeared to be stable; on the other hand, infrastructure along these roads was old and likely to fail or to have already failed. Prior field observations suggested that most of the sediment delivery and mass wasting risks from jammer roads occurred at stream crossings. In order to evaluate these risks, we inventoried two complexes in the Center Horse project area using GRAIP (section 5.1, below), and conducted a census of every jammer road-stream intersection in both project areas (section 5.2. below).

5.1 Complete Complex Inventory

Two complete jammer road complexes totaling 18.5 km in the Center Horse project area were inventoried using the GRAIP method. The eastern complex was located in upper Black Canyon (13.3 km, 8.3 mi), and the western complex was located on the south face of Morrell Mountain (5.1 km, 3.2 mi; Figure 59). The Black Canyon complex may be treated at some point in the future, and the GRAIP method will be used to monitor the outcomes of the treatment.

Table 32. *Summary of sediment production and delivery at drain points on the jammer road complexes that were inventoried with GRAIP in the Center Horse and Morrell/Trail Project Area.*

Drain Point Type	Count	Sediment Production (kg/yr)	Sediment Delivery (kg/yr)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	28	90	0	0%	0	0%
Diffuse Drain	158	560	2	0.4%	20	0.1%
Ditch Relief Culvert	1	0	0	0%	0	0%
Lead Off Ditch	0	0	0	0%	0	0%
Non-Engineered Drain	124	350	6	2%	50	1%
Stream Crossing	9	10	10	100%	100	100%
Sump	0	0	0	0%	0	0%
Water Bar	5	8	0	0%	0	0%
All Drains	**325**	**1020**	**18**	**2%**	**160**	**1%**

There were 325 drainage points recorded. Drainage on these roads occurred mostly through diffuse road segments (158 points) and non-engineered drains (124 points). Most of the road surfaces were undrivable and covered in grass, herbaceous vegetation, or small to medium sized trees (17.9 of 18.4 km; 97%).

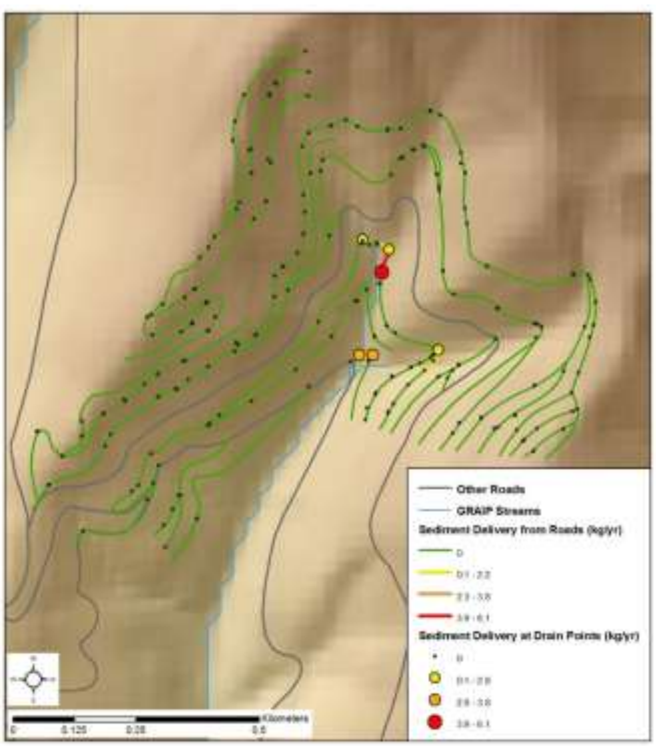


Figure 60. Fine sediment delivery to channels by road segment and drain point in the upper Black Canyon jammer road complex. The road lines and drain points are colored to indicate the mass of fine sediment delivered to channels.

Overall, both complexes had very low sediment production and delivery (Table 32). Roads were highly vegetated and had low slopes. Sediment production totaled 1 Mg/yr for both complexes. There were no delivering drain points in the Morrell Mountain complex. In the Black Canyon complex, there was 0.02 Mg/yr of fine sediment delivered from the road surface to the stream from 0.2 km of road length (2% of all sediment produced from 1% of total length; Figure 60). An estimate of total road surface fine sediment delivery for the Center Horse and Morrell/Trail project area was made by applying the road surface delivery rate from these two complexes to the entire length of jammer roads (Table 33). The estimated total road surface fine sediment delivery was 0.4 Mg/yr.

Table 33. *Estimation of sediment delivery from road surfaces for all jammer roads in the Center Horse and Morrell/Trail project area, based on the road surface sediment delivery rate per kilometer from the inventoried complexes.*

Length of Road Surveyed (km | mi)	19	11
Total Length of Jammer Roads in Center Horse and Morrell/Trail (km | mi)	376	234
Total Road Surface Sediment Delivery (Mg/yr)	0.02	
Road Surface Delivery Rate for Surveyed Roads (Mg/yr/km)	0.001	
Estimated Road Surface Delivery for All Jammer Roads (Mg/yr)	0.4	

In the Black Canyon complex, there was a natural ford stream diversion from a two foot wide side-channel onto the road. As a result of this diversion, there were two gullies observed, totaling 29 Mg (Figure 61; Table 34). Both gullies delivered their sediment to the stream. Also as a result of the stream diversion, there were two non-engineered drains observed to have fill erosion totaling 25 Mg. One of

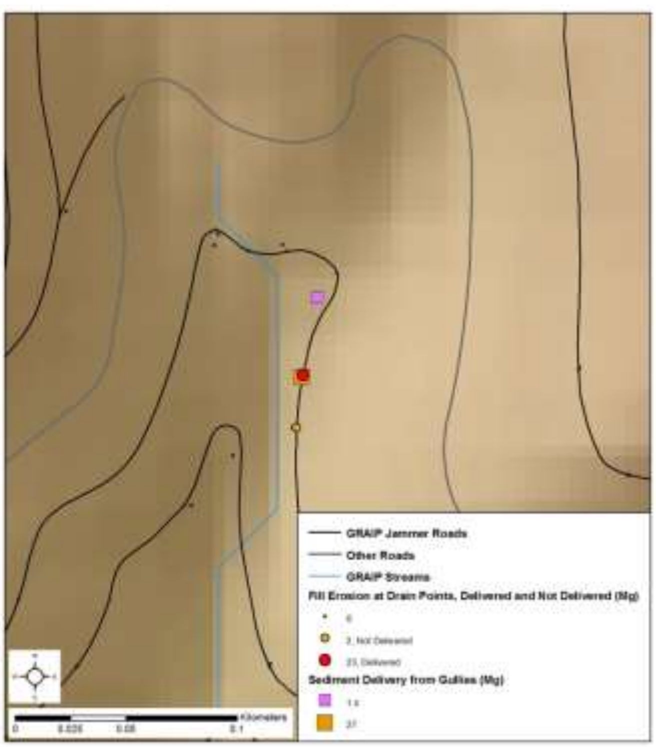


Figure 61. Fill erosion and gullies in the Black Canyon jammer road complex. All mass wasting was due to a diverted stream crossing. There was no other mass wasting observed in either inventoried jammer complex.

the two drain points with fill erosion delivered to the stream, totaling 23 Mg. This mass wasting totaled 53 Mg, with 51 Mg delivered to the stream. Averaged over 20 years, the mass wasting delivery totaled 3 Mg/yr. There were no other observed instances of mass wasting, including landslides, in either complex.

Table 34. *Mass wasting masses and delivery for the observed mass wasting in the Black Canyon jammer complex. No mass wasting was observed in the Morrell Mountain complex.*

Landslide Mass (Mg)	0
Gully Mass (Mg)	29
Fill Erosion Mass (Mg)	25
Total Mass Wasting (Mg)	53
Mass Wasting Delivery (Mg)	51
Mass Wasting Delivery Over 20 Years (Mg/yr)	3

The Black Canyon complex was chosen for this inventory because it was thought to have a high rate of and potential for sediment delivery and other problems. Based on other field observations at other complexes, as well as the stream diversion in the Black Canyon complex, most delivery of sediment from jammer roads probably occurs at stream crossings when the fill erodes into the stream or diverts down the road (see below). Other mass wasting, particularly that delivers to the stream channel, is probably rare.

Other than sediment from stream crossing-related erosion, jammer roads in the Center Horse and Morrell/Trail project area are probably not a major sediment source. Non-stream crossing risks are observed and estimated to be very low. However, it is unknown what the response of these roads may be after a forest fire. Without vegetation, there may be a greater sediment supply, more runoff, and a greater chance of mass wasting. Stream crossings risks are evaluated in the following section.

5.2 Stream Crossing Survey

Prior field observations suggested that most of the risk present on the jammer roads in the Center Horse and Morrell/Trail project area occurred at stream crossings. In order to evaluate this risk, we conducted a census of all of the stream crossings on jammer roads in the area (Figure 59). Crews followed streams up to each consecutive stacked road until the stream channel head was reached or there were no more upslope roads. Streams were defined as continuous features with a bed, banks, and evidence of flow for some part of most years. No minimum size was used in this definition because even small features can cause problems under the right conditions. TauDEM 4.0 (http://hydrology.usu.edu/taudem/taudem4.0) was used to model the probable stream locations. There were a number of modeled streams that were not present in the field, and streams that were found in the field that were not present in the model.

There were 71 stream crossings on jammer roads surveyed in the course of the census. There were 61 natural ford-type crossings (no infrastructure) and ten crossings with culverts. Some of the natural fords may have been log culverts at one time, but the evidence has likely decomposed. Observations at each crossing included channel width, presence of problems such as a blocked culvert or scoured road, volume of fill erosion, and presence of stream diversion. Fill erosion risks were further analyzed to evaluate the rough probability and amount of remaining risk.

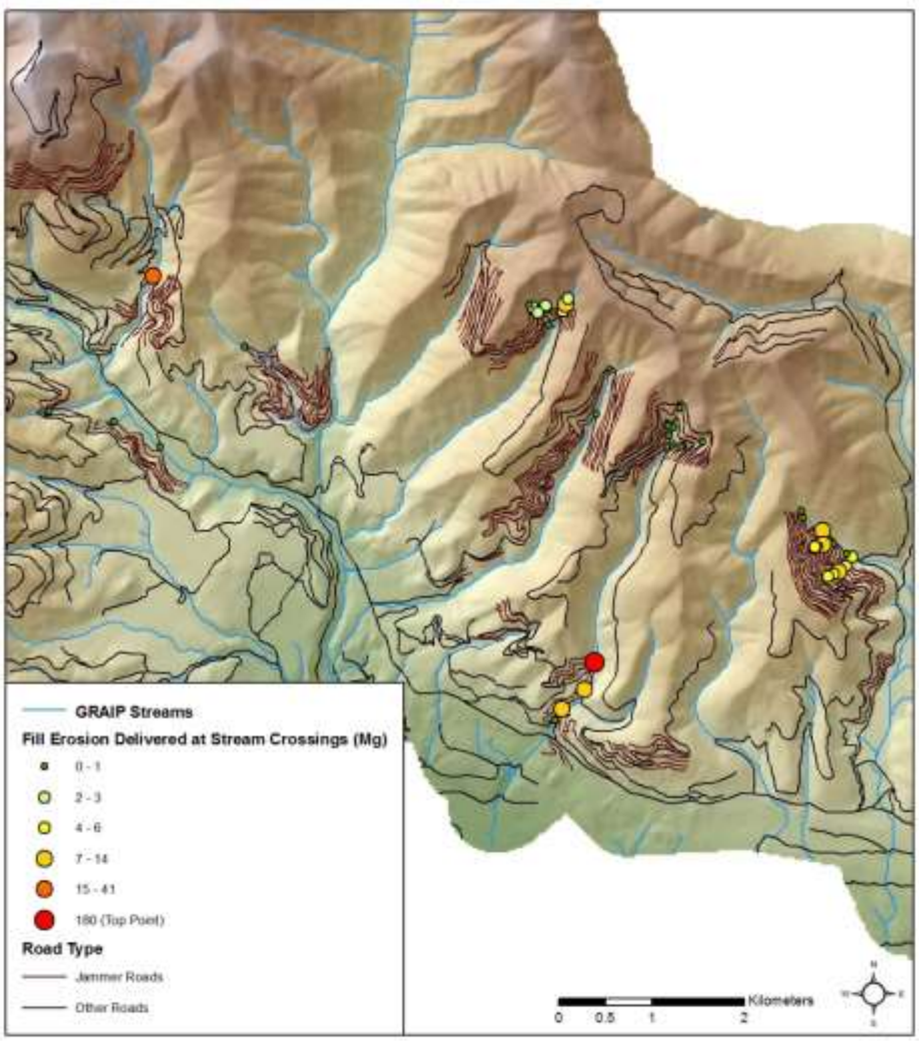


Figure 62. Stream crossings with observed fill erosion on jammer roads in the Center Horse and Morrell/Trail project area. The largest fill erosion volume was due to a stream diversion.

There were 31 stream crossings with fill erosion (44% of all crossings on jammer roads), totaling 207 m^3 (7310 ft^3, 331 Mg; Figure 62; Table 35). One crossing in lower Black Canyon in the Center Horse project area with a stream diversion had more than half of the total fill erosion (3980 ft^3, 113 m^3, 180 Mg). Most crossings with fill erosion had under 300 ft^3 (10 m^3, 15 Mg). The average fill erosion per crossing was 100 ft^3 (3 m^3, 5 Mg). Without the largest outlier volume of fill erosion, the average fill erosion per crossing was 50 ft^3 (1 m^3, 2 Mg). Since this fill erosion occurred at stream crossings, all of it delivered to the stream. Averaged over 20 years, the fill erosion totaled 17 Mg/yr, which is roughly equivalent to the road surface fine sediment delivery for the non-jammer roads in the Center Horse and Morrell/Trail project area. Without the largest outlier mass of fill erosion, the delivery rate over 20 years was 8 Mg/yr.

Table 35. *Fill erosion statistics for the jammer road stream crossings observed in the Center Horse and Morrell/Trail project area.*

Number Surveyed	71
Number With Fill Erosion	31
% Fill Erosion	44%
Volume Fill Erosion (ft^3)	7310
Volume Fill Erosion (m^3)	207
Mass Fill Erosion (Mg)	331
Fill Erosion Delivery Over 20 Years (Mg/yr)	17
Mean Fill Erosion Per Crossing (m^3)	3
Estimated Mean Total Original Fill Volume at Each Crossing (m^3)	12
% of Estimated Original Fill Volume Eroded (m^3)	25%

The volume of fill was estimated at each crossing as being bounded at the base by an area 1.2 times the channel width, with side slopes climbing to the road surface at a slope of 33%. We assumed a road width of 14 ft, and a fill depth of five feet. The slope of the hillslope was used to determine the length of the crossing bottom according to the slopes given by Megahan (1976), modified to account for the narrower road. The estimated average volume of fill at each crossing was 12 m^3 (420 ft^3; Figure 62). Using the average volume of fill erosion per crossing, it is estimated that about 25% of the possible fill erosion has already been eroded, with 75% (about 600 m^3 or 22,000 ft^3) remaining. Much of the observed fill erosion included volumes eroded from stream diversions, so the observed fill erosion volume may be larger than the estimated available volume. There may be more than 75% of the available fill remaining. However, the process of the stream channel cutting through what amounts to a flat step in its longitudinal profile takes time, and will happen episodically during high flow events. Each stream crossing will respond at a different rate due to the available transport capacity of the stream, and may include some deposition.

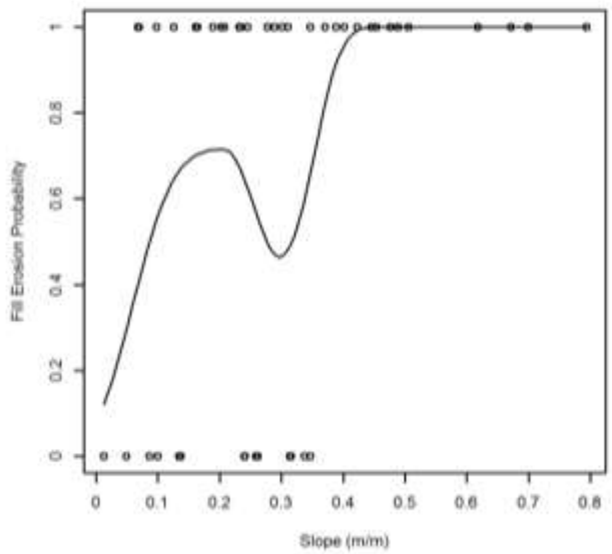


Figure 63. Probability graph output from the local fit regression in R. Fill Erosion Probability is a yes/no field (specific volumes are not accounted for). Though fill erosion occurs throughout the slope range, above about 40% slope, all have fill erosion.

In order to prioritize the stream crossings with the greatest risk of future fill erosion, we used a logistical regression technique (local fit, locfit) in the R statistical computing environment that compared the stream crossings in the Center Horse project area with fill erosion to those without, according to the slope of the hillslope on which the stream runs (Figure 63). The sample includes all crossings with fill erosion, but may be too small to draw broad conclusions. It was found that on hillslopes of greater than about 40%, every stream crossing in the Center Horse area had fill erosion.

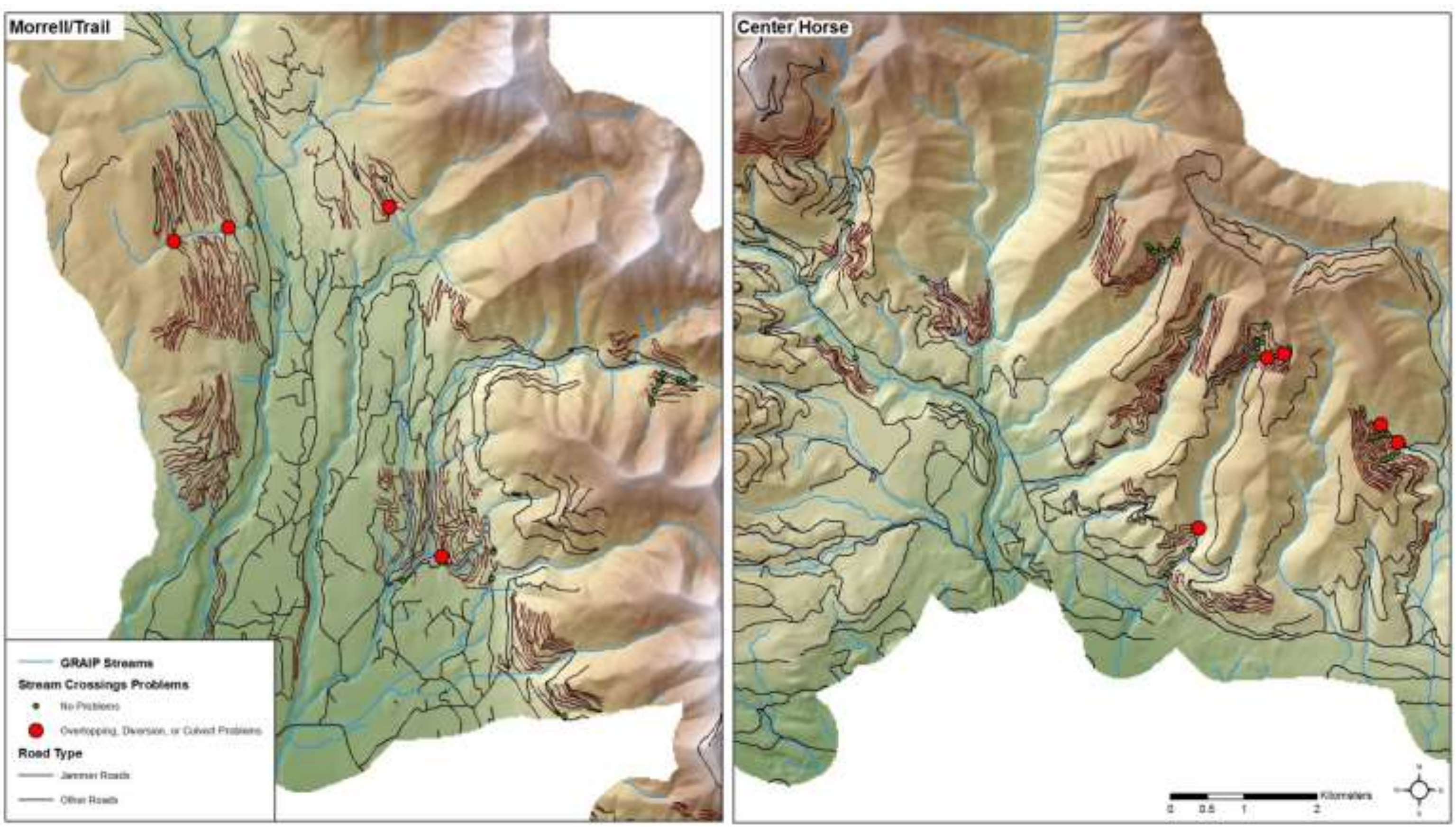


Figure 64. Stream crossings on jammer roads with problems, including observed overtopping, diversion, and culvert problems.

Other problems were observed at the inventoried jammer road stream crossings. Five of the crossings (7%) had evidence of current or recent stream diversions (Figure 64; Table 36). Ten natural ford type crossings were observed to have one direction of possible diversion (two of them already had diversions observed). One other crossing with a culvert and one diversion direction was observed to have been overtopped in the past. Four other crossings (6%) were observed to have other problems, including scoured road surfaces above the crossings and blocked or failing culverts. This is nine crossings in total, or 13%.

Table 36. *Stream crossings on jammer roads with problems in the Center Horse and Morrell/Trail project area.*

Number of Crossings With Stream Diversion Evidence	5
% of Crossings With Stream Diversion Evidence	7%
Number of Crossings With Other Problems	4
% of Crossings With Problems	6%

6.0 Summary and Conclusions

Field inventory and modeling analysis of the public roads in the Center Horse and Morrell/Trail project area, the Poorman Creek watershed area, and the Cold Creek watershed area in the Southwest Crown of the Continent in western Montana using the GRAIP model provided detailed, site specific data on sediment-related watershed impacts from roads. Impacts are both chronic, in terms of annual sediment input to streams, and pulsed, such as during storm events when road connectivity to the channel networks is at its maximum. Inventory data was collected on 769 km (478 mi) of road, including 10,759 drain points, by two field crews during the summer months of 2012 and 2013 (June to October). Additionally, jammer-type logging roads were sampled and their road-stream intersections were surveyed in the Center Horse and Morrell/Trail project area.

The GRAIP model was used to predict sediment risk and sediment-related impacts from roads. The model predicts road to stream hydrologic connectivity, sediment delivery to streams, downstream sediment accumulation, risks of shallow landslides caused by roads, gully initiation risk below drain points, and risks to road-stream crossings (Tables 37, 38, and 39). Inventory data is also used to locate and describe problems with existing drain points. In addition, GRAIP model data will be compared to in-stream PIBO monitoring for these project areas in a separate document.

Center Horse and Morrell/Trail Project Area Summary

In the Center Horse and Morrell/Trail project area, there were 407 km (253 mi) of road and 5061 drain points surveyed. Table 37 presents a summary of the findings for this project area. Hydrologic connectivity was found to be a relatively low 4% of all road length at 16 km out of 407 km (10 mi out of 252 mi). The model predicted 21.4 Mg/yr of delivered road surface fine sediment to stream channels, which is 5% of the 456 Mg generated annually by the road surface. This sediment was delivered through 314 of 5061 (6%) drain points. There was 16.2 Mg/yr of delivery that occurred within 10 m of a stream crossing. This is 76% of all sediment delivery and 57% of all sediment produced within 10 m of a stream crossing.

Specific sediment due to road surface-related sediment for the whole Center Horse and Morrell/Trail project area was 0.10 Mg/km^2/yr, or 1% of the observed total average fine sediment yield for five nearby areas as determined by reservoir coring or suspended sediment extrapolations. Including sediment delivered to streams through other sources (landslides, gullies, and fill erosion at drain points), the specific sediment for the whole project area was 0.21 Mg/km^2/yr, or about 2% of the observed average fine sediment yield for the nearby areas. Some heavily impacted stream reaches had road sediment delivery values as high as 4.9 Mg/km^2/yr with only road surface fine sediment, or 18.1 Mg/km^2/yr including mass wasting sediment. Reaches in Shanley, Little Shanley, Blacks Canyon, and lower Spring Creeks showed particularly high specific sediment values above 0.3 Mg/km^2/yr, or 3% to 19% above the reference sediment yield.

There were 18 landslides observed by field crews in the course of the inventory, with a total volume of 1319 m^3 (1726 yd^3). Of those, 10 were road related. It was conservatively estimated that 176 Mg of landslide derived sediment has been delivered to streams, which is roughly half the rate of that from road surfaces over 20 years (8.8 Mg/yr). It would take about eight years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from landslides. Calibrated stability index modeling with SINMAP conservatively showed that 6 km^2 (2 mi^2), or 3%, of the watershed area was put at higher risk of shallow landslide initiation by road drainage.

Table 37. *Summary of GRAIP-predicted road risk predictions, Center Horse and Morrell/Trail project area.*

Impact/Risk Type	**GRAIP Predicted Risks**
Road-Stream Hydrologic Connectivity	4% of road length, 16 km; 6% of drain points connected
Fine Sediment Delivery	5% of sediment produced, 21.4 Mg/yr
Sediment in Streams	0.21 Mg/km^2/yr; 2% of average sediment yield for nearby areas
Landslide Risk	Estimated 176 Mg of sediment delivered to streams, 3% of watershed area with elevated risk due to roads
Gully Risk	Estimated 11 Mg/yr of sediment delivered to streams, 16% of all drain points exceed ESI_{crit} threshold
Stream Crossing Risks	
- plug potential	27 sites (23%) with elevated risk (SBI > 2)
- fill at risk	6843 m^3 fill at risk, average 60 m^3 per crossing
-diversion potential	61 sites (42%) with diversion potential
Drain Point Problems	811 drain points (16% of all drain points) with problems, 61 m^3 of fill erosion (2% of drain points), estimated 2.9 Mg/yr of fill delivered to streams

Gullies were observed at 33 locations by field crews, totaling 208 m^3 (272 yd^3) in volume, and all occurring in wet swales. It was estimated that these gullies delivered 217 Mg of sediment to the stream channel, equivalent to half the rate of that from road surfaces over 20 years (11 Mg/yr). It would take about ten years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from gullies. Of 3713 applicable drain points, 587 (16%) had an elevated risk of gullying. The critical gully initiation index (ESI) was found to be 14. The average ESI for the points without gullies was 9, while it was 11 for the points with gullies. The gully occurrence rate for drain points that fell above the ESI threshold was 1.0% versus 0.5% for points that fell below the ESI threshold.

There were 116 stream crossings with culverts (as opposed to bridges or fords) recorded. The average blocking index (SBI) for these points was a moderate to low 1.9. There were 25 crossings with an elevated SBI of 3. Two crossings had an SBI of 4, which is the highest possible value. The total calculated volume of fill at risk in an overtopping type event was 6840 m^3 (8950 yd^3). There were 55 stream crossings with the potential to divert stream flow from a plugged culvert down the road and onto unchanneled hillslopes. There were 14 stream crossings with an SBI of 3 or 4 and diversion potential, four of which were observed to have already failed or be at risk for imminent failure. There was a total of 824 m^3 (1077 yd^3) of fill at risk at these points. Six overtopped crossings were observed, five due to sediment plugging and one due to wood plugging. Three of those were due to undersized pipes, and one delivered 26 m^3 (910 ft^3) to streams.

Of the 5061 recorded drain points, 811 (16%) had one or more problem of some type (e.g. blocked or crushed culvert, excess puddling on the road surface). Sumps had the highest rate of problems, with 11 of 24 (46%), followed by ditch relief culverts (155 of 392, 40%). Fill erosion was recorded at 83 drain points (2%), with a total volume of 85 m^3 (3000 ft^3). Fill erosion was most common at non-engineered drains with 28 instances and 23 m^3 (820 ft^3). Stream crossings had 44 m^3 (1550 ft^3) eroded from 4 of 146 crossings (2%). It was estimated that fill erosion delivered 87 Mg of sediment to the stream channel, or about a quarter of the rate of the of road surface sediment over 20 years (4.4 Mg/yr). It would take about four years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from fill erosion.

Poorman Creek Summary

In the Poorman Creek area, there were 174 km (108 mi) of road and 2190 drain points surveyed. Table B presents a summary of the findings for this project area. Hydrologic connectivity was found to be a relatively low 4.7% of all road length at 8 km out of 174 km (5 mi out of 106 mi). The model predicted 11.5 Mg/yr of delivered road surface fine sediment to stream channels, which is 4.6% of the 247 Mg generated annually by the road surface. This sediment was delivered through 97 of 2190 (4%) drain points. There was 5.6 Mg/yr of delivery that occurred within 10 m of a stream crossing. This is 49% of all sediment delivery and 77% of all sediment produced within 10 m of a stream crossing.

Table 38. *Summary of GRAIP-predicted road risk predictions, Poorman Creek area.*

Impact/Risk Type	GRAIP Predicted Risks
Road-Stream Hydrologic Connectivity	4.7% of road length, 8 km; 4% of drain points connected
Fine Sediment Delivery	4.6% of sediment produced, 11.5 Mg/yr
Sediment in Streams	0.19 $Mg/km^2/yr$; 2% of average sediment yield for nearby areas
Landslide Risk	Estimated 91 Mg of sediment delivered to streams, 2.2% of watershed area with possible elevated risk due to roads
Gully Risk	Estimated 0.2 Mg/yr of sediment delivered to streams, too few gullies to determine ESI^{crit}
Stream Crossing Risks	
- plug potential	5 sites (17%) with elevated risk (SBI > 2)
- fill at risk	1399 m^3 fill at risk, average of 48 m^3 per crossing
- diversion potential	8 sites (17%) with diversion potential
Drain Point Problems	270 drain points (12% of all drain points) with problems, 11 m^3 of fill erosion (1% of drain points), estimated 0.2 Mg/yr of fill erosion delivered to streams

Specific sediment due to road surface-related sediment for the whole Poorman Creek area was 0.11 $Mg/km^2/yr$, or 1% of the observed total average fine sediment yield for five nearby areas as determined by reservoir coring or suspended sediment extrapolations. Including sediment delivered to streams through other sources (landslides, gullies, and fill erosion at drain points), the specific sediment for the whole project area was 0.19 $Mg/km^2/yr$, or about 2% of the observed average fine sediment yield for the nearby areas. The most heavily impacted stream reaches had road sediment delivery values as high as 0.8 $Mg/km^2/yr$ with only road surface fine sediment, or 4.0 $Mg/km^2/yr$ including mass wasting sediment.

There were 5 landslides observed by field crews in the course of the inventory, with a total volume of 252 m^3 (329 yd^3). All were road related. It was conservatively estimated that 91 Mg of landslide derived sediment has been delivered to streams, which is roughly half the rate of sediment from road surfaces over 20 years (4.5 Mg/yr). It would take about 8 years for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from landslides. Calibrated stability index modeling with SINMAP conservatively showed that 3 km^2 (1 mi^2), or 2%, of the watershed area was put at higher risk of shallow landslide initiation by road drainage.

Gullies were observed at 7 locations by field crews, totaling 157 m^3 (206 yd^3) in volume, with none occurring in wet swales. It was estimated that these gullies delivered 4 Mg of sediment to the stream channel, which is negligible compared to the rate of road surfaces over 20 years (0.2 Mg/yr). It would take less than one year for the fine sediment delivery from road surfaces to equal the total mass of delivered sediment from gullies. There were too few gullies to determine an ESI_{crit}, suggesting that the gully initiation risks here may be very low. The average ESI across the Poorman Creek area was 8.

There were 29 stream crossings with culverts (as opposed to bridges or fords) recorded. The average blocking index (SBI) for these points was a moderate to low 1.7. There were 5 crossings with an elevated SBI of 3. No crossings had an SBI of 4, which is the highest possible value. The total calculated volume of fill at risk in an overtopping type event was 1399 m^3 (1830 yd^3). There were eight stream crossings with the potential to divert stream flow down the road and onto unchanneled hillslopes. There was one stream crossing with an SBI of 3 and diversion potential. There was a total of 21 m^3 (27 yd^3) of fill at risk at this point. Two natural ford type crossings were observed to divert flow down the road, though no major erosion was observed at the time of the survey.

Of the 2190 recorded drain points, 270 (12%) had one or more problem of some type (e.g. blocked or crushed culvert, excess puddling on the road surface). Ditch relief culverts had the highest rate of problems, with 18 of 56 (32%), followed by broad based dips (120 of 412, 29%). Fill erosion was recorded at 22 drain points (1%), with a total volume of 11 m^3 (400 ft^3). Fill erosion was most common at non-engineered drains with 16 instances and 8 m^3 (300 ft^3). It was estimated that fill erosion delivered 3 Mg of sediment to the stream channel, which is negligible compared the amount of road surface sediment over 20 years (0.2 Mg/yr).

Cold Creek Summary

In the Cold Creek area, there were 198 km (123 mi) of road and 3584 drain points surveyed. Table 39 presents a summary of the findings for this project area. Hydrologic connectivity was found to be a relatively low 4% of all road length at 9 km out of 198 km (6 mi out of 123 mi). The model predicted 9.8 Mg/yr of delivered road surface fine sediment to stream channels, which is 6% of the 162 Mg generated annually by the road surface. This sediment was delivered through 205 of 3584 (6%) drain points. There was 6.6 Mg/yr of delivery that occurred within 10 m of a stream crossing. This is 67% of all sediment delivery and 75% of all sediment produced within 10 m of a stream crossing.

Specific sediment due to road surface-related sediment for the whole Cold Creek area was 0.1 $Mg/km^2/yr$, or 1% of the observed total average fine sediment yield for five nearby areas as determined by reservoir coring or suspended sediment extrapolations. No other sources were observed to deliver sediment to streams. The most heavily impacted stream reaches had road sediment delivery values as high as 1.1 $Mg/km^2/yr$.
There were 9 landslides observed by field crews in the course of the inventory, with a total volume of 175 m^3 (229 yd^3). Only one landslide was not road related. No landslide sediment was observed to have been delivered to streams. Calibrated stability index modeling with SINMAP conservatively showed that 0.6 km^2 (0.2 mi^2), or 0.6%, of the watershed area was put at higher risk of shallow landslide initiation by road drainage.

Table 39. *Summary of GRAIP-predicted road risk predictions, Cold Creek area.*

Impact/Risk Type	**GRAIP Predicted Risks**
Road-Stream Hydrologic Connectivity	4% of road length, 9 km; 6% of drain points connected
Fine Sediment Delivery	4% of sediment produced, 9.8 Mg/yr
Sediment in Streams	0.10 Mg/km2/yr; 1% of average sediment yield for nearby areas
Landslide Risk	No landslide sediment delivered to streams; 0.6% of watershed area with possible elevated risk due to roads
Gully Risk	No gully sediment delivered to streams, too few gullies to determine ESI_{crit}
Stream Crossing Risks	
- plug potential	28 sites (39%) with elevated risk (SBI ≥ 2)
- fill at risk	2095 m^3 fill at risk, average of 31 m^3 per crossing
- diversion potential	39 (34%) sites with diversion potential
Drain Point Problems	284 drain points (8% of all drain points) with problems, 3 m^3 of fill erosion (1% of drain points), estimated 0.005 Mg/yr of fill erosion delivered to streams

Gullies were observed at 3 locations by field crews, totaling 5 m^3 (7 yd^3) in volume, with none occurring in wet swales. No gullies were observed to deliver sediment to the stream channel in Cold Creek. There were too few gullies to determine an ESI_{crit}, suggesting that the gully initiation risks here may be very low. The average ESI across the Cold Creek area was 4.

There were 71 stream crossings with culverts (as opposed to bridges or fords) recorded. The average blocking index (SBI) for these points was a moderate to low 2.3. There were 26 crossings with an elevated SBI of 3. Two crossings had an SBI of 4, which is the highest possible value. The total calculated volume of fill at risk in an overtopping type event was 2090 m^3 (2730 yd^3). There were 39 stream crossings with the potential to divert stream flow from a plugged culvert down the road and onto unchanneled hillslopes. There were 14 crossings with an SBI of 3 or 4 and diversion potential. There was a total of 332 m^3 (434 yd^3) of fill at risk at these points. Of those 14 crossings, half received the stream flow from the ditch, though this appeared to be intentional.

Of the 3584 recorded drain points, 284 (8%) had one or more problem of some type (e.g. blocked or crushed culvert, excess puddling on the road surface). Stream crossings had the highest rate of problems, with 45 of 115 (39%), followed by ditch relief culverts (80 of 266, 30%). Fill erosion was recorded at 23 drain points (1%), with a total volume of 3 m^3 (110 ft^3). Fill erosion was most common at broad based dips with 18 instances and 3 m^3 (90 ft^3). It was estimated that fill erosion delivered 0.5 Mg of sediment to the stream channel, which is negligible compared the amount of road surface sediment over 20 years (0.005 Mg/yr).

Jammer Roads Summary

Two complete jammer road complexes totaling 19 km (11 mi) of road and 325 drain points in the Center Horse project area were inventoried using the GRAIP method. These vegetated and shallow-slope roads delivered 0.02 Mg/yr, which is 2% of the 1 Mg/yr generated on the road surfaces (Table 40). If this delivery rate is applied to all jammer roads, then it can be expected that these roads deliver less than 1 Mg/yr from the road surface. A a small stream diversion was observed that resulted in two delivering gullies (29 Mg) and two non-engineered points with fill erosion, one of which delivered to the stream (23 Mg). There were no other observed instances of mass wasting, including anything not related to the stream crossing or any landslides.

Table 40. *Summary of observed and predicted jammer road risks.*

Impact/Risk Type	Predicted Risks
Complete Complex Inventory	
Fine Sediment Delivery	2% of sediment produced; 0.02 Mg/yr
Estimated Sediment Delivery for All Jammer Roads	0.4 Mg/yr, using a delivery rate of 0.001 Mg/yr/km
Gullies and Fill Erosion Risks	29 Mg delivered to streams from gullies, 23 Mg delivered to streams from fill erosion, estimated 3 Mg/yr
Stream Crossing Survey	
Fill Erosion Risks, Observed	44% of stream crossings with fill erosion, estimated 17 Mg/yr delivered to streams
Fill Erosion Risks, Future Estimated	25% of estimated risk has been realized, up to 75% (600 m^3) may remain
Other Problems	9 crossings (13%) with observed stream diversions or other problems

We conducted a census of all of the stream crossings on jammer roads in the Center Horse and Morrell/Trail project area, for a total of 71 crossings. Streams were defined as continuous features with a bed, banks, and evidence of flow for some part of most years. There were 61 natural ford-type crossings (no infrastructure) and ten crossings with culverts. Nine crossings (13%) were observed to have evidence of stream diversion or other problems. There were 31 crossings (44%) with fill erosion, totaling 207 m^3 (7300 ft^3), all of which was assumed to deliver (331 Mg). This was roughly equivalent to that from road surfaces on non-jammer roads in the Center Horse and Morrell/Trail project area over 20 years (17 Mg/yr).

The average volume of fill available to erode at each crossing was estimated to be 12 m^3 (16 yd^3) per crossing. Of this amount, an average of 3 m^3 (4 yd^3) per crossing has already been eroded, suggesting that 25% of possible erosion has already occurred, and up to 75% remains (about 600 m^3 or 22,000 ft^3). Differences in the shape and construction of each stream crossing, and the timing of high flows and transport capacity of the streams, suggest that each stream crossing will respond at a different rate, and may include some deposition. It was found that on hillslopes of greater than about 40%, every stream crossing in the Center Horse area had fill erosion, suggesting that the stream crossings on steeper slopes may be at higher risk of failure than those on lower slopes.

Conclusions

Under the observed conditions, the GRAIP inventories in the Southwest Crown of the Continent suggest low risk across the measured metrics when considered at the watershed scale. The Center Horse and Morrell/Trail project area had the most risk overall. There are two other non-watershed GRAIP sites in the northern Rockies; one site in the Clearwater National Forest (Cissel et al. 2011A), and one in the Gallatin National Forest (Cissel et al. 2011B). Compared to these sites, these three watersheds fall within the typical range for landslide risk, gully risk, stream crossing plugging potential and diversion potential, and drain point problems and fill erosion for both sites. The stream crossing fill at risk is slightly higher in the Center Horse and Morrell/Trail project area and Poorman Creek, but within the typical range in Cold Creek. The Clearwater site had much higher road surface sediment delivery and hydrologic connectivity, while this data is in range of the Gallatin site. Compared to a site in the Olympic National Forest in western Washington (Cissel et al. 2011C), which is considered to have high risk in all metrics, the Center Horse and Morrell/Trail project area has low to moderately low risk in all areas.

Although sediment delivery risk related to roads is low from the watershed perspective, several road segments were identified that may need treatment to minimize sediment delivery effects that are significant at the stream reach scale. Depending on downstream habitat and species presence, fine sediment delivery effects may be significant at a stream reach scale. Ongoing work comparing aquatic habitat conditions between managed and unmanaged reaches using PIBO data will help refine these questions.

Road maintenance level appears to have a small to moderate effect on the various risk metrics. Higher maintenance levels (ML 3 and 4; more traffic, more frequent and more intense maintenance) had somewhat more sediment delivered from their road surfaces, but mass wasting risks were lower. Lower maintenance level roads (ML 1 and 2; little to no traffic, little to no maintenance) had higher mass wasting risks. These relationships suggest that traffic has an important effect on road surface fine sediment production, but regular more intense maintenance can prevent mass wasting problems. On some lower maintenance level roads, it may be beneficial to treat spots that are at high risk of erosion.

The sediment delivery from fill erosion and mass wasting at jammer road-stream intersections in the Center Horse and Morrell/Trail project area was on the same scale as the road surface fine sediment delivery from non-jammer roads in the same area. The highly vegetated and low slope jammer road surfaces themselves did not appear to have significant impacts. Treatments to jammer roads should be focused on the roads with stream crossings. However, the consequences of removing vegetation on the road surface to access the jammer road stream crossings may increase the contributions of their surface fine sediment to streams. Data to be collected in the summer of 2014 may help to further understand the causes and distribution of erosion at stream crossings on jammer roads.

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Appendix A: Road Risks by Maintenance Level Table

Road risk table for all three project areas, broken out by road maintenance level. There were not enough gullies or landslides in Poorman Creek or Cold Creek to perform this analysis, so they are omitted. See section 4.8 for more information.

	Operational Maintenance Level	# Drain Points	Sediment Production (kg/yr)	Sediment Delivery (kg/yr)	% Sediment Delivery	# Drain Point Problems	% Drain Point Problems	Fill Erosion (Mg)	Fill Erosion Delivery (Mg)	% Fill Erosion Delivered	# Gullies (n = 32)	Mass of Gullies (Mg)	Delivered Mass of Gullies (Mg)	# Landslides (n = 18)	Mass of Landslides (Mg)
Center Horse and Morrell/Trail	Unclassified	2131	112,500	4700	4%	368	17%	62	47	76%	9	183	172	9	1720
	1 - Basic Custodial Care (Closed)	616	34,680	1450	4%	79	13%	18	11	59%	6	45	38	1	27
	2 - High Clearance Vehicles	1251	154,740	4940	3%	160	13%	5	1	13%	7	15	6	5	171
	3 - Suitable for Passenger Cars	492	123,560	9540	8%	98	20%	10	0	0%	8	76	1	2	175
	4 - Moderate Degree of User Comfort	197	12,030	670	6%	55	28%	0	0	0%	2	13	0	0	0
	NA - Not Applicable	374	18,700	60	0.3%	51	14%	1	0	0%	1	1	0	1	18
	Total	**5061**	**456,200**	**21,360**	**5%**	**811**	**16%**	**97**	**59**	**60%**	**33**	**332**	**217**	**18**	**2111**
Poorman Creek	Unclassified	542	33,950	660	2%	38	8%	0	0	0%					
	1 - Basic Custodial Care (Closed)	169	11,030	4	0.03%	5	3%	0	0	0%					
	2 - High Clearance Vehicles	1118	125,710	1680	1%	145	13%	6	1	9%					
	3 - Suitable for Passenger Cars	361	76,720	9160	12%	82	23%	12	3	24%					
	Total	**2190**	**247,420**	**11,500**	**5%**	**270**	**12%**	**18**	**3**	**19%**					
Cold Creek	Unclassified	767	24,320	500	2%	47	6%	0	0	0%					
	1 - Basic Custodial Care (Closed)	2467	87,880	5780	7%	200	8%	5	0	11%					
	2 - High Clearance Vehicles	17	440	0	0%	6	35%	0	0	0%					
	3 - Suitable for Passenger Cars	333	49,190	3530	7%	31	9%	0	0	0%					
	Grand Total	**3584**	**161,840**	**9810**	**6%**	**284**	**8%**	**5**	**0**	**10%**					
All Three	Unclassified	3440	170,780	5850	3%	453	13%	62	47	76%					
	1 - Basic Custodial Care (Closed)	3252	133,590	7240	5%	284	9%	23	11	49%					
	2 - High Clearance Vehicles	2386	280,890	6620	2%	311	13%	12	1	11%					
	3 - Suitable for Passenger Cars	1186	249,470	22,230	9%	211	18%	22	3	13%					
	4 - Moderate Degree of User Comfort	197	12,030	670	6%	55	28%	0	0	0%					
	NA - Not Applicable	374	18,700	60	0.3%	51	14%	1	0	0%					
	Total	**10835**	**865,460**	**42,670**	**5%**	**1365**	**13%**	**120**	**62**	**52%**					

Appendix B: Glossary of Selected Terms

Below is a list of terms, mostly of drainage point types, but also of some other commonly used terms, for the purpose of clarification. Adapted from Black, et al. (2012), Fly, et al (2010), and Moll (1997).

Broad based dip. ***Constructed:*** Grade reversal designed into the road for the purpose of draining water from the road surface or ditch (also called dip, sag, rolling grade, rolling dip, roll and go, drainage dip, grade dip). ***Natural:*** A broad based dip point is collected at the low point where two hillslopes meet, generally in a natural swale or valley. This is a natural low point in the road that would cause water on the surface of the road to drain out of the road prism.
Cross drain. This is not a feature collected specifically in GRAIP, and it can refer to a number of other drainage features. It is characterized by any structure that is designed to capture and remove water from the road surface or ditch. Ditch relief culverts, waterbars, and broad based dips can all be called cross drains.
Diffuse drain. This is a point that is characterized by a road segment that does not exhibit concentrated flow off the road. Outsloped roads or crowned roads often drain half or all of the surface water diffusely off the fillslope. Although collected as a drain point, this feature is representative of an area or a road segment rather than a concentrated point where water is discharged from the road prism. A drop of water that lands on a diffuse road segment will not flow down the road or into the ditch, but more or less perpendicular to the centerline off the road surface and out of the road prism. Also called sheet drainage or inter-rill flow.
Ditch relief culvert. This drain point is characterized by a conduit under the road surface, generally made of metal, cement, or wood, for the purpose of removing ditch water from the road prism. This feature drains water from the ditch or inboard side of the road, and not from a continuous stream channel.
Flow path. This is the course flowing water takes, or would take if present, within the road prism. It is where water is being concentrated and flowing along the road from the place where it enters the road prism, to where it leaves the road prism. This can be either on the road surface, or in the ditch.
Lead off ditch. This drain point is characterized by a ditch that moves flow from the roadside ditch and leads it onto the hillslope. Occurs most often on sharp curves where the cutslope switches from one side of the road to the other. Also known as a daylight ditch, mitre drain, or a ditch out (though this term can also describe other types of drainage features).
Mg, megagrams. This unit is equivalent to 1 metric tonne, 1000 kg, and 1,000,000 g. Equivalent to 2204 lbs, and 10% larger than 1 U.S. short ton (2000 lbs).
Non-engineered drainage. This drain point describes any drainage feature where water leaves the road surface in an unplanned manner. This can occur where a ditch is dammed by debris, and the water from the ditch flows across the road, where a gully crosses the road, where a wheel rut flow path is diverted off the road due to a slight change in road grade, or where a berm is broken and water flows through. This is different from a diffuse drain point, which describes a long section of road that sheds water without the water concentrating, whereas this point describes a single point where a concentrated flow path leaves the road.
Orphan drain point. This is any drain point that does not drain any water from the road at the time of data collection. Examples include a buried ditch relief culvert, or a water bar that has been installed on a road that drains diffusely.
Stream crossing. This drain point is characterized by a stream channel that intersects the road. This feature may drain water from the ditch or road surface, but its primary purpose is to route stream water under or over the road via a culvert, bridge, or ford. A stream for the purposes of GRAIP has an armored

channel at least one foot wide with defined bed and banks that is continuous above and below the road and shows evidence of flow for at least some part of most years.

Sump. ***Intentional:*** A closed depression where water is intentionally sent to infiltrate. ***Unintentional:*** Any place where road water enters and infiltrates, such as a cattle guard with no outlet, or a low point on a flat road.

Waterbar. This drain point is characterized by any linear feature that is perpendicular to the road that drains water from the road surface and/or ditch out of the road prism or into the ditch. Waterbars may be constructed by dipping the grader blade for a short segment, or adding a partly buried log or rubber belt across the road. Some road closure features may also act as a waterbar, such as a tank trap (also known as a closure berm or Kelly hump). Cattle guards that have an outlet that allows water to flow out are also considered to be water bars. These features may also be known as scratch ditches if they drain water into the ditch.

Appendix C: GRAIP Data Management Plan

Project Title: A new model of watershed-scale aquatic monitoring from the Crown of the Continent: Quantifying the benefits of watershed restoration in the face of climate change

Data Input-New Collection

1	**General**
Description	Road Inventory data and output from the Geomorphic Road Analysis and Inventory Package (GRAIP)
Budget	
Format	Grids, and shapefiles
Data Processing & Scientific Workflow	See The Geomorphic Road Analysis and Inventory Package (GRAIP) Volume 1 Data Collection Method and Volume 2: Office Procedures. Rocky Mountain Research Station General Technical Report RMRS-GTR-280WWW http://www.treesearch.fs.fed.us/pubs/40654 and 281WWW http://www.treesearch.fs.fed.us/pubs/40655
Protocols	See The Geomorphic Road Analysis and Inventory Package (GRAIP) Volume 1 Data Collection Method and Volume 2: Office Procedures. Rocky Mountain Research Station General Technical Report RMRS-GTR-280WWW and 281WWW
Backup and Storage	The original input data were copied to a local PC at RMRS Boise and backed up on second hard-drive and a local server.
QA/QC	See field and office manuals above
Metadata	With each output file
Volume Estimate	2 GB
Archive Orgs	Final data to be archived on DVD at RMRS Boise and sent to GNLCC web portal for archiving.
Access and Sharing	Data will be shared with partners and cooperators as it is collected, analyzed, and published.
Exclusive Use	We request a maximum of a two year extension following the conclusion of the funding period to write manuscripts and publish our results. During this time data will be shared with cooperators and upon request with non-project related researchers and data and project managers. After the extension period, no restrictions to the data access.

Restrictions	We do not anticipate restrictive use of the data after publication. Proper reference to source required.
Citation	TBD
TBD	NA
Contact	Tom Black USDA Forest Service Rocky Mountain Research Station, Boise. tblack@fs.fed,us

Data Inputs

1	**Elevation data (DEM)**
Description	30 meter DEM
Format	Raster Data-Grid
Data Processing & Scientific Workflow	Use as acquired, resampled to 5 meter using bilinear resampling
Source	National Elevation Dataset (NED)
Protocols	See The Geomorphic Road Analysis and Inventory Package (GRAIP) Volume 2: Office Procedures. Rocky Mountain Research Station General Technical Report RMRS-GTR-281WWW
Backup and Storage	The original input data were copied to a local PC at RMRS Boise and backed up on second hard-drive and a local server.
Volume Estimate	50 MB
Access and Sharing	Free
Restrictions	Unrestricted use

2	**GRAIP Road Inventory Field Data**
Description	A GPS referenced field inventory documenting the hydrology and geomorphology of the road network
Format	ArcGIS 9.3 shapefiles
Data Processing & Scientific Workflow	These files have been exported from the GPS device, differentially corrected in Pathfinder Office, edited to minimize GPS errors in road alignment and combined and exported as shapefiles. See The Geomorphic Road Analysis and Inventory Package (GRAIP) Volume 1 Data Collection Method and Volume 2: Office Procedures. Rocky Mountain Research Station General Technical Report RMRS-GTR-280WWW

	and 281WWW
Protocols	Data is collected following the protocol in the field manual by persons receiving a two week intensive training course teaching the material in the Field manual, (see above).
Backup and Storage	The original input data were exported from field devices to a field laptop. Files are then copied to a PC at RMRS Boise and backed up on second hard-drive and a local server.
QA/QC	Field and Office QA/QC documented in the manuals, see above
Metadata	With each file and directory
Volume Estimate	5-20 MB

Data Outputs

1	**GRAIP Model Output Shapefiles**
Description	Road line, Drain point and stream shapefiles that contain observed and modeled sediment production, delivery and other geomorphic and hydrologic attribute data.
Format	ArcGIS 9.3 shapefiles
Data Processing & Scientific Workflow	See office manuals
Protocols	See office manuals
Backup and Storage	Files are produced on a PC at RMRS Boise and backed up on second hard-drive and a local server.
QA/QC	See office manuals
Metadata	Associated with each file and directory
Volume Estimate	10-50 MB
Archive Orgs	Final data to be archived on DVD at RMRS Boise and sent to GNLCC web portal for archiving.
Access and Sharing	Data will be shared with partners and cooperators as it is collected, analyzed, and published.
Exclusive Use	We request a maximum of a two year extension following the conclusion of the funding period to write manuscripts and publish our results. During this time data will be shared with cooperators and upon request with non-project related researchers and data and project managers. After the extension period, no restrictions to the data access.
Restrictions	We do not anticipate restrictive use of the data after publication. Proper reference to source required.
Citation	TBD

Digital Object Identified (DOI) Link	TBD
Contact	Tom Black USDA Forest Service Rocky Mountain Research Station, Boise. tblack@fs.fed,us

2	**GRAIP Model Intermediate and Output GRIDS**
Description	GRAIP uses various grids created by the programs TauDEM to route sediment and create a channel network. The program SinMap makes slope stability predictions from the DEM. These grids are called on and updated by GRAIP.
Format	ArcGIS 9.3 grids
Data Processing & Scientific Workflow	See office manuals
Protocols	See office manuals
Backup and Storage	Files are produced on a PC at RMRS Boise and backed up on second hard-drive and a local server.
QA/QC	See office manuals
Metadata	Associated with each directory and in the office manual
Volume Estimate	20-50 MB
Archive Orgs	Final data to be archived on DVD at RMRS Boise and sent to GNLCC web portal for archiving.
Access and Sharing	Data will be shared with partners and cooperators as it is collected, analyzed, and published.
Exclusive Use	We request a maximum of a two year extension following the conclusion of the funding period to write manuscripts and publish our results. During this time data will be shared with cooperators and upon request with non-project related researchers and data and project managers. After the extension period, no restrictions to the data access.
Restrictions	We do not anticipate restrictive use of the data after publication. Proper reference to source required.
Citation	TBD
Digital Object Identified (DOI) Link	TBD
Contact	Tom Black USDA Forest Service Rocky Mountain Research Station, Boise. tblack@fs.fed,us

Software

1	**GRAIP**
Description	GRAIP is a free software package that runs as an

	extension in ArcGIS 9.3 (at present). It performs the calculations of road sediment and routes the sediment to streams in addition to calculating a variety of road hydro-geomorphic risk metrics.
Restrictions	This software is in the public domain.
Fees	Free
Source/Link	http://www.neng.usu.edu/cee/faculty/dtarb/graip/

2	**TauDEM**
Description	TauDEM is a tool that runs in Arc GIS to calculate hydrologic attributes of a landscape using a DEM
Restrictions	This software is in the public domain.
Fees	Free
Source/Link	http://www.neng.usu.edu/cee/faculty/dtarb/graip/

3	**SINMAP 2.0**
Description	GRAIP
Restrictions	This software is in the public domain.
Fees	Free
Source/Link	http://www.neng.usu.edu/cee/faculty/dtarb/graip/

4	**ArcGIS 9.3**
Description	Geographic Information System Software
Restrictions	This software is available for purchase form ESRI
Fees	TBD
Source/Link	http://www.ESRI.com