Power Fire GRAIP
Watershed Roads Assessment

Bear River, Panther Creek, and
Upper North Fork Mokelumne River Watersheds
Eldorado National Forest, California

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Executive Summary

This report presents results from a watershed-wide inventory and assessment of roads in Bear River, Panther Creek, and upper North Fork Mokelumne River watersheds which encompass the Power Fire area in the central Sierra Nevada mountains in California. The method used was the Geomorphic Road Analysis and Inventory Package (GRAIP), 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:

- Evaluate the types and sources of road-related hydrologic risk in the watershed
- Locate and quantify sediment sources and contributions to streams
- Identify and prioritize future restoration actions

The GRAIP model was used to predict risk and impacts from roads. The model predicts road to stream hydrologic connectivity, sediment production and 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. Inventory data are also used to locate and describe problems with existing drain points.

Field inventory, modeling, and analyses were carried out for 337 km (209 mi) of roads. Field data were collected in the summers of 2014 and 2015.

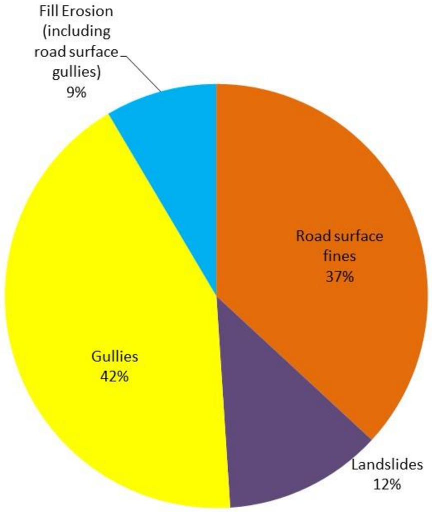
Observations of road surface erosion used to estimate road surface sediment production were made from sediment plots in geologically and climatologically similar watersheds north of Quincy, CA in the Sierra Nevada where there were four plots on roads in granitic geology types, and four on volcanic geology types. Six plots were installed in the Power study area and measurements will begin in 2016.

Several main results were found:

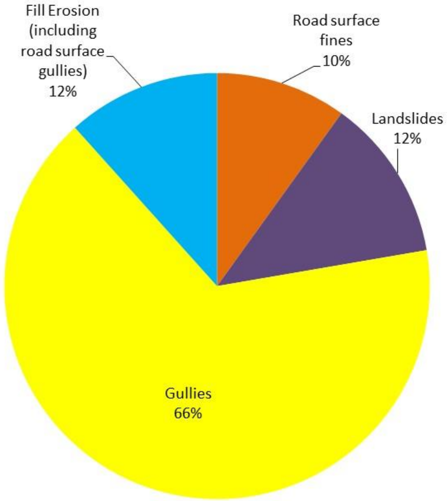
- Among road related sediment sources, gullies produced and delivered the most sediment.
- Road surfaces produced nearly the same amount of sediment mass as gullies, but delivered less sediment.
- Fill erosion and landslides delivered similar amounts of sediment as road surfaces.
- 90% of delivered road surface sediment was delivered through 5% of drain points.
- Areas with the highest predicted road surface fine sediment delivery in streams per unit of watershed area were in the area north of Lower Bear River Reservoir, in Rattlesnake Creek, and in East Panther Creek.
- Diffuse drains were the most effective drain point type at reducing hydrologic connectivity. Waterbars and lead off ditch drains were also very effective. Reduction of stream connectivity should be focused on drain point types that represented the highest

percentage of total sediment delivered: non-engineered drains, broad based dips, ditch relief culverts and stream crossings.

- Native road surfaces produced and delivered the majority of road surface fine sediment. Road surfaces with rocky condition represented the highest percentage (41%) of total road surface fine sediment produced and delivered (52%). Surfaces with rilled/eroded condition delivered 29% of the normalized total, followed nearly equally by surfaces that had a good or rutted condition (11% and 9%, respectively). The same pattern existed when the analysis was performed with only native surface roads.
- Roads with base of fill located within 15 m (50 ft) of a stream had a high connectivity rate (60%).
- Areas with the highest gully occurrence rates, substantial gully initiation risk, and the highest gully sediment production and delivery were along Highway 88 and along paved roads underlain by Mehrten Formation, glacial deposits, and undifferentiated Paleozoic geology types.
- Landslides in the study area were concentrated in the East Panther Creek watershed. Landslides along 8N05 were activated in winter 2004/2005 and have since been repaired. Active landslides on 8N36 were less accessible, and the delivering features were small. Large landslides encompassed or buried, and blocked the roads 8N65 and 8N05B, but were not road caused.
- If the stream crossings with the greatest risk of failure, and those that were failing at the time of study were to deliver the entire mass of fill present at those crossings, the total mass would be 2,430 mg, or 3.5 times the delivered amount of all the other sediment sources combined.



Percent of total sediment produced from each road related sediment source in the Power study watersheds.



Percent of total sediment delivered from each road related sediment source in the Power study watersheds.

Summary table of GRAIP road-related risk predictions in the Power study watersheds.

Impact/Risk Type	**GRAIP Predicted Risks**
Road-Stream Hydrologic Connectivity	54 km (34 mi), 16% of road length, and 778 (17%) drain points were stream connected
Fine Sediment Delivery	70 Mg/year, 14% of all fine sediment produced from road surfaces delivered to streams
Landslide Risk	Estimated 1,740 Mg delivered to streams, (51% of all road related landslide sediment produced);
Gully Risk	Estimated 9,300 Mg of gully sediment delivered (80% of all gully sediment produced); An average of 50% of all drainage locations exceed ESI_{crit} threshold for paved roads in Mehrten Formation, glacial deposit, and undifferentiated Paleozoic geology types
Stream Crossing Risk	
- plug potential	16 sites (8%) with elevated risk (SBI of 3)
- fill at risk	27,970 m^3, 44,750 Mg
- diversion potential	104 sites (41%) with diversion potential
Drain Point Problems	1,148 drain points (25% of all) with problems; 1,640 Mg of road derived fill erosion delivered (70% of all fill erosion sediment produced)

16% of surveyed road length was hydrologic connected to the stream network; 54 km out of 337 km (34 mi out of 209 mi). The model predicted 70 Mg yr^{-1} of delivered road surface fine sediment to stream channels, which is 14% of the 503 Mg yr^{-1} predicted sediment production. This sediment was delivered through 778 of 4,657 (17%) drain points. It was found that road surfaces that were rocky, rilled, or eroded were most likely to deliver sediment to streams, and that roads with native surfaces delivered the majority of sediment. Less than 5% of drain points delivered 90% of road surface sediment. This information can help focus remediation efforts on a limited set of drain points in the area.

Specific sediment due to road surface-related fine sediment in some small catchments was as high as 18 Mg km^{-2} yr^{-1}. Specific sediment delivery from all road related sources in this study was 1.8 Mg km^{-2} yr^{-1}. Specific sediment from all road related sources in this study was about 1.2% of the sediment accumulation rate in Tiger Creek Afterbay reservoir at the downstream end of the study area.

There were 20 landslides observed by field crews in the course of the inventory, with a total volume of 12,740 m^3 (16,660 yd^3). Of those, 17 were observed as having direct interaction with the road prism. It was conservatively estimated that as much as 1,740 Mg of road related landslide derived sediment has been delivered to streams. If delivered over 20 years, an average annual landslide delivery rate can be estimated at 87 Mg yr^{-1}, or roughly 1.2 times the fine sediment amount delivered annually from road surfaces. It would take the road surfaces 25 years to deliver the same mass as the total mass delivered by road related landslides in the study area. Calibrated stability index modeling with SINMAP showed that 28 km^2 (11 mi^2), or roughly 18%, of the watershed area was put at higher risk of shallow landslide initiation by road drainage.

Gullies were observed at 218 drain points by field crews, totaling 7,220 m^3 (9,450 yd^3) in volume. Of those, two occurred in a wet swale, and 21 had flow contributions from springs, seeps, and other flow diversions (e.g. from an overtopped stream crossing). It is estimated that these gullies delivered 9,300 Mg of fine sediment to the stream channel. If delivered over 20 years, an average annual rate can be estimated at 465 Mg/yr, or roughly 7 times the amount of fine sediment delivered annually from road surfaces. It would take the road surfaces 133 years to deliver the same mass as the total mass delivered by gullies in the study area. Among the 3,487 applicable drain points in the entire project area, 198 (6%) had a gully. A critical gully initiation index (ESI_{crit}) was not meaningful across the entire study area. Areas within the study area where there were meaningful ESI_{crit} values were along state Highway 88, and along paved roads in Mehrten, glacial, or undifferentiated Paleozoic geology types. The ESI_{crit} value along Highway 88 was found to be 5.6, and along paved roads in those geologies, 6.3.

There were 216 stream crossings with culverts recorded, of which 212 were analyzed for plugging risk. The average stream blocking index (SBI) for these points was low at 1.5. No crossings had an SBI of 4, which is the highest possible value. Sixteen crossings had an elevated SBI of 3. The total magnitude of fill at risk at all crossings in an overtopping type event was 27,970 m^3 (36,580 yd^3, 44,750 Mg). There were 104 stream crossings with the potential to divert stream flow from a plugged culvert down the road and onto unchanneled hillslopes and eight were actively diverting. There were 16 stream crossings with elevated risk in more than one area (SBI, fill at risk, diversion potential). Seven had an SBI of 3, but no diversion potential. There were three crossings with an SBI of 3 and no diversion potential, but more than 100 m^3 of fill at risk. There were 9 crossings with an SBI of 3 and the potential to divert streamflow. Four had more than 100 m^3 of fill at risk. These four crossings have the highest combined stream crossing risk and are good candidates for risk reduction treatments. Eighteen other crossings had a high priority for treatments because they had totally blocked culverts, had fill erosion through the fill due to overtopped or diverted stream flow, or were actively diverting flow. All crossings were assigned a treatment priority rank based on presence of problems, risk factors, and magnitude of fill at risk.

Of the 4,657 recorded drain points, 1,148 (25%) had one or more problems of some type (e.g. blocked or crushed culvert, excess puddling on the road surface). Non-engineered drains had the highest frequency of problems, with 525 of 1,190 (44%), followed by ditch relief culverts (368 of 872, 42%). Site fill erosion was recorded at 153 drain points (3%), with a total volume of 1,100 m^3 (38,660 ft^3, 1,750 Mg). Road surface gully fill erosion routed sediment to 76 (2%) drain points, with a total mass of 595 Mg (360 m^3, 12,750 ft^3). Estimated total fill erosion sediment delivery mass was 1,640 Mg (1,030 m^3, 36,410 ft^3), or about 70% of total fill erosion mass produced. If delivered over 20 years, an average annual fill erosion delivery rate can be estimated at 82 Mg yr^{-1}, or roughly 1.2 times the amount of fine sediment delivered from road surfaces. It would take the road surfaces 23 years to deliver the same mass as the total mass delivered by road related landslides in the study area.

The road surface-derived fine sediment delivery rate in the Bear River, Panther Creek, and upper North Fork Mokelumne River watersheds was found to be similar to results from studies in regionally and geologically similar study areas, and much higher than in areas of Oregon underlain by volcanic geology types. Percent connectivity by road length in the Power study watersheds was similar to studies in geologically similar study areas, and in areas of Oregon underlain by volcanic geology types, but much lower than for studies in western Oregon and Washington with much higher annual precipitation and an older era of road construction.

1.0 Background

The National Forest Transportation System represents a major public investment and provides many benefits to forest managers and the public. However, forest roads can also have negative effects on water quality, aquatic ecosystems, and other resources (Cedarholm et al. 1981, Megahan and Kidd 1972, Nelson and Booth 2002, Wemple et al. 1996). There is currently a large backlog of unfunded maintenance, improvement, and decommissioning work needed on National Forest roads. Many roads were built before modern Best Management Practices (BMPs) were implemented. Critical components of the infrastructure (e.g., culverts) are nearing or have exceeded their life-expectancy, adding further risks and impacts to watershed and aquatic resources.

Lower Bear River, Panther Creek, and upper North Fork Mokelumne River watersheds (Power study area) are some of the uppermost headwater tributaries to the Mokelumne River. North Fork Mokelumne and upper Mokelumne Rivers are currently under consideration and study for designation as Wild and Scenic Rivers (California Legislature 2015). They represent a valuable and important source of water for wildlife habitat, recreation, agricultural irrigation, and domestic drinking water along their entire length and ultimately to the major water supply for 1.3 million San Francisco Bay area residents (USDA 2005). In order to quantify the amount and location of sediment contributions from roads to streams in the Power study watersheds, the Rocky Mountain Research Station used a site-specific road sediment inventory of their design, the Geomorphic Road Analysis and Inventory Package (GRAIP, Prasad et al 2007, Cissel et al. 2012A, Black et al. 2012, http://www.fs.fed.us/GRAIP). Settlement funds generated in 2013 from the October 2004 Power Fire that burned 69 km^2 (16,993 acres, 27 mi^2), most of which was within the study area (Figure 5), were allotted to study fire effects and design restoration projects in the watersheds surrounding the fire, and provided the impetus for employing GRAIP.

The GRAIP data collection and analysis procedure provided land managers with field-based data that captured the extent to which roads interact with the stream channel, and can be used to prioritize actions to minimize adverse watershed and aquatic impacts from roads. GRAIP identified precise locations where sediment delivery occurred, where drainage features were compromised, and where road maintenance, restoration, or decommissioning could be recommended.

2.0 Objectives and Methods

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

- Identify the current level of fine sediment delivery from roads to streams in the Bear River, Panther Creek, and upper North Fork Mokelumne River watersheds.
- Identify the types and sources of road-related hydrogeomorphic risk in the watersheds.
- Locate and quantify sediment sources and contributions to streams.
- Select and prioritize future restoration actions to improve watershed conditions.
- Compare GRAIP results with other local and geologically similar sediment production and delivery rates.

GRAIP was 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 field surveys were 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 coupled 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 (Cissel et al. 2012A). Detailed information about the performance and condition of the road drainage infrastructure was also collected.

The base erosion rate is the annual road surface sediment production rate that is derived directly from field measurement methods. Transported sediment discharged from distinct road plots was collected and measured twice a year. The base erosion rates were calculated based on mass collected, plot length and slope, surface type, and vegetation (Black and Luce 2013). The units are kilograms of mass produced per year, per vertical meter of elevation (kg yr^{-1} m^{-1}).

Field measurements used to calculate the base erosion rates were from sediment collected from eight study plots from two watersheds in Plumas National Forest that were geologically and climatologically similar to the Power study watersheds (Cabrera et al. 2015). In the Plumas, plots in geology types referred to as volcanics were located within a large conglomerate unit capped by rhyolite upslope. Plots in granitic geology types were located within Sierran granodiorite. In this study volcanic geology types included the Merhten Formation (strongly welded lahar), the Valley Springs Formation (sandstone, ash, interbedded tuffs, and claystone), and undifferentiated Paleozoic metamorphic rocks. Granitics included Sierran granite and granodiorite, and glacial deposits.

Plots were constrained upslope and downslope by constructed waterbars, and all surface and ditch flow was directed via a culvert into settling tanks. Plot construction and data processing methods are well documented (Black and Luce 2013). Plots were installed in June 2014 and derived rates are based on 1.5 years of data, from three collection times; October 2014, May 2015, and October 2015. Base erosion rates derived represent the existing conditions in the plot which were installed to account for differences in geology type and vegetation cover. Four plots were installed on road segments in granitic geology, and four in volcanic geology so that a unique base erosion rate could be calculated for each geology type. The plots were all installed on native surface roads. A multiplier was applied in the model to adjust for rocked or paved surfaces of roads in the GRAIP surveys. Similarly, vegetation presence or absence was a multiplier in the model. Observations of vegetation cover taken in the 2014 survey were of loose vegetation and pine needles. The 2015 survey vegetation observations were taken of only live rooted vegetation. Observations of the two different types of vegetation cover on the plots were made so that a base erosion rates could be calculated for both the 2014 and 2015 surveys and their specific vegetation cover observation type. The two types of vegetation observations were made in the plots for each of the two geology types, so the result were four unique base erosions rates: volcanic geology with loose vegetation and pine needle cover, volcanic geology with live rooted cover, granitic geology with loose vegetation and pine needle cover, and granitic geology with live rooted cover.

The base erosion rates derived for loose vegetation cover were 22 kg yr^{-1} m^{-1} for volcanic geology, and 36 kg yr^{-1} m^{-1} for granitic geology. The base erosion rates derived for live rooted vegetation were 84 kg yr^{-1} m^{-1} for volcanic geology, and 63 kg yr^{-1} m^{-1} for granitic geology. For the 2014 roads with observations recorded for loose vegetation cover, the volcanics base erosion rate was applied to 89 km (55 mi, 26%) of road length, and the granitics base erosion rate was applied to 112 km (70 mi, 33%) of road length. For the 2015 roads with observations recorded for live rooted vegetation, the volcanics base erosion rate was applied to 73 km (45 mi, 22%) of road length, and the granitics base erosion rate was applied to 63 km (39 mi, 19%) of road length.

Geology type was determined using a digitized version of the California Division of Mines and Geology Geologic Map of the Sacramento Quadrangle, California, 1:250,000 (Wagner et al. 1981, Figure 6). Roads mapped as underlain by granitic rock types (granite or diorite) or volcanic rock types (Mehrten or Valley Springs Formations) were easily assigned the corresponding base rate. Roads underlain by undifferentiated Paleozoic metamorphic rocks were surrounded by, and were most similar to volcanics, and were assigned the volcanics base erosion rates. Roads underlain by glacial deposits were surrounded by, and were most similar to granitics, and were assigned the granitics base erosion rates. There were 52 km (32 mi, 15%) of road length in the undifferentiated Paleozoic geology type, and 25 km (16 mi, 7%) of road length in glacial deposits.

3.0 Assumptions and Limitations

Assumptions

It was demonstrated by Luce and Black (1999) that the variables length, slope, and vegetation cover in the equation used to calculate road surface sediment production reflect the physical mechanisms which actually control erosion from roads surfaces. The multiplier in the equation that accounts for surface type was shown to be a significant factor by (Burroughs 1989).

Streams were defined as having discernable channel morphology with a minimum bed width of one foot (0.3 m), evidence of active sediment transport in the form of exposed, fresh, mobile grains, and channel continuity for at least 100 feet up and downstream from the road. Culverted drain points in swales which did not meet all those criteria were designated as ditch relief culverts. If the flow path below a ditch relief culvert reached or became a flow path that met stream crossing definitions, it was determined to be stream connected. A record of magnitude of fill sediment mass at those drain points designated as ditch relief culverts was considered unnecessary due to low probability of adequate flow to cause plugging the culvert, and thus, low risk of fill failure at those sites.

Where a drain point was observed to be hydrologically connected to the stream channel network, sediment delivery from the associated road related sediment sources was assumed to be total. No partial delivery was estimated for road surface, gully, landslide, or fill erosion contributions. For estimated annual sediment delivery, accumulation, and specific sediment rates in the stream network, it was assumed that any sediment delivered to a stream channel and routed down through the stream network remained in suspension with no instream deposition.

For comparison of chronic annual road surface sediment delivery rates to episodic sediment delivery from the other sediment sources (landslides, gullies, and fill erosion), a 20-year period was used to average the total masses delivered from each source. This “annual” delivery rate for mass wasting oversimplified the intermittent character of these sources, but realistically reflects the observed increase of mass wasting events triggered in the December and January 1996/1997 20-year storm events (CNRFC 2016B, Archer 2016).

Base rates used to estimate road surface sediment production and delivery rates were derived from data collected in Plumas National Forest. It was assumed that the Plumas plots were in geology types similar to geology traversed by the roads in this study. Some differences were notable and were discussed in Section 2.0.

Limitations

This GRAIP study records a snapshot in time of existing geomorphic evidence observable in the field at the time of study, and therefore reflected a short term view of the geomorphic and hydrologic conditions. The percent connection, road surface erosion rates, and base rates reported in this study may not reflect a long term average because of the short term period of observation of this study during a period following four years of drought conditions. Given the Exceptional drought conditions in which the survey was conducted, this study likely recorded a period of generally low erosion rates.

Base rates are intended to represent a wide range of conditions such as rainfall, road surface, and runoff conditions over time, but may be higher or lower than a true long-term average due to the short duration of observation. Field data collected to calculate the base erosion rates were collected during Severe and Exceptional drought years so were likely lower than a long term average.

The study surveyed only road related sediment sources. Any sediment generated by hillslope processes not related to the roads was not accounted for.

Connectivity was determined by observable evidence only. If indicators of flow below a drain point were not observed to be continuous to a stream channel (as defined by GRAIP), the drain point was considered not stream connected. The duration for which evidence of flow remains observable post-emplacement was unknown for the study area, therefore it was not possible to report a time period for which the observed connectivity encompassed. Suppose drain points that had no evidence of connectivity at time of study had experienced large storm events that would have cause connectivity, but the storms had occurred far enough in the past that flow evidence had deteriorated by time of study, then connectivity could have been greater than reported here. This hypothetical case would apply mostly to drain points that discharged near streams or floodplains. It is unknown what magnitude of storm, and in turn, what period of time would be necessary to obscure its flow evidence, would conform to this hypothetical situation.

GRAIP does not directly address the impacts to stream conditions such as water quality, channel morphology, and flows. The study measured and reported the road related sources and represents a limited few components of a complete sediment budget in the watersheds. Previous research cited states that increases in sediment input to streams can have negative watershed impacts (Cedarholm et al. 1981, Megahan and Kidd 1972, Nelson and Booth 2002, Wemple et al. 1996).

Many roads within the watersheds were excluded which likely had an effect on watershed scale results. Only some of all existing non-system roads were surveyed due to time limitations. Excluded non-system roads, roads outside the designated study area, and roads not surveyed within private lands represent some portion of road sediment production and delivery not accounted for in some of the subwatersheds within the study area, especially Rattlesnake Creek, Upper Beaver Creek, and East and West Panther Creeks, and to a lesser extent in Little Bear River and Cole Creek.

4.0 Study Area

The study area lies in the Sierra Nevada within the upper Mokelumne River watershed in eastern Amador County, CA (Figure 1, Figure 2). The project boundaries are the Mokelumne Wilderness on the east, North Fork Mokelumne River along the south, private logging company property boundary on the west, the ridge along State Highway 88 along the northwest, and the ridge above Bear River Reservoir on the north (Figure 7). Bear River, East and West Panther Creeks, and Cole Creek within the project area are major tributaries which flow from north to south to the North Fork Mokelumne River. The watersheds from headwaters to the North Fork Mokelumne confluence with Panther Creek drain 436 km^2 (169 mi^2, 107,740 acres). The project area encompasses 160 km^2 (62 mi^2, 39,540 acres) within the watersheds (37%), and its southern boundary runs along 21.3 km (13.2 mi) of the North Fork Mokelumne River from the upper reach of Salt Springs Reservoir to a point upstream of the Panther Creek confluence.

The generally west-southwest flowing, 100 km (62 mi) long North Fork Mokelumne River forms the longest tributary in the upper Mokelumne River system. Its headwaters begin at the Sierra Nevada crest roughly 10 km (6 mi) east of the project area, and it becomes upper Mokelumne River from its confluence with the Middle Fork Mokelumne River to Pardee and Camanche Reservoirs roughly 62 km (39 mi) west of the project boundary. Below Camanche Dam, the lower Mokelumne River meanders another 55 km (34 mi) through the California Central Valley in San Joaquin County to its mouth at the San Joaquin River about 31 km (34 mi) west of Lodi, CA (Figure 2).

Water in the North Fork Mokelumne River is valued for habitat, recreation, and power generation. The North Fork Mokelumne and upper Mokelumne Rivers from Salt Springs Reservoir to Pardee Reservoir are under consideration for designation as a California Wild and Scenic River as of October, 2015. The state mandated study to assess the river for suitability of the designation is scheduled to conclude by December, 2017 (California Legislature 2015). The upper North Fork Mokelumne river hosts habitat for several rare, threatened, endangered, and sensitive fish and amphibian species including the foothill yellow-legged frog, mountain yellow-legged frog, and western pond turtle (USDA 2005, Foothills Conservancy 2013), as well as native rainbow trout, introduced brook and brown trout, and various aquatic invertebrates (PG&E 2009). Its waters are prized by recreationalists who enjoy camping, fishing, and swimming, and whitewater boating. These species and activities all rely on adequate flow releases from the reservoirs (PG&E 2009, Foothills Conservancy 2000).

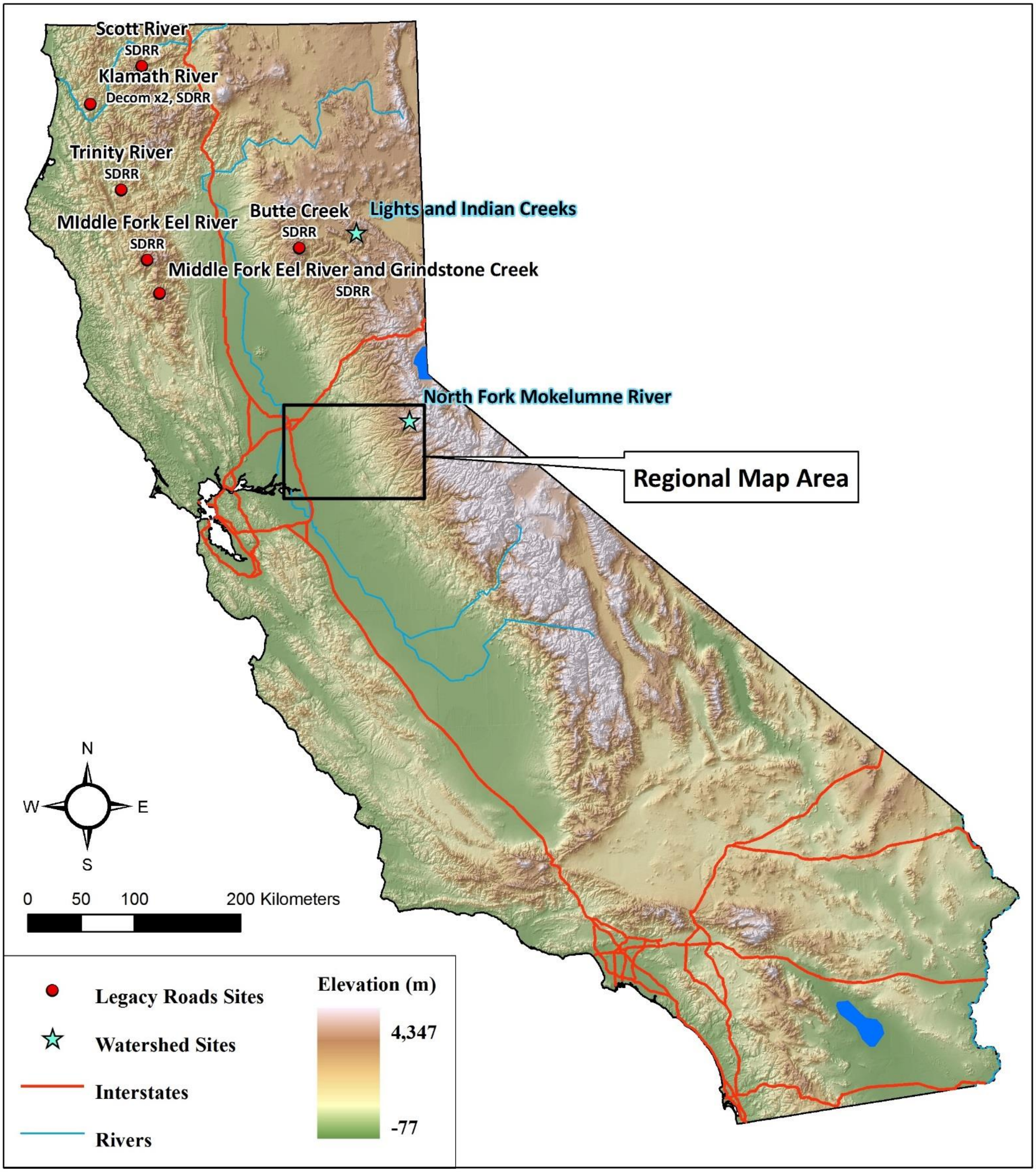


Figure 1. Location of watershed inventories and Legacy Roads Monitoring Project sites in the California section of the Pacific Southwest Region.

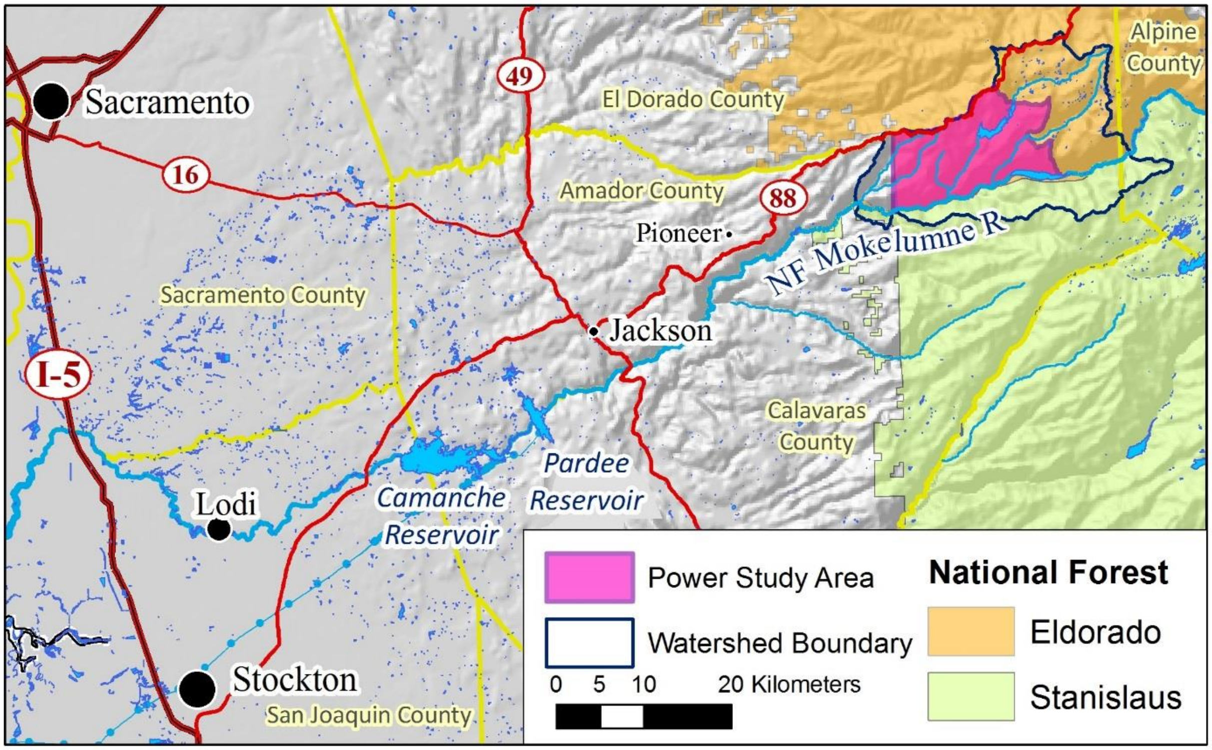


Figure 2. Power study area location and surrounding National Forests, counties, major highways, cities, reservoirs, and Mokelumne River in region downstream of study area.

Water quality in the upper Mokelumne River is an important source to the lower Mokelumne River below Camanche Dam, which provide municipal water supply to 1.3 million East Bay Municipal Utility District customers as well as to agriculture, and wildlife habitat (EBMUD 2012, San Joaquin County 1992, FWS 2016). The California Central Valley below Camanche Dam is an area of intense focus for fish passage and wildlife habitat restoration, as well as regulation of water development projects (FWS 2016b).

Pacific Gas and Electric (PG&E) owns and operates the Mokeulmne River Hydroelectric Power Project in the North Fork Mokelumne River. Above Salt Springs Reservoir infrastructure includes Upper and Lower Blue Lakes, Twin Lake, and Meadow Lake dams. Within the project area are Bear River, Lower Bear River, and Salt Springs Reservoirs, the aqueducts between them, Salt Springs Powerhouse, and Tiger Creek Regulatory Canal. Tiger Creek Regulatory Canal begins at Salt Springs Reservoir and carries flow via an above ground canal with two tunnels to Tiger Creek Afterbay Reservoir and Tiger Creek Powerhouse downstream of the project area.

The Power study is the second watershed-scale GRAIP inventory to be completed in the Forest Service Pacific Southwest Region (Region 5, Figure 1). The other GRAIP watershed study was completed in 2015 in the Plumas National Forest in two large tributaries to the North Fork Feather River (Cabrera et al. 2015). The Legacy Roads Project conducted GRAIP monitoring at 6 sites in multiple National Forests in Northern California (Nelson et al. 2012).

Power Fire

In October, 2004, the Power Fire burned about 69 km^2 (16,993 acres, 27 mi^2), the majority of the southern portion of the Power study area (Figure 5). Along with roads, high intensity fires can result in the highest erosion rates among any other land use impacts in the Sierra Nevada (Coe 2006), and the Power Fire was noted as a large and intense fire. Impacts were significant in high and moderate intensity vegetation burn areas, which removed 25-100% of trees in 61% of the total burn area. There were 16.2 miles of perennial streams, and 21.9 miles of seasonal streams affected, with the most intense effects in Beaver and East Panther Creeks. High post-fire rates of soil erosion and sedimentation to streams were observed in the fire area (USDA 2005), and these can have an impact on water quality and reservoir capacity (Buckley et al. 2014).

Post-fire erosion rates vary dramatically and are dependent upon degree of vegetation cover and precipitation especially in the first two winters post-fire (MacDonald et al. 2004, Cafferata 2015). Studies that performed direct measurement of hillslope erosion north of the Power Fire (MacDonald et al 2004), and modeled erosion in the North Fork Mokelumne River basin (Elliot et al. 2015) showed that hillslope erosion rates in the first year post-fire can be two to three orders of magnitude higher than undisturbed forested erosion rates especially in high severity burn areas. Precipitation the two water years following the Power Fire were 128% and 145% of average (CDEC 2016). Recovery of post-fire erosion rates to pre-fire level also can vary widely and decrease as dramatically as post-fire rates increase, however are generally expected to return to pre-fire rates within 5 years post-fire (Cafferata 2015, USDA 2005), and possibly sooner depending on post-fire storm intensities and vegetation cover (MacDonald 2014). In the Power project area it was found that probability of stream connection below drain points within high severity areas was nearly half that for drain points within other burn severity areas or outside the fire (see Section 5.1). During the study, high severity burn areas were observed to have very dense vegetation which, among other possible factors, was potentially a factor in limiting connectivity (Figures 3 and 4, MacDonald 2014).

Figure 3. High severity burn area along road 8N16D in the Power Fire showing removal of forest cover in foreground, and intact forest in non-burned area in the North Fork Mokelumne River canyon in the background.

Figure 4. High severity burn area in the Power Fire showing dense shrub regrowth 10 years post-fire in 2014 on road 8N06.

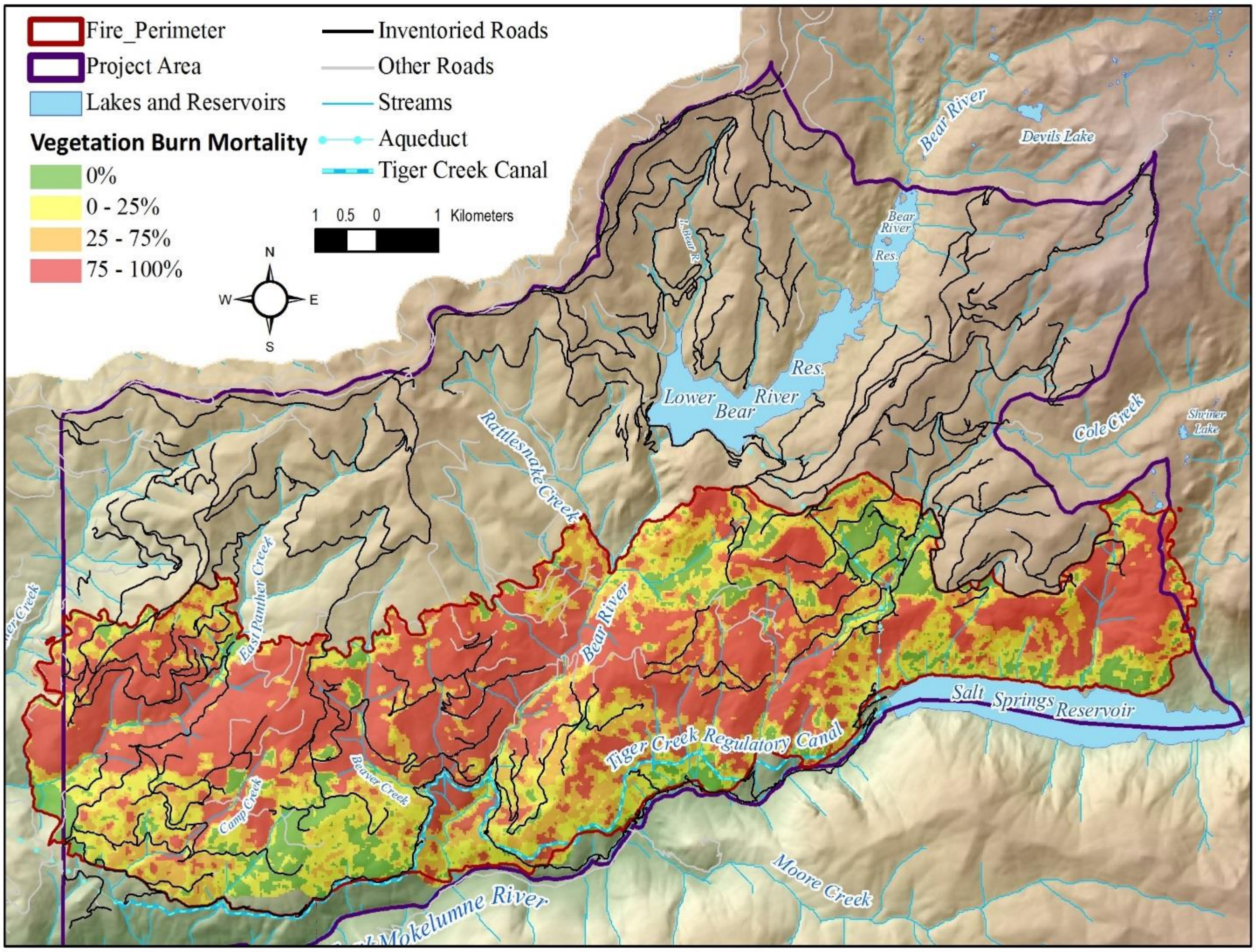


Figure 5. Map showing Power study area, Power Fire area, vegetation fire burn mortality one year post-fire, inventoried roads, and major tributaries.

Geology

The study area lies within the Sierra Nevada geologic province. The eastern boundary of the study area lies roughly 10 km (6 mi) west of the Sierra Nevada crest, and rock ages progress generally from younger to older from east to west (Figure 6, Wagner et al. 1981). The east half of the study area is dominated by plutonic rocks of the massive Sierra Nevada Batholith including Mesozoic (250-60 million years old) granite, quartz monzonite and diorite. The granite is overlain sporadically by glacial deposits formed by glacial activity during the late Quaternary Period (2 million to 10,000 years old). The plutonic batholith intruded through older Paleozoic (540-255 million years old) metavolcanic and metasedimentary rocks, which lie in the lower elevations in the western part of the study area. They resemble, but are not specifically assigned to the Calaveras complex. They are thinly bedded, highly deformed, and weakly metamorphosed, and are comprised of fine grained, dark siliceous hornfels derived from siltstone, mudstone, and shale, with minor interbeds of fine-grained meta-sedimentary rock, marble, quartzite, chert, calcareous or dolomitic siltstone, and lenses of mafic volcanic rock

(Spittler 1995). Bedding planes and metamorphic planar structures dip steeply west and generally trend north-northwest. They are bound on the west by a major, but uncertain fault mapped roughly 16 km (10 mi) west of the project boundary (Wagner et al. 1981). Atop the older rocks, over a pronounced erosional unconformity (Spittler 1995), are late Cenozoic (19-5 million year old, Duffield 1975) rocks of the Mehrten Formation derived from a volcanic source near the Sierra Nevada Crest (Gutierrez 2011). The Mehrten formation is a formerly extensive volcanic mudflow tuff breccia deposit, up to about 60 meters thick, composed of gravel, cobble and boulder conglomerate of mostly andesite, and some granitic and metamorphic clasts, in a very hard, strongly welded matrix of finer andesite (Duffield 1975, Gutierrez 2011). There are a few minor areas of Valley Springs Formation comprised of Cenozoic (20-30 million years old, Duffield 1975) sandstone, ash, interbedded tuffs, and claystone (Gutierrez 2011).

Climate and Elevation

Elevations in the study area range between 890-2,500 m (2,920-8,200 ft, Figure 7). The low point is in the southwest of the study area on the North Fork Mokelumne River, and the highest point is in the northeast above Devil's Lake. Precipitation occurs mostly between late fall and early spring as rain in lower elevations and as snow in higher elevations, and in summer as infrequent thunderstorms. Average annual precipitation for the study area ranges between 810-1700 mm (32-67 in.) per year depending on elevation (CDEC 2016). Snowfall typically occurs at elevations above 1,700-1,980 m (5,600-6,500 ft; USDA 2005), but can fall as either rain or snow in that elevation range. Climatic data in the area were measured at Salt Springs Reservoir at 1,128 m (3,700 ft) elevation, which is maintained by PG&E (CDEC 2016). Daily average temperature at this gage since 2000 ranged between 4.4-26 °C (40-79 °F). Maximum temperature during that time was 40 °C (104 °F°) and minimum temperature was -18 °C (0 °F).

The survey was conducted in a climatic context of regional drought. Following a winter of increasing drought severity in water year 2012/2013, the entire state of California was in "Severe" drought by June, 2013, "Extreme" drought by November, 2013, and "Exceptional" drought by April, 2014 where it remained during both data collection periods (US Drought Monitor 2016). Since water year 1982/1983, Sierra Nevada snow water content in water year 2014/2015 was the lowest on record, and water year 2013/2014 was less than half of average (CNRFC 2016A).

Given the dry period in which the study was conducted, erosional features observed during the study were likely governed by the patterns of precipitation prior to the study. Annual precipitation at the Salt Springs Reservoir gage the two water years following the Power Fire of October 2004 were 128% and 145% of average. During the next seven water years leading up to the onset of the study in September 2014, only 2010/2011 was above average at 143% of normal. All the other water years were normal (70-100%), or less than normal (<70%). The water years during which the study was conducted were 56%, and 65% of normal for 2013/2014, and 2014/2015, respectively (CDEC 2016).

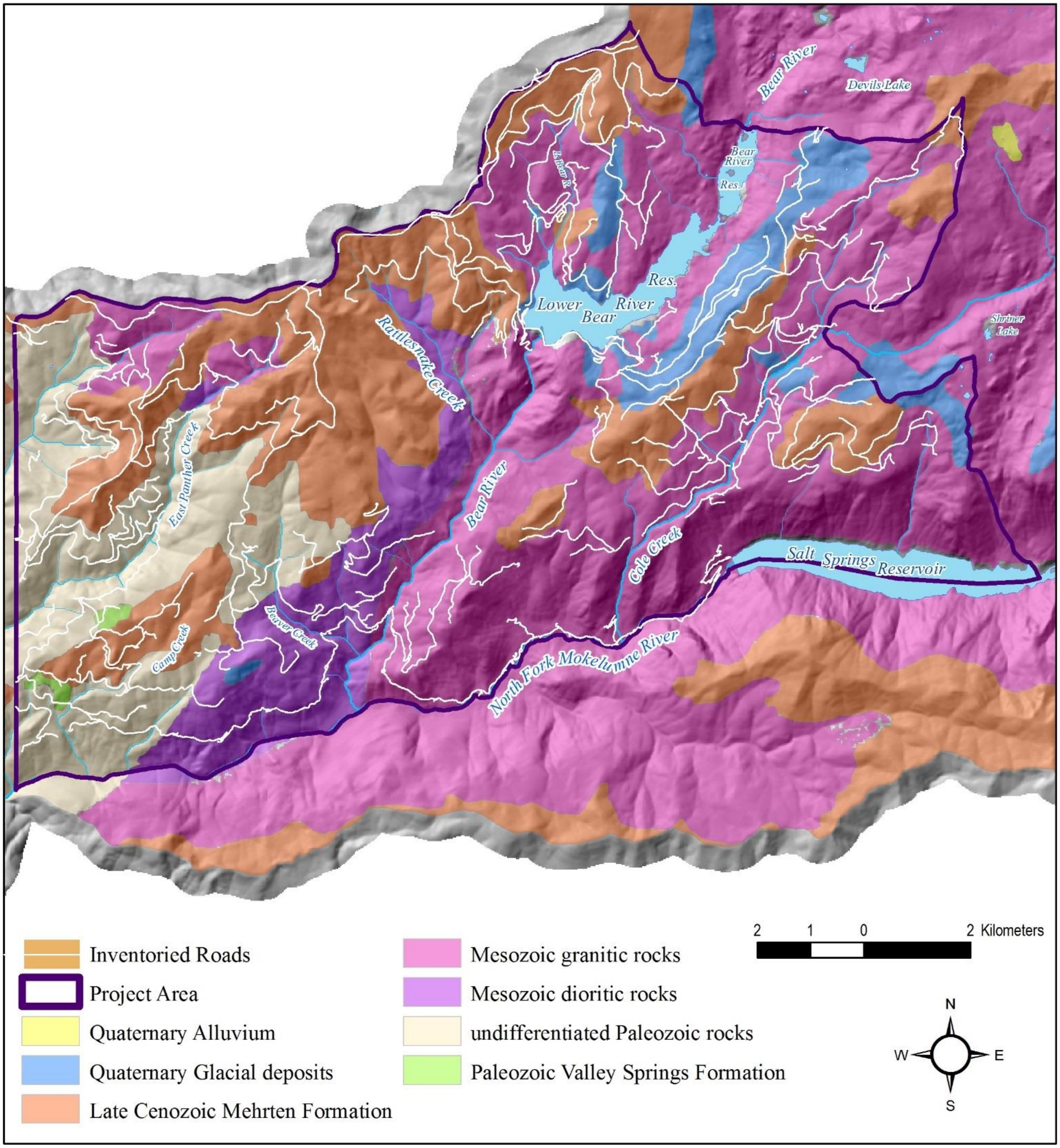


Figure 6. Geology of the Power study watersheds.

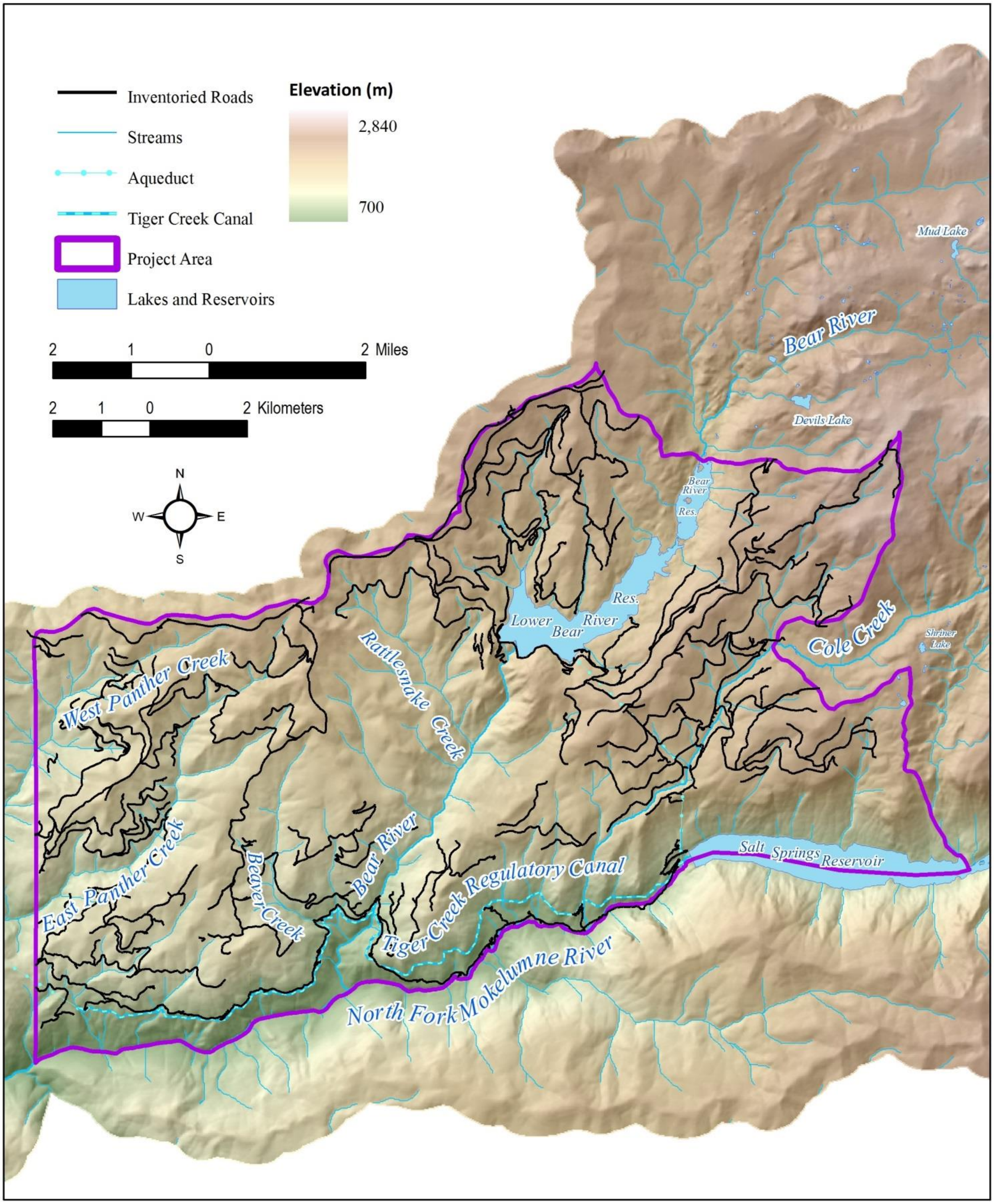


Figure 7. Elevation and location of inventoried roads within the Power study watersheds.

Even though total annual precipitation was low on average prior and during the study, large storm events, including winter rains and summer thunderstorms, can produce locally heavy precipitation intensities and runoff, which may represent an increasing fraction of available erosional force as annual snowpack declines and precipitation falls more as rain (USDA 2013). Erosional force for particle detachment and transport increases in part as a function of storm intensity and rainfall total (Black and Luce 1999, Wischmeier and Smith 1978), so it is valuable to examine patterns of storm events in the study area. Storm intensity can be examined by looking at daily total precipitation. In summer months, precipitation events occurred 0-3 times per summer with the majority of events of less than 19 mm (0.75 in.). Each of 2011, 2012, and 2013 had a summer event greater than 25 mm (1 in.). The summer of 2015 was unusual in that five events occurred. Rain events during autumn through spring months from 2004 to 2015 at Salt Springs Reservoir gage number on average between 30 to 50 events. Of those events, 30-50% were greater than 25 mm (1 in.), and only four events were between 76-102 mm (3-4 in.). Winters of 2013/2014 and 2014/2015 each had very little snow (CDEC 2016) which likely allowed winter storms to provide greater erosive force from rainfall prior to each of the summer survey periods. Winter storms also played a role. The combined precipitation for December and January of 1996/1997 were the wettest on record in the Northern Sierra since 1920 with nearly 1,219 mm (48 in.) of precipitation. Geomorphic evidence related to the large 1996/1997 event such as landslides and gullies were likely recorded in the survey (Archer 2016, CNRFC 2016B, see Sections 5.4 and 5.5). The larger and more frequent winter precipitation events, especially in the absence of snow, frequent or large summer precipitation events, and infrequent but exceptionally large events provided the bulk of erosive power in the study area. However, given the drought climate in which the survey was conducted, this study likely reflects a period of generally average or low erosion rates with episodic high pulses of erosion during storms.

Land Ownership

The project area encompasses 160 km^2 (62 mi^2, 39,540 acres), 37% of the surrounding Bear River, Panther Creek, and North Fork Mokelumne River watersheds (436 km^2, 169 mi^2, 107,740 acres, Figure 8). The watersheds are comprised of primarily federally owned and managed land. Within the watersheds, the Eldorado National Forest manages 82% of the area (359 km^2, 139 mi^2, 88,710 acres), and private land comprises the remaining 18%. Within the project area, 30 km^2 (12 mi^2, 7,410 acres, 19%) are privately owned and managed, and the remaining 130 km^2 (50 mi^2, 32,120 acres, 81%) are Eldorado National Forest including a small portion of the Mokelumne Wilderness.

Roads Surveyed

337 km (209 mi) of road length were surveyed within the study area. Within the study area 361 km (224 mi) of roads on existing geographic information system (GIS) layers (Eldorado 2014) were targeted for survey. Approximately 86% of these mapped roads were surveyed (Figure 8). This study focused on roads within Forest Service management jurisdiction, so some mapped

roads were not surveyed. Mapped roads not surveyed were because of restricted access to their location on timber or other private land. Several major access roads managed by the Forest Service for public use, but which ran through private land, were surveyed because of their prominence in the road network. Roads not mapped on existing GIS maps prior to the GRAIP survey, referred to as non-system roads, were also targeted for inventory within Forest Service and PG&E land. There were 26 km (15 mi) of non-system road length surveyed along 115 non-system roads, which were 8% of the total 337 km (209 mi) of road length surveyed. The extent of other non-system roads not surveyed in this study is not known because these roads can be difficult to locate, and time limitations prevented a more exhaustive survey.

Within Forest Service property, 294 km (183 mi) of mapped roads, and 24 km (15 mi) of non-system roads were surveyed. Within private lands, 19 km (12 mi) were surveyed, of which 2 km (1.2 mi) were within PG&E land. Roads surveyed on private land represent only 6% of all road length surveyed. Many roads that exist on private land do not appear in Figure 8, nor on the Eldorado (2014) GIS roads layer. Nearly all private roads on private lands were excluded. Only 30% of roads mapped within private land were surveyed. Roads not surveyed within private lands represent some portion of road sediment production and delivery not accounted for in some of the subwatersheds within the study area, especially Rattlesnake Creek, Upper Beaver Creek, and East and West Panther Creeks, and to a lesser extent in Little Bear River and Cole Creek (Figures 7 and 8).

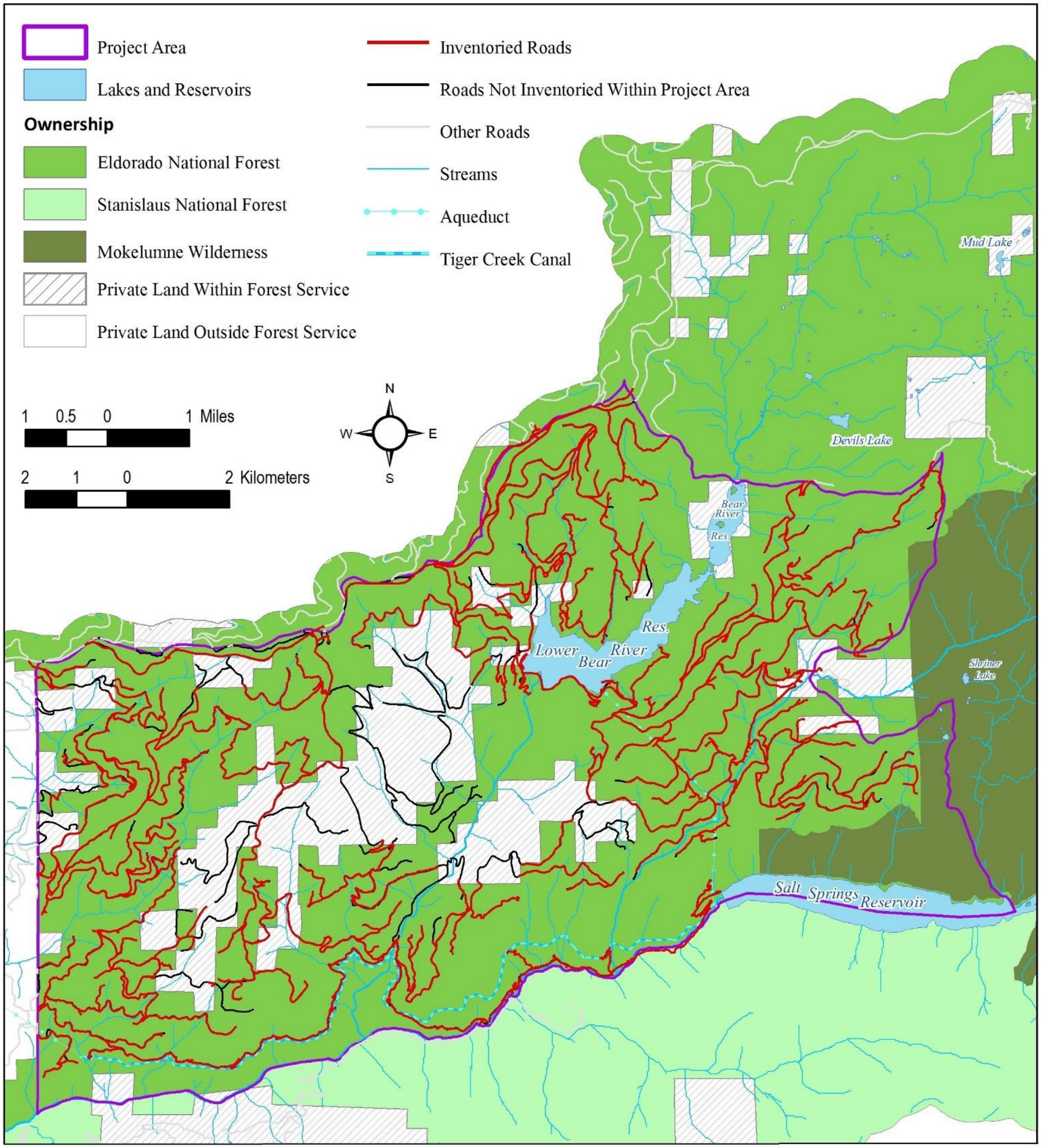


Figure 8. Land ownership and all roads within the Power study watersheds.

5.0 Results

A total of 4,657 drain points, 5,886 road segments, and 1,301 other associated features (including 218 gullies, 20 landslides, 1,001 photo points, and 62 gate points) were inventoried in five months of field surveys by four field crews in 2014 from September 23 through October 25, and by one field crew in 2015 from June 16 through September 21. Each crew surveyed an average of 2–3 km (1–2 mi) of road per day. Data analyses provide specific information on the condition and function of 337 km (209 mi) of roads (Figure 8). 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

.5.1 Road-Stream Hydrologic Connectivity

Roads can intercept shallow groundwater and convert it to surface runoff, resulting in local hydrologic impacts when that water is discharged directly to channels (Wemple and Jones 2003, 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).

The hydrologically connected portion of the road system was 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 was followed until evidence of overland flow ceased or the flow path reached a channel. Road-stream hydrologic connectivity represents the maximum extent that roads are integrated with streams, and is controlled by the pattern and distribution of runoff, slope length, slope distance from discharge point to stream, vegetation, and delivery paths, among other factors (Bracken and Crocke 2007). Several patterns of road stream connectivity were found in the Power study watersheds.

A total of 54 km (34 mi, 16%) of effective road length were hydrologically connected to the stream network. In stark contrast, of the 9.7 km (6 mi) of road length with base of fill within 15 m (50 ft) of a stream channel, 60% (5.9 km, 3.7 mi) were hydrologically connected (Figure 9; Appendix B, Map 1). For roads with base of fill located greater than 15 m (50 ft) from a stream channel, 15% of the length was stream connected.

That road distance from streams may have a significant effect on the likelihood that a road is stream connected is not new (Croke et al. 2005, Ketcheson and Megahan 1996, Packer 1967).

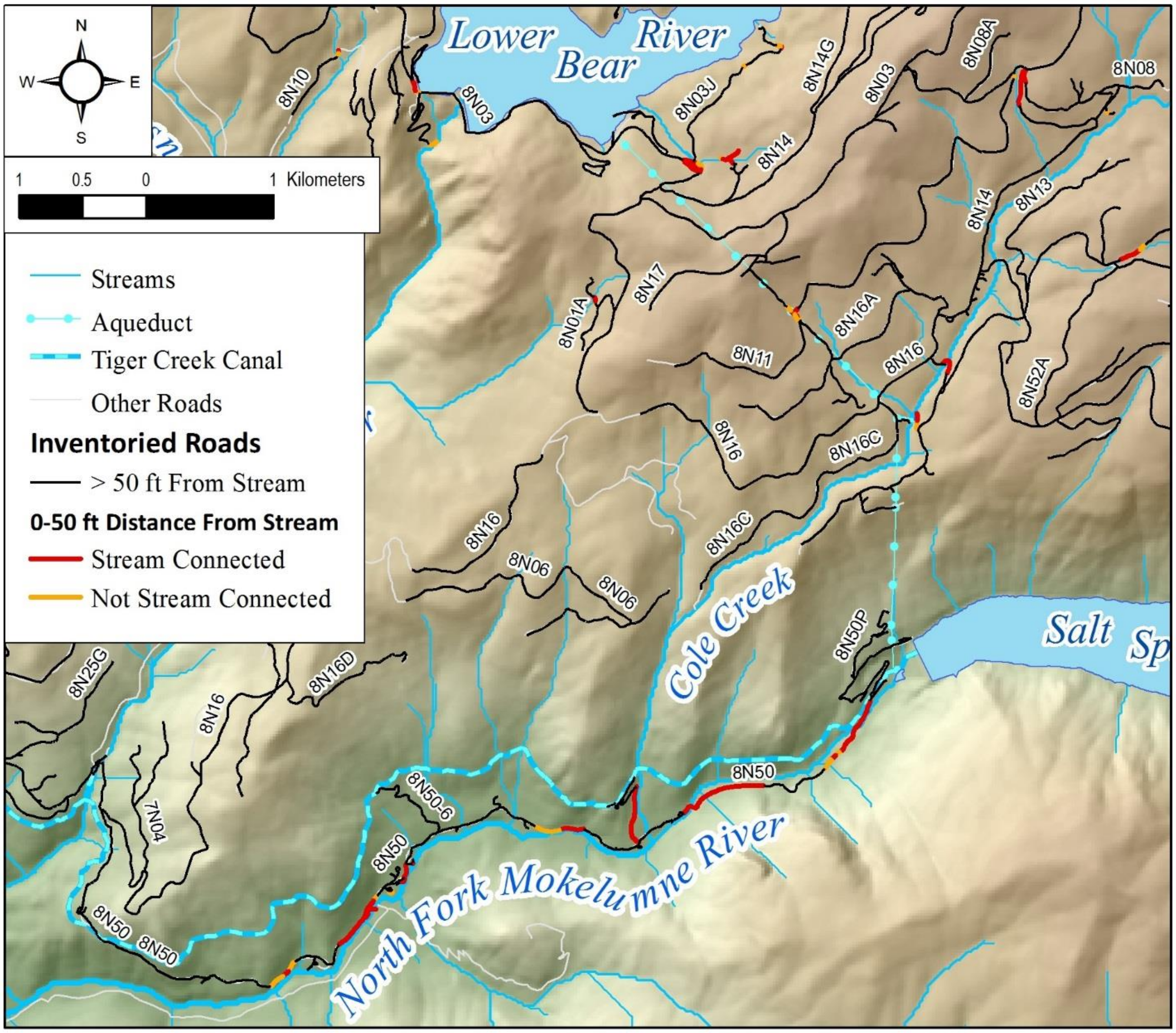


Figure 9. Road segments within 50 feet of stream channels in the south central portion of the Power study area.

Distance from drain point to nearest stream was graphed against observations of stream connection for all drain points. Calibrations were completed using a logistical regression technique (local fit, locfit) in the R statistical computing environment to generate a probability versus distance function plot (in blue on Figure 10). There was a relationship between drain point distance from streams and stream connectivity for all points, and for points inside and outside of the fire perimeter.

For all drain points that discharged within about 30 m (98 ft) from a modeled stream, there was a 60% chance that the drain point was stream connected. As drain point distance increased further from the modeled stream, probability of connection decreased from about 45% at 50 m (160 ft) to about 10% at 400 m (1,310 ft). Drain points within the fire perimeter had a 5-10% lesser probability of stream connection than for drain points outside the fire (Figure 10). There

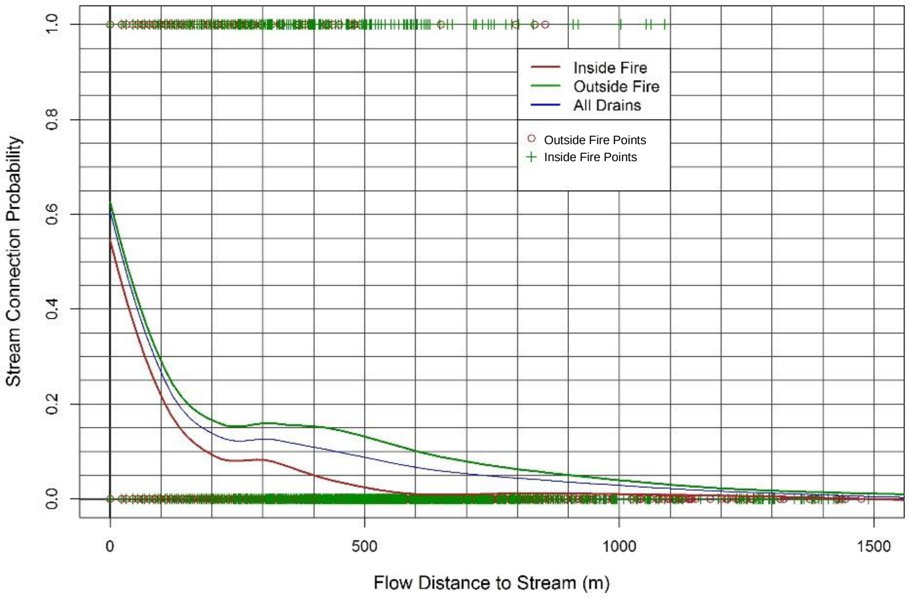


Figure 10. There was a lower probability of stream connection within the Power Fire perimeter compared to drain points outside the fire.

were 2,914 drain points outside the fire perimeter, and 1,743 within. Outside of the fire, for drain points that discharged 50 m (160 ft) from a modeled stream, probability of connection was the same as for all points (45%), but for drain points within the fire perimeter probability at that same distance from stream was 35%. At drain point distance to stream of 400 m (1,310 ft), outside the fire, probability of connection was 15%, and for drain points within the fire perimeter, 5%. This counterintuitive pattern may be due to a variety of factors resulting from post-fire effects, but one factor observed commonly in the study area that has been shown to reduce post-fire erosion was vegetation cover (MacDonald 2014). The extreme density of vegetation regrowth during the 10 years after the fire is shown in Figure 4.

Patterns of connectivity based on drain point type were evident. Broad based dips and non-engineered drain points were the most common types of drainage features (1,189 and 1,190 features, respectively). Including ditch relief culverts (872 features), and waterbars (639 features), these four feature types drained 79% (267 km, 166 mi) of the road network (Table 1). Ditch relief culverts had the most hydrologic connectivity at 33% of connected road length (18 km, 11 mi), and 28% of all drain points connected (221 of 778). Ditch relief culverts along with stream crossings, broad based dips, and non-engineered drain points, comprised 94% (51 km, 32 mi) of all hydrologic connectivity. There were 255 stream crossings, and they drained 14 km (9 mi) of the road network, all of which were connected.

Table 1. *Summary of contributing road lengths by drain point type. Sumps cannot be stream connected, while stream crossings are connected by definition.*

	All Drain Points			Not Connected Drain Points			Connected Drain Points			
Drain Type	**Count**	**Average Contributing Length (m)**	**∑ Contributing Length (m)**	**Count**	**Average Contributing Length (m)**	**∑ Contributing Length (m)**	**Count**	**Average Contributing Length (m)**	**∑ Contributing Length (m)**	**Drain Point % Length Connected***
Broad Based Dip	1,189	85	102,600	1,100	85	93,400	89	100	9,200	17%
Diffuse Drain	416	120	49,500	410	120	48,300	6	200	1,200	2%
Ditch Relief Culvert	872	75	64,000	651	70	46,300	221	80	17,700	33%
Lead Off Ditch	84	65	5,600	79	65	5,000	5	120	600	1%
Non-Engineered	1,190	65	74,900	1,022	65	64,200	168	65	10,700	20%
Stream Crossing	255	55	13,500	0	0	0	255	55	13,500	25%
Sump	5	100	500	5	100	500	0	0	0	0%
Waterbar	639	40	25,800	612	40	24,800	27	40	1,000	2%
Excavated Stream Crossing	7	45	300	0	0	0	7	45	300	1%
All Drains	**4,657**	**70**	**336,700**	**3,879**	**70**	**282,500**	**778**	**70**	**54,200**	100%

* Drain Point Connected ∑ Length / All Connected ∑ Length

5.2 Fine Sediment Production and Delivery

Road surface fine sediment production (E) routed to a drain point was estimated with a base erosion rate and the properties of two flow paths along the road (Luce and Black 1999, Cissel et al. 2012A, Prasad 2007), as shown below.

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

B is the base erosion rate[1] (kg m^{-1})
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^{-1})
V is the vegetation cover factor for the flow path
R is the road surfacing factor

Delivery of eroded road surface sediment to the channel network was determined by observations of each place that water left the road. Each of these drain points was classified as either delivering or not delivering to the stream network. No estimate of fractional delivery was made, because there is insignificant hillslope sediment storage in locations where there is a clear connection to the channel under most circumstances. A map of the road surface sediment delivered through each drain point (Appendix B, Map 2), and by each road segment (Appendix B, Map 3) is shown for the whole watershed, as well as for a portion of the project area northwest of Lower Bear River Reservoir (Figure 11).

Delivery of fine sediment occurred through a mix of road drainage features, including broad based dips, diffuse road segments, ditch relief culverts, lead off ditch drains, non-engineered drains, and waterbars (Appendix A). There were 4,657 drain points observed, 778 of which (17%) delivered sediment to stream channels. Model predictions indicated that these points delivered an estimated 70 Mg yr^{-1}, or 14% of the estimated 503 Mg yr^{-1} generated on the road

Diffuse drains were the most effective drain point type at reducing hydrologic connectivity with 1% of diffuse drains stream connected. They received 11% of total estimated sediment produced, but routed only 1% of total estimated sediment delivered (Table 2, Figures 12, 13, and 14). Waterbars and ditch lead-offs were also very effective. Six percent of all waterbars, and 8% of ditch lead off drains were stream connected. Waterbars received 13% of all sediment produced, but delivered only 6% of all sediment delivered. Lead off ditch drains received 3% of sediment produced, and delivered 2%. Non-engineered drains, broad based dips, stream crossings, and ditch relief culverts routed the most delivered sediment (91% collectively; 21 Mg/yr, 17 Mg/yr, 14 Mg/yr, and 12 Mg/yr, respectively; Table 2, Figures 12, 13, and 14). Four percent of broad based dips and non-engineered drains were located within 10 m (33 ft) of a stream crossing point. Including these with stream crossings, there was a 72% delivery rate. Drain points outside of 10 m (33 ft) of a stream crossing had a 10% delivery rate. Sediment delivery in the study area was routed by a very small percentage of all drain points. 90% of delivered sediment was routed via only 5% of drain points (Figure 15, Appendix B, Map 2).

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[1] See Section 2.0 Objectives and Methods for a discussion of base erosion rates.

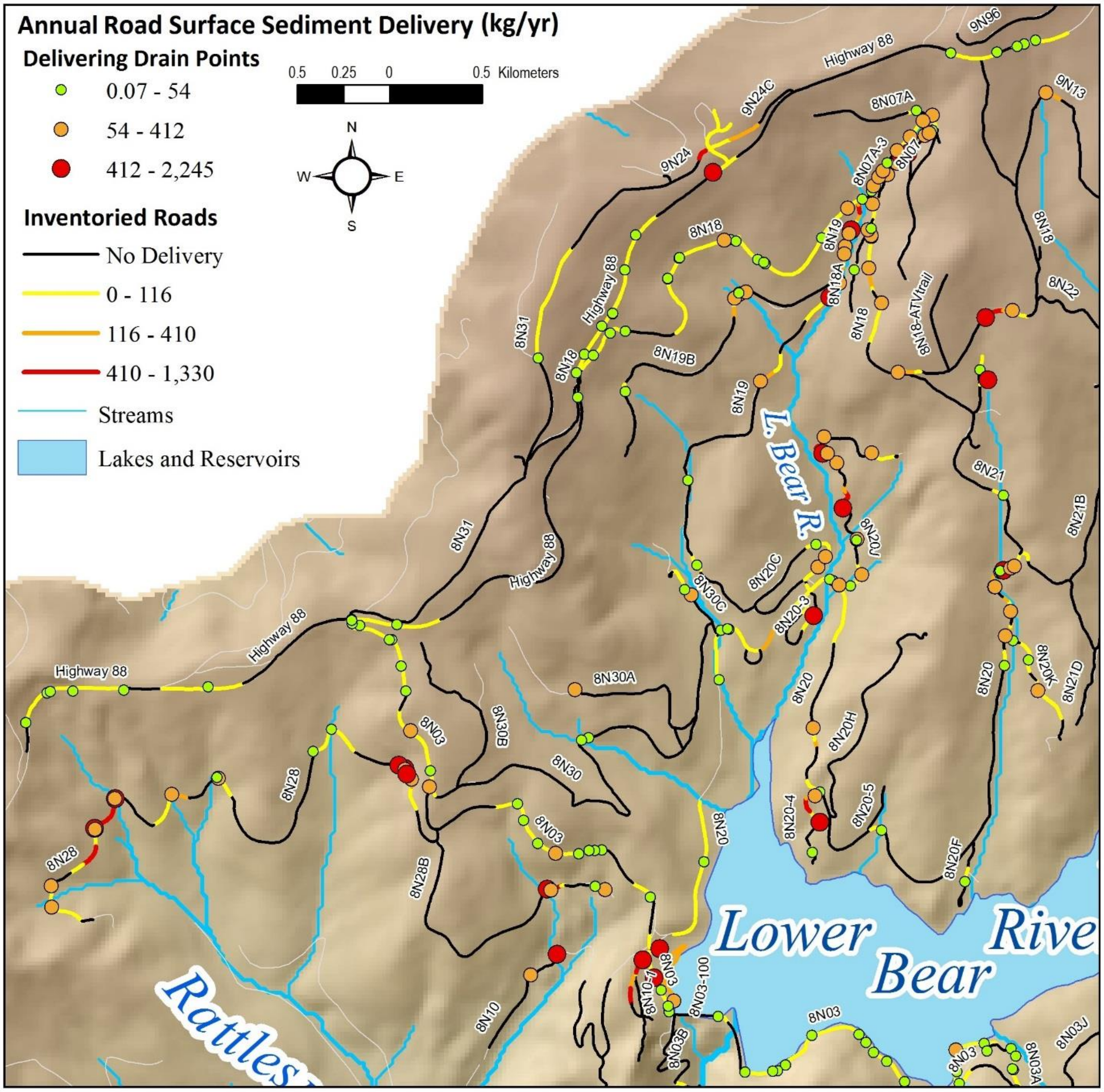

Figure 11. Road surface fine sediment delivery to channels by road segment and drain point in the northwest portion of project area. The road lines are colored to indicate the mass of fine sediment delivered to channels. Drain points that do not deliver sediment are not pictured.

***Table 2**. Summary of road surface fine sediment production and delivery by drain point types.*

Drain Type	Count	∑ Sediment Production (kg/yr)	Total % Sediment Production[*]	∑ Sediment Delivery (kg/yr)	Drain Point % Sediment Delivery[◦]	Total % Sediment Delivery[•]	Length Connected (m)	Drain Point % Length Connected[†]
Broad Based Dip	1,189	182,320	36%	17,090	9%	24%	9,200	9%
Diffuse Drain	416	55,740	11%	630	1%	1%	1,200	2%
Ditch Relief Culvert	872	50,390	10%	11,920	24%	17%	17,700	28%
Lead off ditch	84	15,390	3%	1,290	8%	2%	600	11%
Non-Engineered	1,190	116,690	23%	20,590	18%	29%	10,700	14%
Stream Crossing	255	14,120	3%	14,120	100%	20%	13,500	100%
Sump	5	500	0%	0	0%	0%	0	0%
Waterbar	639	67,680	13%	4,020	6%	6%	1,000	4%
Excavated Stream Crossing	7	380	0%	380	100%	1%	300	100%
All Drains	**4,657**	**503,210**	**100%**	**70,040**	**14%**	**100%**	**54,200**	**16%**
Drains within 10 m of a Stream Crossing[#]	428	30,600	6%	21,980	**72%**	31%	18,280	71%
Drains outside 10 m of a Stream Crossing	4,229	472,600	94%	48,060	**10%**	69%	35,920	11%

[*] Drain Point ∑ Sediment Production / Total ∑ Sediment Production
[◦] Drain Point ∑ Sediment Delivery / Drain Point ∑ Sediment Production
[•] Drain Point ∑ Sediment Delivery / Total ∑ Sediment Delivery
[†] Drain Point Length Connected / Drain Point ∑ Length
[#] Including Stream Crossings

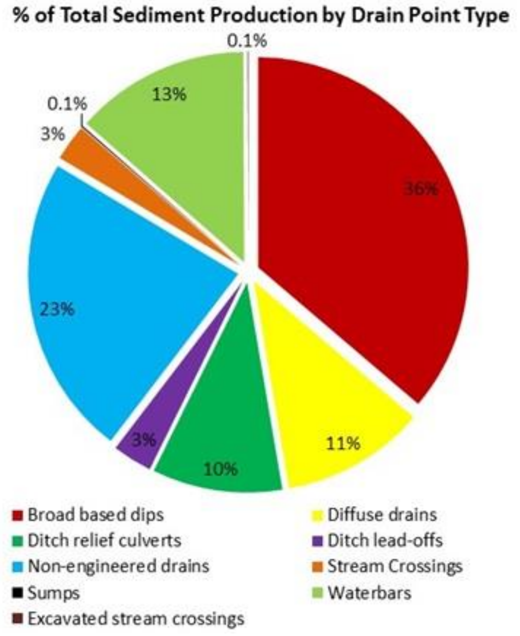

Figure 12. Relative portion of total produced road surface sediment that was routed to each drain point type.

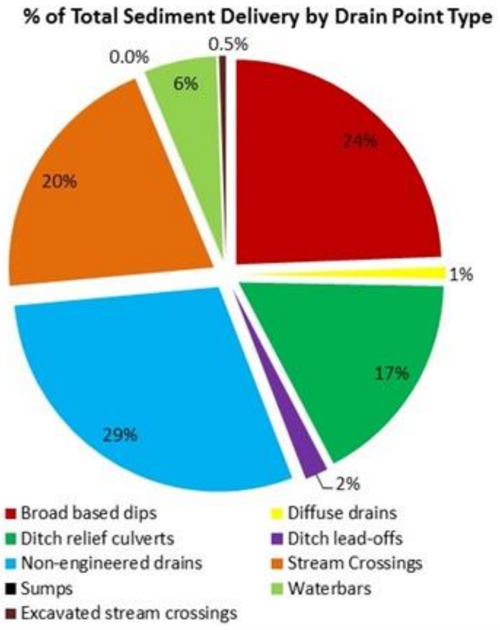

Figure 13. Relative portion of road surface sediment delivered to streams via each drain point type.

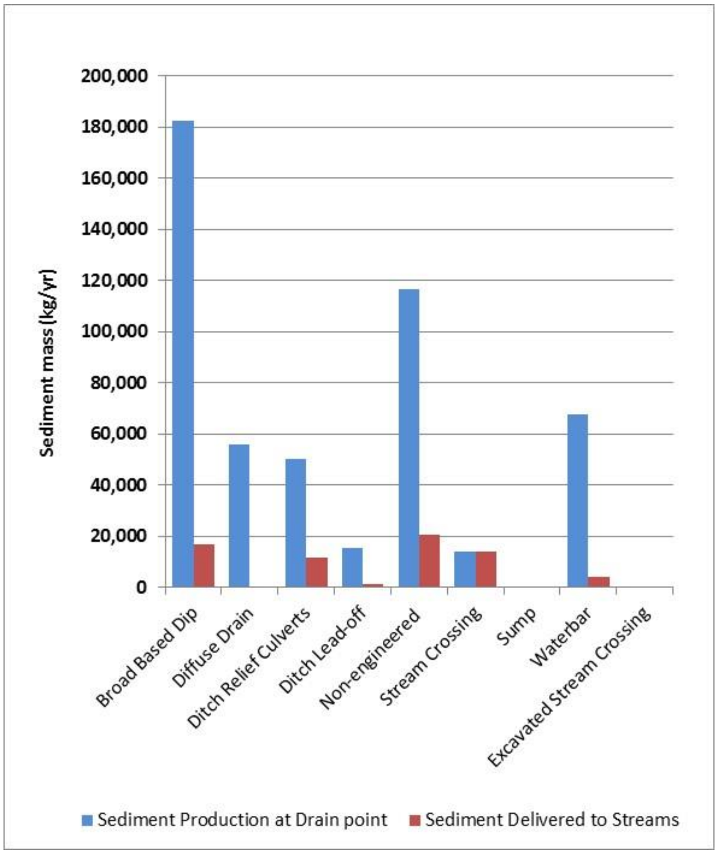

Figure 14. Road surface sediment production and delivery by drain point type.

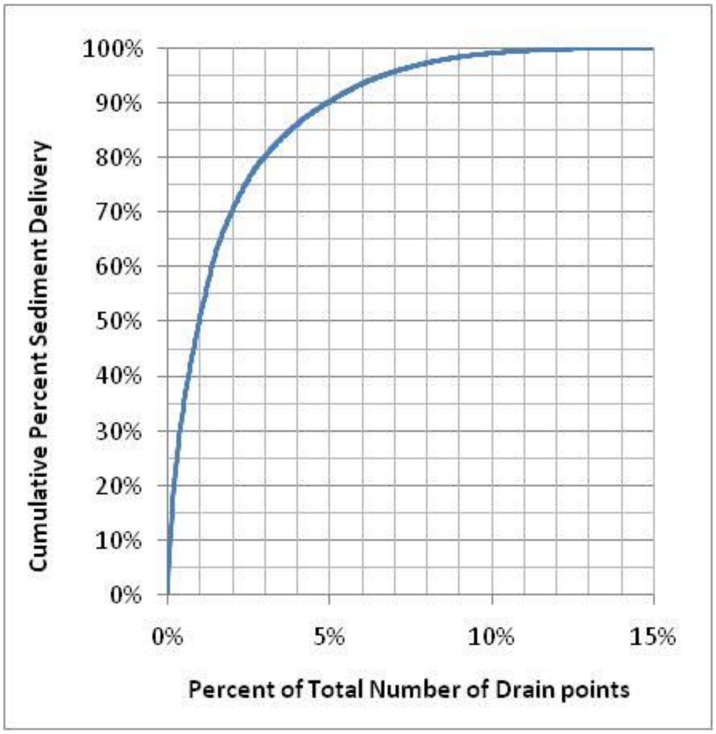

Figure 15. Cumulative percent of total sediment delivered to streams by percent of drain points. 5% of all drain points deliver 90% of the delivered sediment.

Road tread surface condition played a role in sediment delivery. Where erosional force was adequate to significantly erode road surfaces, rills and rocky surfaces were formed. The same force which caused increased erosion on the surfaces may have played a role in higher delivery rates from surfaces that were more eroded. Surface condition information was collected in the field for each road segment. A road segment was classified as being in good condition if there was little erosion present. Where road surfaces were observed to be more eroded, the road segments were classified as rilled and/or eroded, rutted, or rocky (Cissel et al. 2012A). There were 300 km (213 mi, 89%) classified as being in good condition, while the remaining 11% of road length had some surface problem. In Table 3, sediment produced and delivered from each of these surface condition types was normalized by the total road length for each erosion category. Figure 16 and Table 3 show that sediment production was lowest on road surfaces with a rutted condition (15% of normalized total), followed nearly equally by surfaces that had a good condition (20%) or were rilled/eroded (24%). Surfaces that were rocky had the highest sediment production by far (41%). Sediment delivery was highest on surfaces in rocky condition (52% of normalized total). Surfaces with rilled/eroded condition delivered 29% of the normalized total, followed nearly equally by surfaces that had a good or rutted condition (11% and 9%, respectively). The same pattern existed when the analysis was performed with only native surface roads.

Using the same method of normalizing sediment production and delivery by road length it was clear that native surface roads produced and delivered the vast majority of sediment (Figure 17). Roads with native surfaces were 20% (67 km, 42 mi) of road length surveyed, 93% (6.5 kg m^{-1} yr^{-1}) of normalized road surface sediment produced, and 77% (3 kg m^{-1} yr^{-1}) of normalized road surface sediment delivered. Roads with crushed rock surfaces were 51% (173 km, 108 mi) of road length surveyed, 4% (0.3 kg m^{-1} yr^{-1}) of normalized sediment produced, and 18% (0.7 kg m^{-1} yr^{-1}) of normalized sediment delivered. Roads with paved surfaces were 29% (97 km, 60 mi) of road length surveyed, 3% (0.2 kg m^{-1} yr^{-1}, in ditches and on shoulders) of normalized sediment produced, and 6% (0.2 kg m^{-1} yr^{-1}) of normalized road surface sediment delivered.

Table 3. *Sediment production and delivery by surface type and normalized by road length for each surface type with percent of total sediment delivery and production.*

Surface Condition	**∑ Length (m)**	**% Total Length**	**∑ Sediment Production (kg yr^{-1})**	**∑ Sediment Delivery (kg yr^{-1})**	**% of Total Sediment Delivery**	**∑ Sediment Production Normalized (kg m^{-1} yr^{-1})**	**∑ Sediment Delivery Normalized (kg m^{-1} yr^{-1})**	**% of Total Sediment Production Normalized**	**% of Total Sediment Delivery, Normalized**
Good	299,670	89%	423,190	49,810	71%	1.4	0.2	20%	11%
Rilled/eroded	18,900	6%	31,120	8,150	12%	1.6	0.4	24%	29%
Rutted	2,000	1%	2,100	260	0.4%	1.1	0.1	15%	9%
Rocky	15,060	4%	42,240	11,700	17%	2.8	0.8	41%	52%
Total	**335,630**	100%	**498,650**	**69,920**	**100%**	**1.5**	**0.2**	**100%**	**100%**

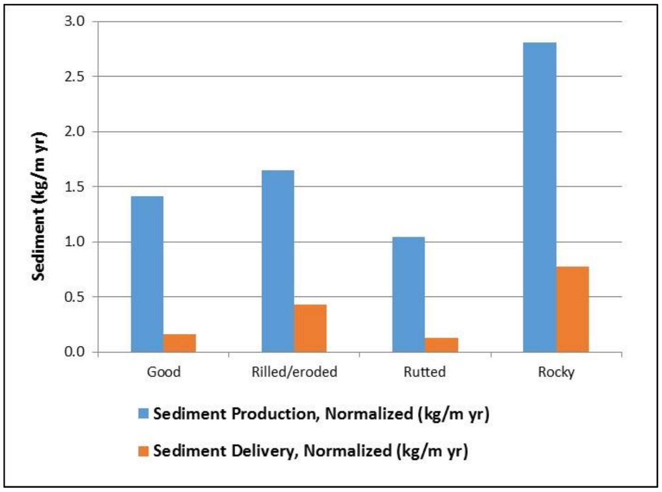

Figure 16. Normalized sediment production and delivery by road surface condition. The values are normalized by road length for each surface condition category.

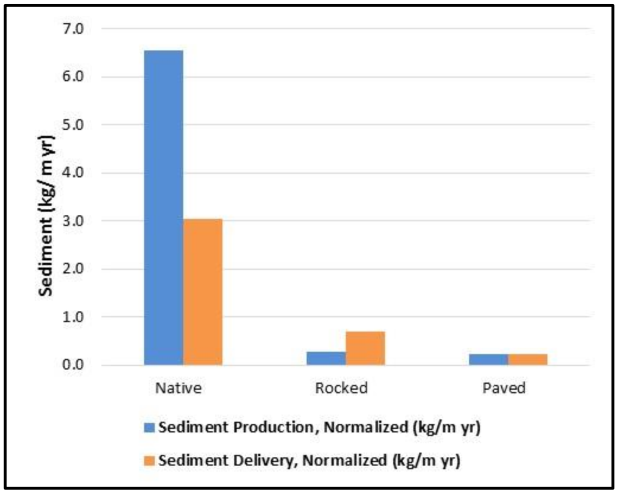

Figure 17. Normalized sediment production and delivery by road surface type. The values are normalized by road length for each surface type category.

5.3 Downstream Sediment Accumulation

For drain points that were observed in the field to be stream connected, the GRAIP model predicted the mass of road surface derived fine sediment to the point, then routed the mass over DEM modeled hillslopes to the nearest stream segment in the TauDEM modeled stream network. Upstream and downstream endpoints of segments were defined by confluences and road-stream intersections. Any given stream segment can receive sediment from multiple drain points as well as from all upstream stream segments. From these sediment inputs, GRAIP calculated two measures of road sediment for each stream segment. The first measure, sediment accumulation (Figure 18), was the total mass of road-related sediment received by a stream segment per year, expressed in kilograms 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. This is likely independent of pulsed, mass-wasting driven coarse sediment transport (Benda and Dunne 1997). The second measure, specific sediment accumulation (Figure 19), was the mass of accumulated road-related sediment in a given stream segment normalized by the upstream contributing area, expressed in megagrams per square kilometer per year. In this metric, watershed area is used as a proxy for stream discharge, allowing us to compare the sediment impacts to channel segments with differing contributing areas. Maps for sediment accumulation and specific sediment accumulation for the entire watershed area are in Appendix B, Maps 4 and 5.

Accumulated and specific sediment values in streams below Bear River, Lower Bear River, and Salt Springs dams did not subtract sediment that may be trapped behind the dams. Rather, they included all sediment routed through the system as if there were no dams. The estimated value of accumulated road surface sediment in Lower Bear River Reservoir at the dam was 24 Mg yr^{-1}, and at Salt Springs dam was 0.3 Mg yr^{-1}. The estimated value of accumulated sediment from all road derived sources (gullies, landslides, fill erosion, and road surface) in Lower Bear River Reservoir at the dam was 292 Mg yr^{-1}, and at Salt Springs dam was 0.4 Mg yr^{-1}.

The study did not include roads outside project area or within private lands within the project area, so not all road related sediment sources were surveyed within subwatersheds or for the

Table 4. *Summary of areas excluded from survey by subwatershed.*

Sub Watershed	Area (km^2)	Area Outside Project Boundary (km^2)	Excluded Private Area within Project Boundary (km^2)	Total Area Excluded (km^2)	Percent Watershed Area Excluded
Panther Creek	49	20	7	27	55%
Bear River	136	65	19	84	62%
Cole Creek	61	41	2	42	70%
N.F. Mokelumne River above Salt Springs Reservoir	113	97	0	97	85%
N.F. Mokelumne River below Salt Springs Reservoir and above Panther Creek	77	54	3	56	73%

entire watershed area. Therefore, stream sediment values reported here include only sediment from roads surveyed, and were likely lower than actual values that would account for all roads within the study area, especially for the larger subwatersheds (Figures 7 and 8, Table 4). In the Power study, large areas excluded from the survey were private timber lands in Rattlesnake Creek, Upper Beaver Creek, and East and West Panther Creeks, and smaller areas of private land in Little Bear River and Cole Creek. The entire watershed area south of North Fork Mokelumne River was excluded because it is outside Eldorado National Forest. Areas excluded in the upper reaches of Bear River, Cole Creek, and North Fork Mokelumne River likely have much less influence on specific sediment values because they were wilderness with few roads. Though reported stream sediment values may be lower than actual values, reported values represent the portion of road related sediment in the streams due to the surveyed roads in the project area.

For the entire study area, road surface accumulated sediment was 70 Mg yr^{-1} (Figure 18, Table 5). The majority of road surface-related sediment was in the North Fork Mokelumne River above Panther Creek with 59 Mg yr^{-1}, compared to 38 Mg yr^{-1} and 11 Mg yr^{-1} at the mouths of Bear River and Panther Creek, respectively.

For the entire study area road surface specific sediment was 0.2 Mg km^{-1} yr^{-1} Specific road surface sediment was highest at the mouth of Little Bear River at 1.7 Mg km^{-2} yr^{-1} (Figure 19, Table 5). This was about ten times higher than the average of other subwatersheds. Specific sediment at the mouths of Bear River, Panther Creek, and North Fork Mokelumne River above Panther Creek confluence were 0.3 Mg km^{-2} yr^{-1}, 0.2 Mg km^{-2} yr^{-1}, and 0.2 Mg km^{-2} yr^{-1}, respectively

Including the sediment from delivering road-related landslides, gullies, and fill erosion at drain points (see Sections 5.4, 5.5, and 5.7), in addition to sediment from the road surface, total accumulated sediment for the entire study area was 803 Mg yr^{-1} (Table 5). Two thirds of that was from the North Fork Mokelumne River above Panther Creek confluence, with a value of 521 Mg yr^{-1}. Values in Bear River and Panther Creek were 468 Mg yr^{-1} and 281 Mg yr^{-1}, respectively, with the majority of sediment in Panther Creek from East Panther Creek.

Including all sediment sources, specific sediment for the entire study area was 1.8 Mg km^{-2} yr^{-1}; also with the greatest value in Panther Creek at 5.8 Mg km^{-2} yr^{-1}. The specific sediment values for Bear River and North Fork Mokelumne River above Panther Creek confluence were 3.0 Mg km^{-2} yr^{-1}, and 1.3 Mg km^{-2} yr^{-1}, respectively.

The large difference in specific sediment values between road surface sediment and all sediment sources at the mouths of Little Bear River and Rattlesnake Creek was mostly due to gully sediment. At the mouth of East Panther Creek it was mostly due to landslide sediment, and at the mouth of Beaver Creek due to both gully and landslide sediment. The moderate increase in the specific sediment value at the mouth of West Panther Creek was due to gully, landslide and fill erosion sediment. There were few inputs from mass wasting sources in the

North Fork Mokelumne River subwatersheds. The overall increase in specific sediment at Mokelumne River below Panther Creek was 26% due to landslide sediment, 65% due to gully sediment, and 9% due to fill erosion sediment.

Table 5. *Study area streams and sediment accumulation and specific sediment accumulation at the stream mouth, calculated using only delivering road surface-related sediment and all delivering road sediment sources (landslides, gullies, and fill erosion at drain points).*

Sub-watershed	**Stream Name**	**Road Surface Sediment at Mouth (Mg yr^{-1})**	**Road Surface Specific Sediment at Mouth (Mg km^{-2} yr^{-1})[1]**	**All Sediment Sources at Mouth (Mg yr^{-1})**	**All Sediment Sources Specific Sediment at Mouth (Mg km^{-2} yr^{-1})[1]**
Bear River	Little Bear River (into Lower Bear River Reservoir)	16	1.7	182	20
	Bear River (into Lower Bear River Reservoir)	8.0	0.1	87	1.0
	Bear River at Lower Bear River Reservoir Dam	***24***	***0.3***	***292***	***3.0***
	Rattlesnake Creek	7.0	0.7	122	12
	Beaver Creek	1.3	0.1	68	6.8
	Bear River	***38***	***0.3***	***468***	***3.4***
Panther Creek	East Panther Creek	8.4	0.4	249	11
	West Panther Creek	2.4	0.1	33	1.4
	Panther Creek	***11***	***0.2***	***281***	***5.8***
N. F. Mokelumne River	N. F. Mokelumne R. at Salt Springs Dam	0.3	0.003	0.4	0.003
	N. F. Mokelumne R. above Cole Creek mouth	1.7	0.01	3.5	0.03
	Cole Creek	10	0.2	36	0.6
	N. F. Mokelumne R. above Bear River mouth	20	0.1	50	0.2
	Camp Creek	0.3	0.1	0.3	0.1
	N. F. Mokelumne R. above Panther Creek mouth	***59***	***0.2***	***521***	***1.3***
	Power Project Watersheds	**70**	**0.2**	**803**	**1.8**

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[1] Area used is for entire subwatershed. Study did not include roads outside project area or within private lands within the project area. The areas used here included roads that were not surveyed, so these values are likely lower than those that would account for all roads in these watersheds. If project area is used, specific sediment values for all Power project watersheds would be 0.4 Mg km^{-2} yr^{-1} for road surface sediment delivered, and 5 Mg km^{-2} yr^{-1} for all sediment sources.

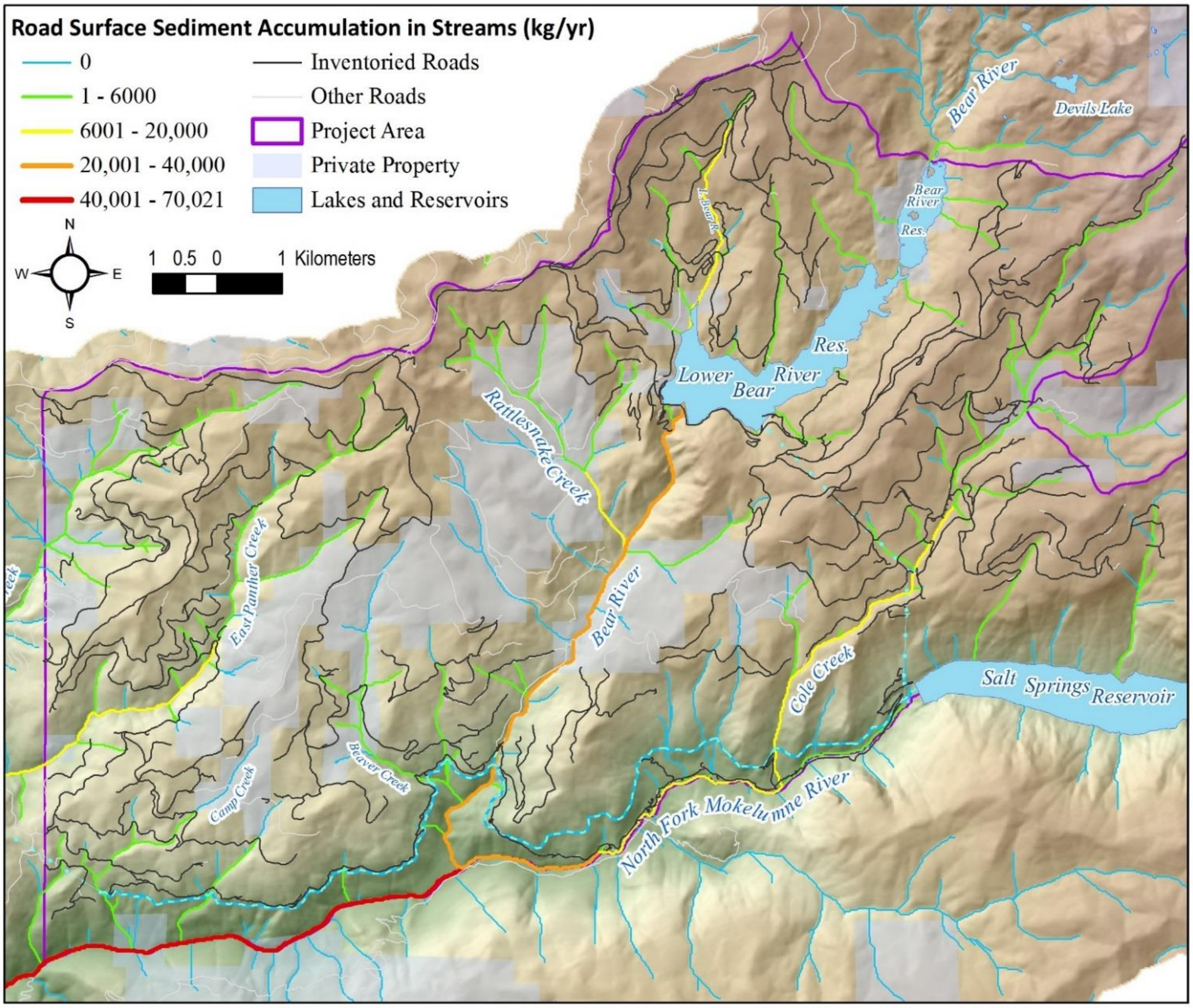

Figure 18. Sediment accumulation from road surfaces to streams in the Power study watersheds.

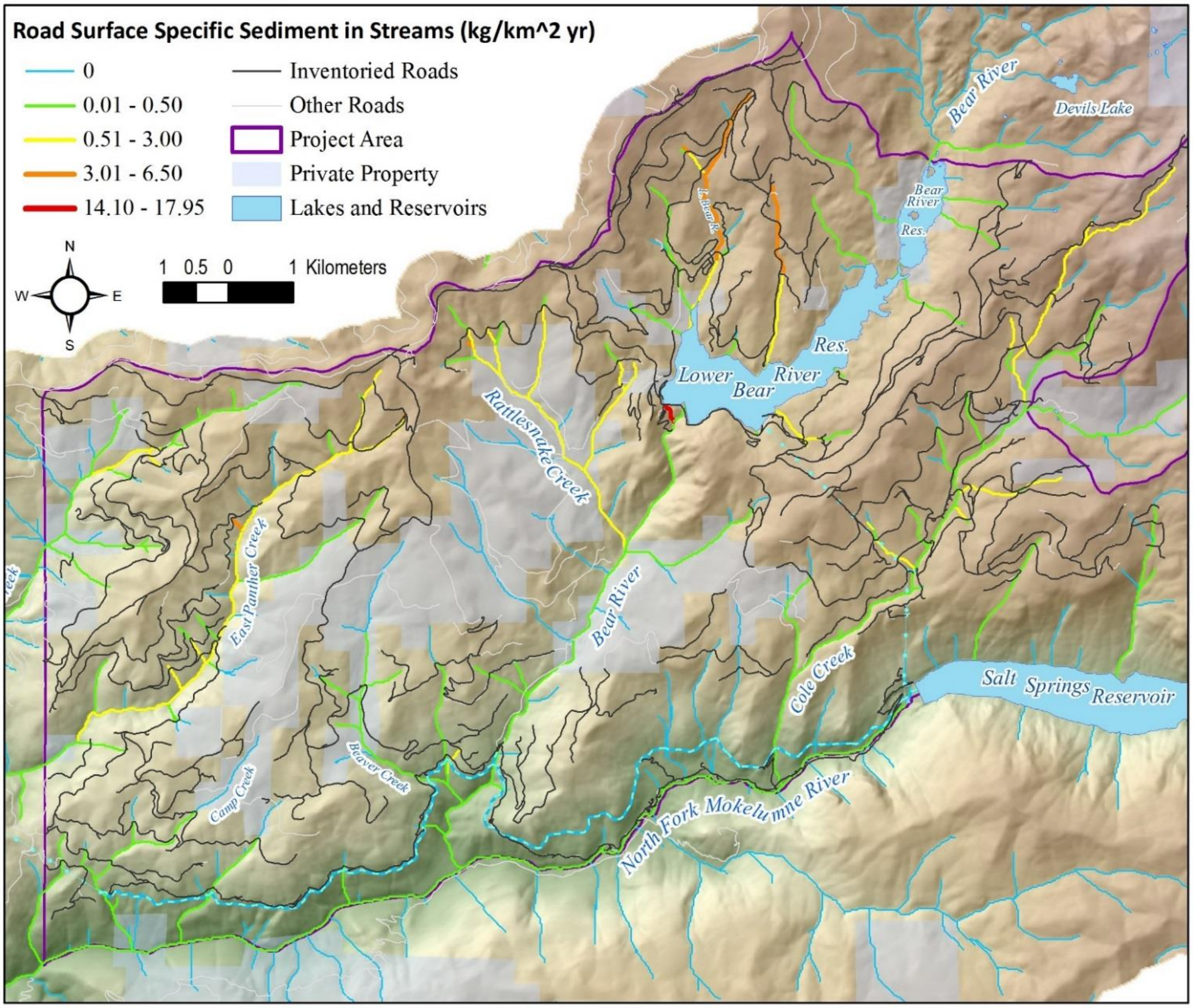

Figure 19. Specific sediment from road surfaces to streams in the Power study watersheds.

5.4 Landslide Risk

Existing Landslides

In the Power study watersheds, the majority of landslides were concentrated in the inner gorge and lower slopes of East Panther Creek (Figure 20). Only four minor features were not in that area. The inventory recorded 20 landslides (Table 6), totaling 3,300 m^3 (4,310 yd^3, 5,280 Mg). Landslide volume was estimated for all landslides visible from the road greater than a minimum threshold of 10 feet in slope length and 6 feet in slope width. There were 17 that were caused by the road in some way. Road-caused landslides totaled 2,060 m^3 (2,680 yd^3, 3,300 Mg). Including non-road caused landslides, there were 6 cutslope failures (630 m^3, 825 yd^3, 1,010 Mg, Figure 21), 9 fillslope failures (1,375 m^3, 1,800 yd^3, 2,200 Mg, Figure 22) and 5 hillslope failures (1,290 m^3, 1,690 yd^3, 0,070 Mg). Locations of all observed landslides by size and mass delivered are shown on Appendix B, Map 6. Appendix B, Map 6 also shows the predicted natural risk (see below).

Landslides were determined to be connected to the channel network if an associated drain point was connected to the channel network, if an associated road surface flow path that would be expected to intercept the landslide sediment was connected to the network, or if the landslide was observed in the field to be connected to the network. Landslides in this project area, based on percent of mass delivered, had moderate rate of connectivity. There were 11 landslides found to be stream connected, of which 8 were road caused. Using a bulk density for fill of 1.6 Mg m^{-3} (Madej 2001), the mass of sediment generated from road caused, connected

Table 6. *Number and types of observed landslides, and masses and volumes of sediment generated and delivered to the stream channel network in the Power study watersheds.*

Location	Count	Volume (yd^3)	Volume (m^3)	Mass Produced (Mg)	Mass Delivered (Mg)	% Mass Delivered	Mass Delivered (Mg yr^{-1}) over 20 yr
Cutslope	**6**	**825**	**630**	**1,010**	**0**	**0%**	**0**
Road Caused	*6*	*820*	*630*	*1,010*	*0*	*0%*	*0*
Fillslope	**9**	**1,800**	**1,375**	**2,200**	**1,660**	**75%**	**83**
Not Road Caused	*1*	*35*	*25*	*40*	*40*	*100%*	*2*
Road Caused	*8*	*1,760*	*1,350*	*2,160*	*1,610*	*75%*	*81*
Hillslope	**5**	**1,690**	**1,290**	**2,070**	**2,070**	**100%**	**104**
Not Road Caused	*2*	*1,590*	*1,220*	*1,950*	*1,950*	*100%*	*98*
Road Caused	*3*	*100*	*80*	*130*	*130*	*100%*	*7*
Totals	**20**	**4,310**	**3,300**	**5,280**	**3,730**	**71%**	**187**
Not Road Caused	***3***	***1,625***	***1,245***	***1,990***	***1,990***	***100%***	***100***
Road Caused	***17***	***2,680***	***2,060***	***3,300***	***1,740***	***53%***	***87***

landslides was estimated to be 1,740 Mg, or 53% of total road caused landslide mass produced (Table 6). Three landslides that were stream connected, but not road caused were not used in values of road related sediment sources.

In order to make a comparison between the episodic sediment delivered from landslides to the annual sediment delivered from fine road surface sediment, the road related landslide sediment total delivered mass was averaged over a 20-year period. This 20-year time frame was reflected by episodic mass wasting in this area. Triggered movement at many of the mass wasting locations corresponded with winter of water year 1996/1997 (Archer 2016), in which combined precipitation for December and January were the wettest on record in the Northern Sierra since 1920 with nearly 1,219 mm (48 in.) of precipitation (CNRFC 2016B). Using this method, an estimated annual sediment delivery rate from road caused landslides was about 87 Mg yr^{-1}, or roughly 1.2 times the annual road surface fine sediment delivery. Put another way, regardless of the duration and mechanism of landslide delivery, it would take the road surfaces 25 years to deliver the same mass road related landslides delivered in total. Landslide masses represent pulsed, as opposed to chronic sediment inputs to streams, so in any given year, the amount of sediment delivered to streams is likely to be higher or lower than this estimated annual rate. Estimates of total mass delivered represent the entire landslide volume and 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). Due to these uncertainties, actual delivered volumes may be lower. Appendix B, Map 6 shows locations of all observed landslides by size and mass delivered, and Figure 20 shows the East Panther Creek area.

Susceptibility to landslides in the study area may be governed in part by underlying geology (Figures 6 and 20, Spittler 1995). Though not strongly prone to landslides within the unit, the Mehrten Formation is permeable and readily transmits water, commonly creating springs and decreasing stability in less permeable underlying units (Spittler 1995). McKitterick (1995) classifies East and West Panther Creek watersheds as High to Extremely Susceptible to landslides due to recently observed landslide activity, and the Mehrten formation overlying undifferentiated Paleozoic metamorphic rocks (Figure 20) which were observed in the field to be a highly deformed, steeply tilted assemblage that formed weathered surfaces with an abundance of clay. The inherent decompositional properties of this unit, along with spring flow from the base of the Mehrten Formation may play a role in the high frequency of landslides in the area. The metamorphic Paleozoic rocks, though susceptible to landslides, hold steep slopes and develop soils that are not highly erodible. The Mehrten Formation forms soils susceptible to surface erosion which may be a factor in the high occurrence of gully formation in the unit throughout the study area (see Section 5.5). The degree of weathering in granite has a strong influence on its erodibility and landslide susceptibility (Spittler 1995, Clayton et al. 1979). Areas of very poorly cohesive, deeply weathered, biotite rich granite are highly susceptible to surface erosion. Areas within the project area with weathered granitic rocks, especially near the Mehrten contacts are classified as Moderately Susceptible to rotational landslides (McKitterick 1995). In this study large rotational landslides were not recorded and few shallow landslides were observed in granitic areas.

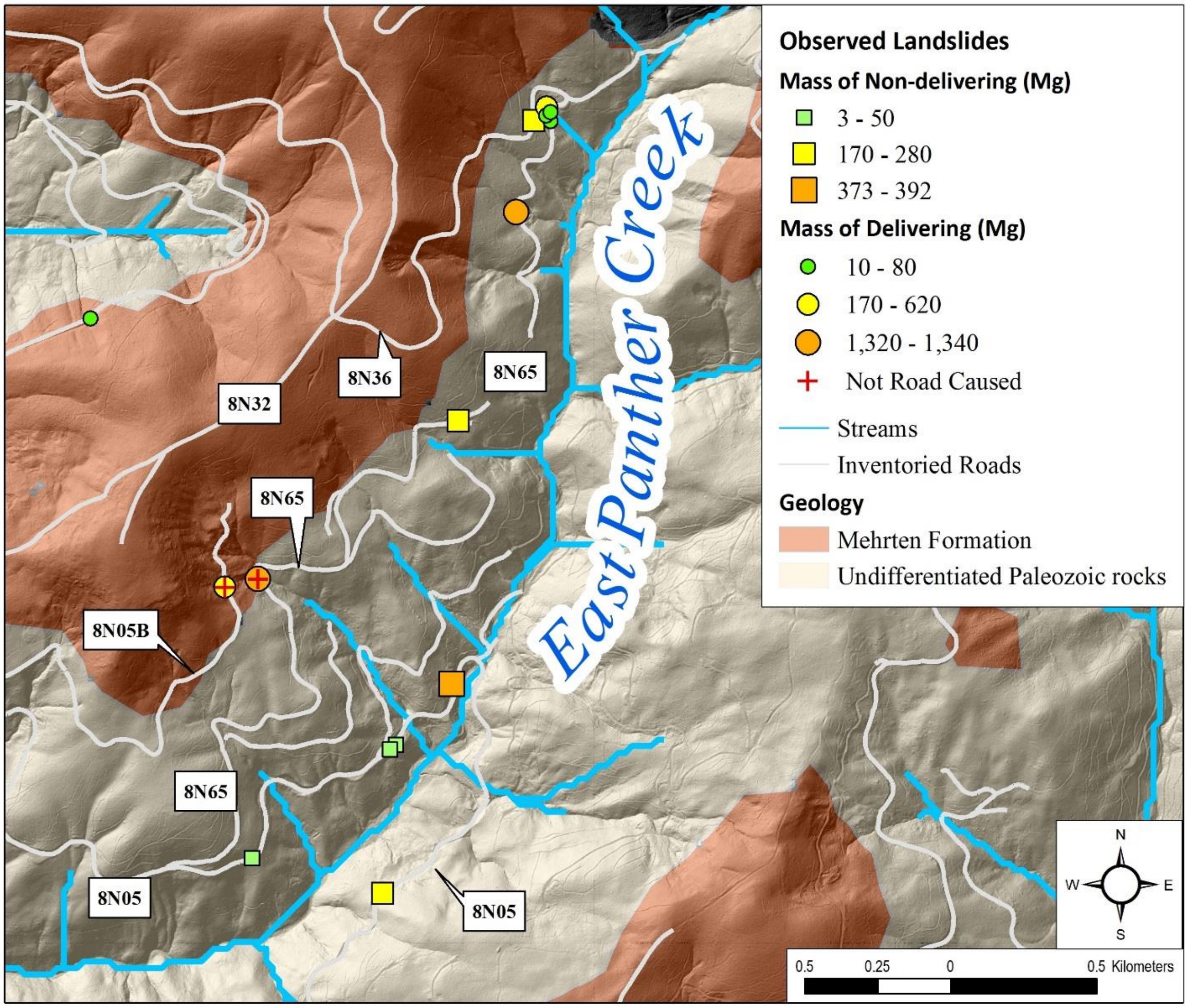

Figure 20. Locations of the majority of all observed landslides; East Panther Creek area.

Figure 21. Cutslope failure type landslide.

Figure 22. Fillslope failure type landslides.

Changes to Landslide Risk Due to Roads

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. 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.

Calibration was performed using a set of points locating shallow landslide features within the study area. Features were visually identified on the Eldorado National Forest (2015) LiDAR-based hillshade. Only features that met selection criteria with a high degree of certainty were used for the calibration, so it is likely there are a greater number of shallow landslides which exist that were not used in the calibration. Forty-four features with distinct headscarp, body, and toe were identified by a search at 1:3,500 scale, which dictated a minimum feature size of roughly 10 meters wide. No road related, rotational, bedrock, rockfall, stream bank, or features

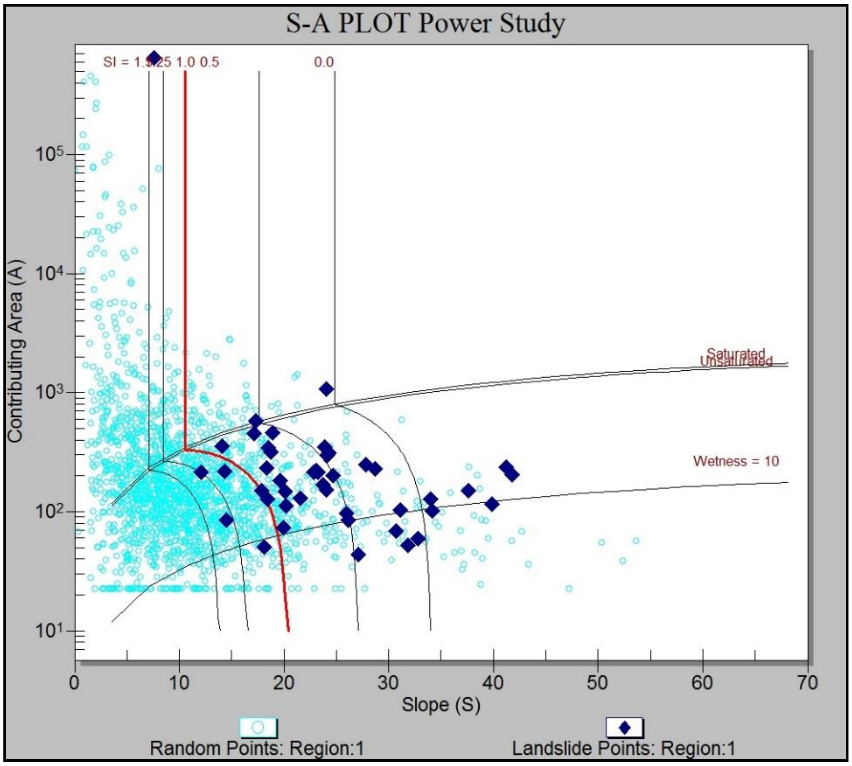

Figure 23. SINMAP generated calibration graph. Points that lie to the right of the red line are considered to be unstable.

within deep seated landslides were selected. There was no maximum feature size. Features were marked with a single point at the top of headscarp. Comparison was made to a local California Department of Conservation, Division of Mines and Geology landslide map (McKittrick 1995). Agreement on landslide types (deep seated, inner gorge, debris flow, or debris slide) at a large scale was good between our interpretations of features on LiDAR and the corresponding areas on the McKittrick (1995) map.

Figure 23 shows the calibration plot for all areas within the watersheds from SINMAP (see documentation on the SINMAP website). Two types of points were plotted on the contributing area-slope graph. The first type was a random selection of points that represented the slope-area distribution throughout the watershed, and the second type were the landslide calibration points. Points that fell to the right of the red line were considered to be at high risk.

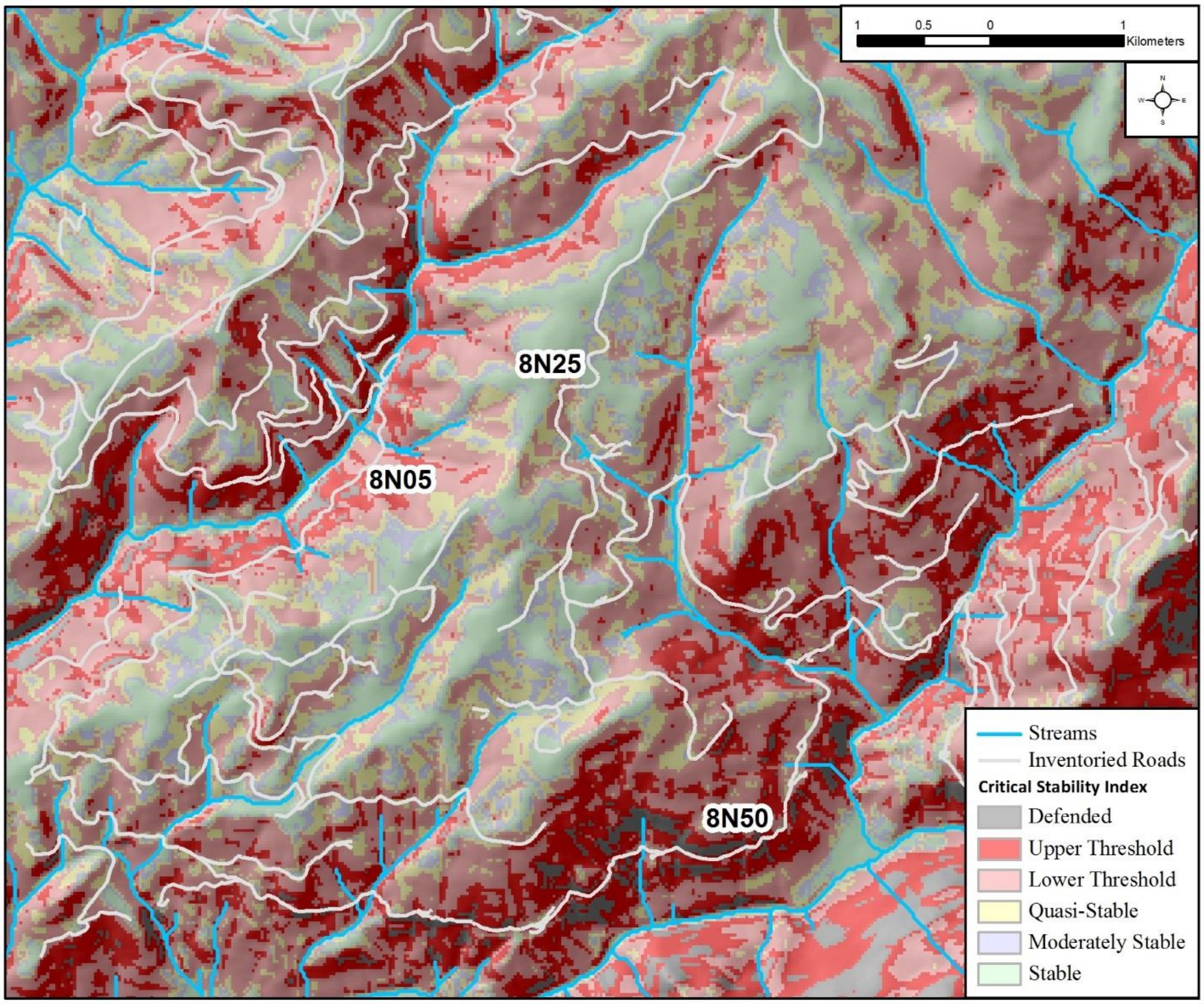

Figure 24. Natural slope stability in the south central portion of the Power study watersheds. The yellow, blue, and green cells are generally considered to be stable, while the pink, red, and grey cells are generally considered to be unstable.

Figures 24, 25 and 26 illustrate the natural slope stability risk and change in risk with the addition of water from roads to hillslopes in the south central portion of the Power study watersheds. SINMAP was calibrated and run initially to determine the intrinsic stability of the slopes over which the roads traversed, and to identify locations that were at a high risk of failure without the road. The surveyed roads were distributed across various landscapes with 56% of inventoried road length located in SINMAP predicted naturally unstable, and 44% in stable areas. Modeled landslide risk was generally high across the steepest slopes throughout the watershed (Figure 24; Appendix B, Map 7).

A second calibrated stability index run was performed to address the effects of road water contribution to drain points. In Figure 25, shown in red are the areas in the south central portion of the watershed where roads changed the risk from the stable category (stable, moderately stable, quasi-stable from Figure 24, above) to the unstable category (lower threshold, upper threshold, defended). These were areas where road drainage was installed

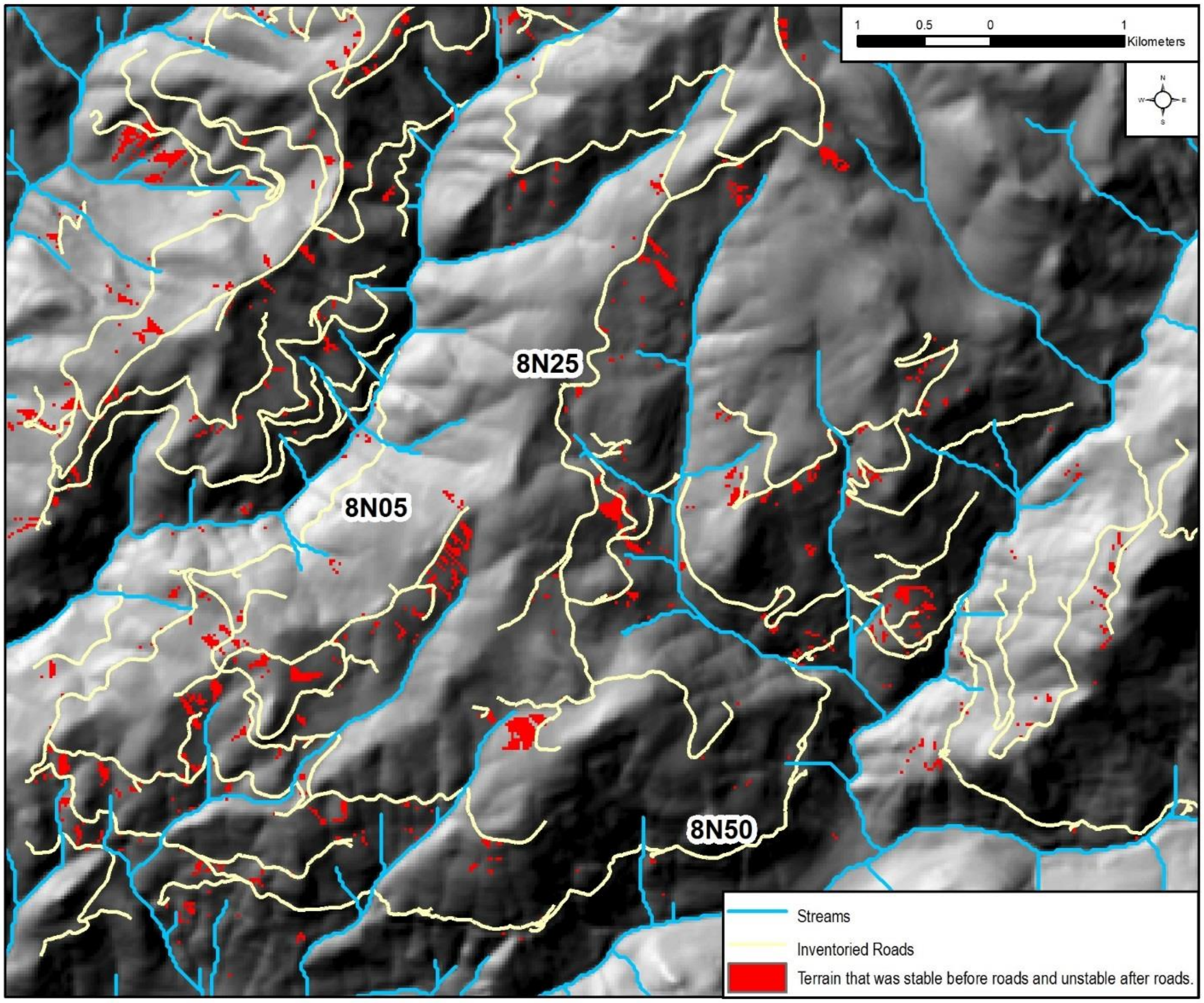

Figure 25. The most significant slope stability risk changes due to the roads in the south central portion of the Power study watersheds. The risk in the red areas was significantly increased.

over slopes predicted by SINMAP to be naturally stable, and the added water increased the predicted instability of the area into the unstable category.

Figure 26 adds the areas where the risk of shallow landsliding was high both before and after road construction. The orange cells are areas where the predicted risk increased (became less stable) after road construction. The terrain was unstable (lower threshold, upper threshold) prior to road construction, but changed to a higher degree of instability due to the installation of road drainage over naturally unstable slopes. Risk may not extend as far downslope as is shown. In steep and wet areas with naturally high landslide initiation risks such as this, it may be difficult to place road drainage in such a way that risk is not significantly increased.

Figure 27 adds all areas where SINMAP predicted naturally high risk. They are shown in light grey hatches and correspond to the pink, red, and grey unstable categories (lower threshold, upper threshold, and defended) on the natural slope stability image (Figure 24). This shows

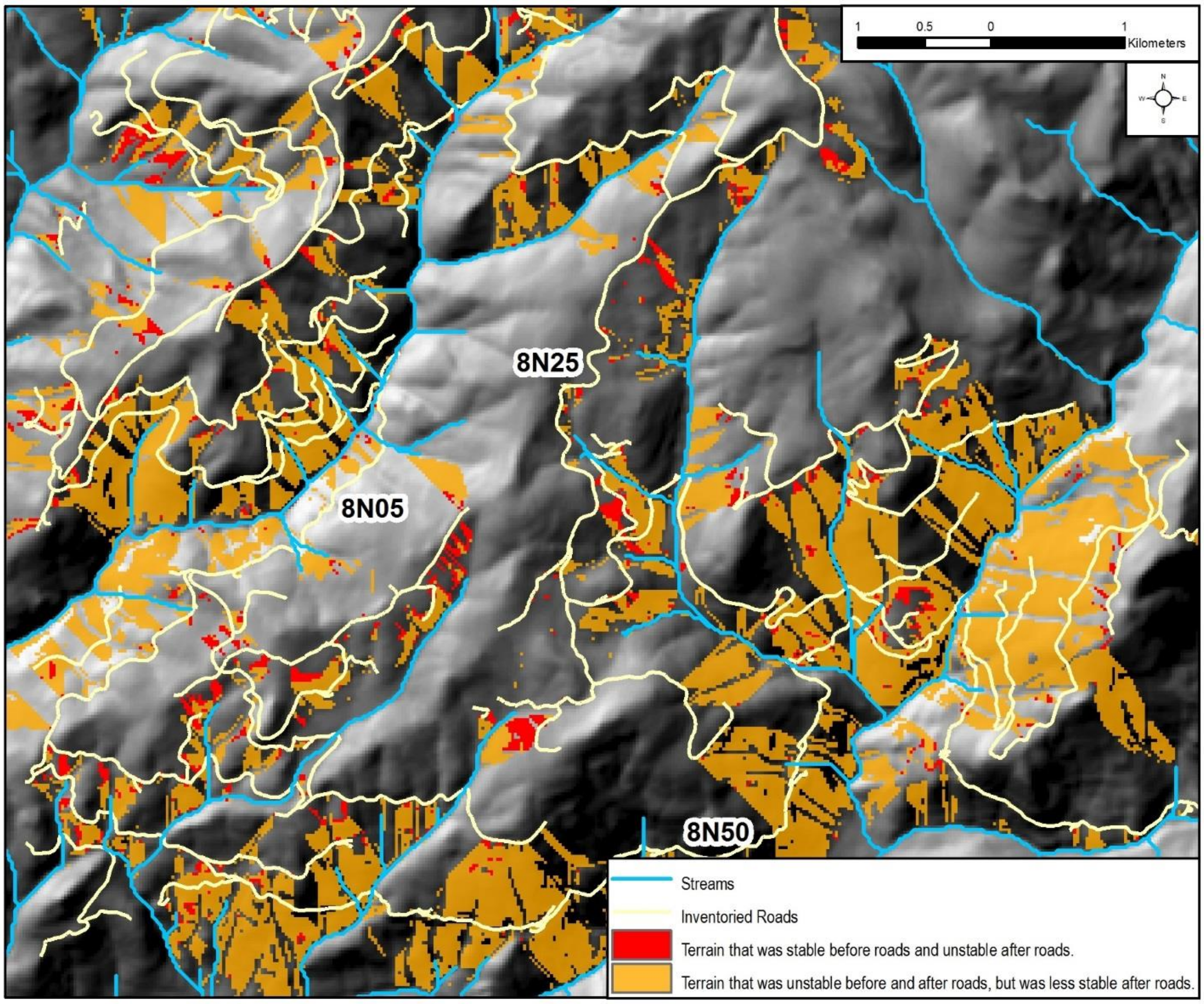

Figure 26. Changes in slope stability risk in the south central portion of the Power study watersheds. The orange areas are where the risk increased. Risk may not extend as far down slope as shown in some locations.

areas where naturally high risk was not increased to even higher predicted risk categories with increased road flow.

Appendix B, Map 8 and Table 7 show areas of SINMAP predicted risk, changes in predicted risk, and locations of landslides identified in the GRAIP study across the project area. Of the 154 km^2 (60 mi^2, not including lake areas) that comprise the Power study watersheds, 3.3 km^2 (1.3 mi^2, 2%) were stable before road construction and are now unstable, and 25 km^2 (10 mi^2, 16% were unstable before road construction and are now less stable due to road drainage (Table 7). This was a total of 28 km^2 (11 mi^2, 18%) of the watershed that experienced an increase in SINMAP predicted landslide risk due to roads.

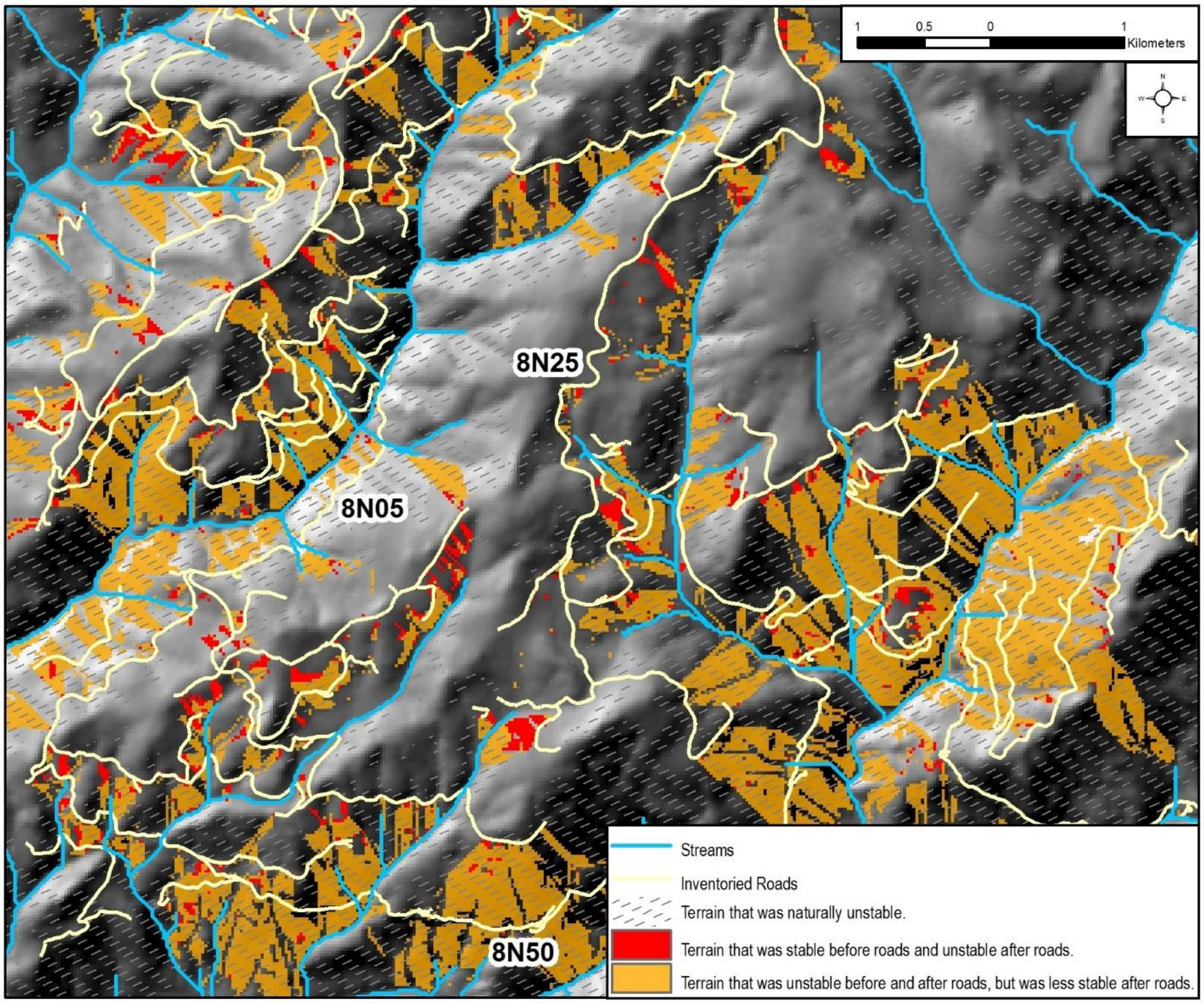

Figure 27. Areas of naturally high risk and risk changes, south central portion of Power study watersheds.

Table 7. *Landslide risk changes in the Power study watersheds by category and area.*

Risk Category	**Area (m^2)**	**% of Total Area**	**Number of Landslides**	**% of Total Landslides**
Total Project Area (m^2)	153,577,700[1]	100%	20	100%
Area Naturally Stable (m^2)	72,448,400	47%	4	20%
Area Naturally Unstable (m^2)	81,129,300	53%	16	80%
Area Stable Before Roads, Now Unstable (m^2)	3,311,900	2%	2	10%
Area Unstable Before Roads, Now Less Stable (m^2)	24,788,000	16%	5	25%
Total Area Affected by Road Water Discharge (m^2)	**28,099,900**	**18%**	**7**	**35%**

[1] Area is project area minus lake areas.

The majority (80%) of landslides observed in the survey occurred in areas predicted by SINMAP to be inherently unstable. The study area had a high concentration of landslides in the East Panther Creek inner gorge (Figure 20). Evidence of the higher instability in this area was also observed at stream crossings along landslide prone roads in the East Panther Creek inner gorge area. Among 22 stream crossings in the area there was debris flow evidence at five crossings, and partial or totally blocked inlets at 11 crossings. Precipitation the two winters following the Power Fire were 128% and 145% of average (CDEC 2016), and likely played a role in instability in the area. Multiple landslides were observed in undifferentiated Paleozoic geology on road 8N05 along the approaches down to East Panther Creek in December, 2005 during a 10-year storm event only one year after the large and intense Power Fire (Markman 2006). That December saw a total precipitation amount at Salt Springs Reservoir gage of 559 mm (22 in.), one third of the total precipitation for that water year (CDEC 2016). Landslide risk outside of the areas below the Mehrten contact was relatively low, and the SINMAP predicted risk was likely not as applicable.

Although landslide occurrence was relatively infrequent, the mass delivered from landslides was significant in the study area. Options for treatment of high risk areas are few. Additional drainage can be added to reduce the length of road that drains to a given point or points, and therefore reduce the quantity of water, but this may result in even more road-related unstable area if the drain spacing is not close enough. Additionally, if a slope is naturally unstable, as is about half of the project area, then any addition of water, however small, will only decrease stability further and increase risk. Another option is to remove drainage features that occur at high risk locations, and instead route water further down the road to a more stable area. However, this may result in excessive road surface or ditch erosion, and the point to where the water is routed may then become unstable or it might deliver large quantities of sediment to the stream. In areas where landslide activity is extreme it may be best to reroute the road entirely, however, few areas in the project area require this most extreme measure.

5.5 Gullies and Gully Initiation Risk

Existing Gullies

To distinguish between road-related gullies and natural incipient channel heads, a feature was mapped as a gully if it occurred below a road drain point, but was 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. The Power study area had, overall, relatively moderate to high occurrence rates of road related gullies heterogeneously distributed based on geology and road engineering. Rates were especially high in Mehrten Formation and along paved roads. In the entire study area there were 218 gullies observed (at nearly 5% of all drain points) during the course of the survey, with a total volume of 7,220 m^3 (9,450 yd^3, Table 8). There were 115 gullies that occurred only on the hillslope (4,550 m^3, 5,950 yd^3), 33 that occurred only on the fillslope (320 m^3, 420 yd^3), and 61 that occurred on both the fillslope and hillslope below a drain point (2,100 m^3, 2,750 yd^3), and 9 above the road. There were 2 gullies that occurred in a wet swale, 21 that had flow contribution from springs or flow diversions, and 52 that terminated in a stream. 16 gullies were no longer actively eroding, while 193 were actively eroding. Figure 29 shows a typical gully below a ditch relief culvert. Appendix B, Map 9 shows the locations, delivered and non-delivered masses, and activity, of all inventoried gullies as well as information pertaining to road surface type, geology type, and gully risk (see below).

Table 8. *Inventoried gullies in the Power study watersheds (does not include those observed on road surfaces).*

Location of Gully *Activity of Gully*	**Count**	**Volume (yd^3)**	**Volume (m^3)**	**Number That Occur in Wet Swale**	**Number With Flow Contributions From Springs and/or Flow Diversion**	**Number That Terminate At A Stream**
Above Road	**9**	**330**	**250**	**1**	**5**	**0**
Still Eroding	*9*	*330*	*250*	*1*	*5*	*0*
Hillslope	**115**	**5,950**	**4,550**	**1**	**9**	25
Not Active	*8*	*70*	*50*	*0*	*0*	*0*
Still Eroding	*107*	*5,880*	*4,490*	*1*	*9*	*25*
Fillslope	**33**	**420**	**320**	**0**	**1**	**7**
Not Active	*4*	*40*	*30*	*0*	*0*	*1*
Still Eroding	*29*	*400*	*300*	*0*	*1*	*6*
Fillslope and Hillslope	**61**	**2,750**	**2,100**	**0**	**6**	**20**
Not Active	*4*	*30*	*20*	*0*	*0*	*1*
Still Eroding	*57*	*2,720*	*2,080*	*0*	*6*	*19*
Totals	**218**	**9,450**	**7,220**	**2**	**21**	**52**
Not Active	*16*	*140*	*100*	*0*	*0*	*2*
Still Eroding	*193*	*9,000*	*6,870*	*1*	*16*	*50*

Figure 30 shows the locations of the gullies in the northwest portion of the watershed and along Highway 88, as well as the same gully initiation risk information.

Gully occurrence rates were much higher in some classes when classified by road surface type and underlying geology (Figure 28). Only drain points that concentrate flow on hillslopes below the drain were considered in gully analyses. Stream crossings direct flow to streams, not hillslopes, and diffuse drains diffuse rather than concentrate flow, so these drain point types are not included in gully analyses. The average incidence of road-related gullies below drain points (not including stream crossings or diffuse drains) on all roads throughout the entire project area was 6%. Gullies were observed at a higher rate below drain points along all paved roads (14%), as compared to native or rocked roads (3%). Rates were also higher along roads in geologies of the Mehrten Formation, Glacial deposits, or the metamorphic undifferentiated Paleozoic rocks (MGP, 8%) as compared to those in granitics or alluvium (GA, 3%). Broken into finer categories, rates were higher along paved roads in either geology type, and especially high in MGP geologies along paved roads at 19% versus unpaved roads at 3%. Gully rates were highest below drain points off Highway 88. Gullies were below 40% of all drain points along Highway 88, 47% in MGP geologies, and 33% for GA geologies. These results suggest that remediation efforts should be focused along Highway 88 and along paved roads especially in MGP geologies. Remediation methods are discussed in the next section, Gully Initiation Risk.

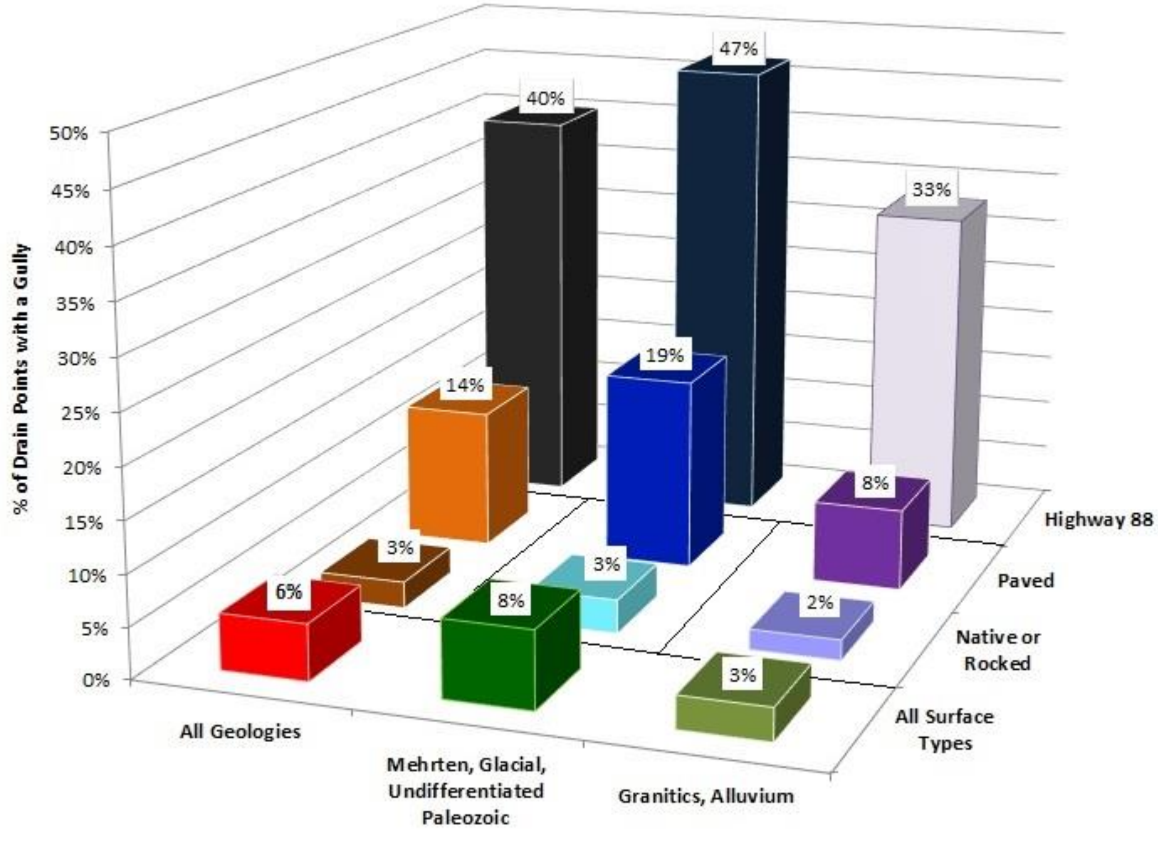

Figure 28. Gully rates as percent of drain points in each category (not including stream crossings or diffuse drains) by surface type and geology type. Lines are drawn to guide comparisons between classes within groups.

Gullies were determined to be connected to the stream channel network if an associated drain point that discharged through the gully was connected to the channel. There were 130 gullies (60%) that were determined to be connected to the channel. Using a bulk density for fill of 1.6 Mg m^{-3} (Madej 2001), the mass of sediment generated at all connected gullies was 9,300 Mg (Table 9). This was 80% of the mass generated at all gullies. As in the discussion of landslide sediment mass delivery in Section 5.4, it is useful to compare episodic delivery of gully sediment mass to annual road surface fine sediment delivery, by distributing gully sediment delivery over a given time span. If the total mass were averaged over a 20 year period, then gullies in the Power study had an estimated average annual sediment delivery rate of 465 Mg yr^{-1}, or about 7 times the amount of road surface fine sediment delivered annually. Or put another way, regardless of the duration and mechanism of gully mass delivery, it would take the road surfaces 133 years to deliver the same mass road related gullies delivered in total. Gully mass sediment delivery 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. Actual annual sediment delivery from gullies is likely higher or lower than these estimates in any given year.

Gullies observed on the road surface or in the ditch as opposed to the hillslope or fillslope were not counted in the above calculations because these gullies were not influenced by the same processes as the hillslope gullies. They eroded road surface material along road surface flow paths instead of fillslope and/or hillslope material. Road surface gullies are considered with fill erosion (see Section 5.7).

Table 9. *Sediment masses produced and delivered by active gullies in the Power study watersheds.*

Gully Location	**Mass Produced (Mg)**	**Mass Delivered (Mg)**	**% Sediment Delivery**	**Average Delivery Rate Over 20 years (Mg yr^{-1})**
Above Road	410	260	63%	13
Hillslope	3,370	2,800	83%	140
Fillslope	520	270	52%	13
Fillslope and Hillslope	7,280	5,970	82%	299
Totals	**11,580**	**9,300**	**80%**	**465**

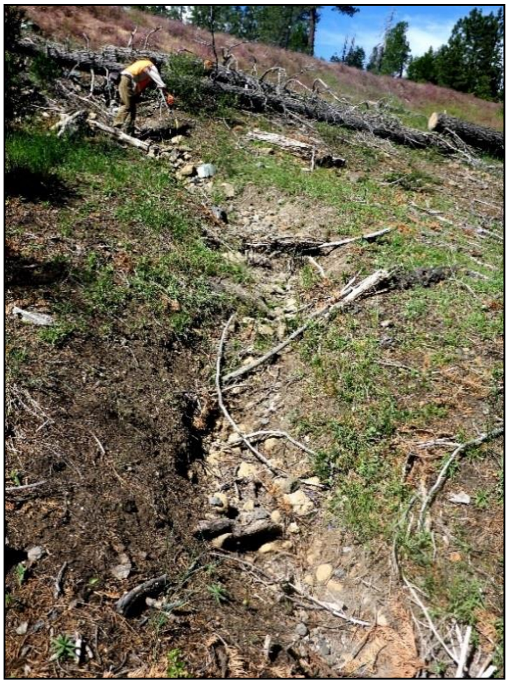

Figure 29. Gully below the outlet of a ditch relief culvert.

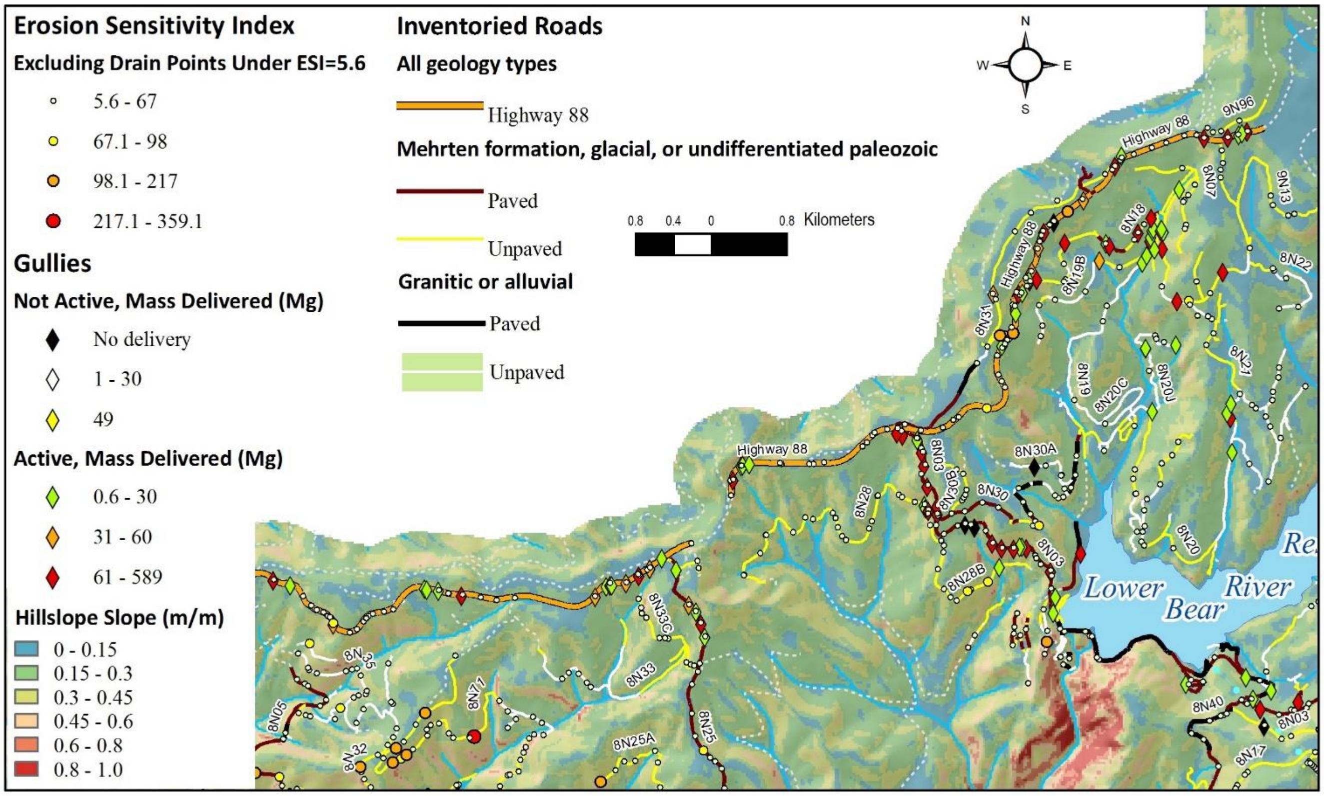

Figure 30. Locations of observed gullies with activity level and delivered mass, ESI risk at drain points, hillslope slopes below drain points, paved and unpaved surfaces, and roads in two geology groups along Highway 88 and the northwest portion of the study area. Only drain points with ESI>5.6 are shown. Drain points are shown whether or not a gully is present at the drain point, but for drain points where $ESI>ESI_{crit}$, the drain point is superimposed on the gully point.

Gully Initiation Risk

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 were compared to a critical ESI threshold (ESI_{crit}) to identify areas with a higher risk of gully formation (i.e., where ESI $>ESI_{crit}$). ESI_{crit} was empirically derived using inventoried gullies, and was the ESI value above which the risk of gully formation increased significantly. In order to derive a meaningful ESI_{crit} value from a data set, the gully rate (percent of drain points with a gully) must be large enough. In the Power study watersheds, the gully rate was very different between paved and unpaved roads, and between two different sets of geology types as discussed in the previous section. Data sets with gully rates above about 14% produced meaningful ESI_{crit} values, and represented areas where gully formation was a risk, and where ESI_{crit} values can guide remediation efforts to specifically address reduction of gully risk. Other areas had lower gully rates and therefore may not require remediation to reduce already low gully risk.

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) were not included in these analyses 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. Though several gullies formed along diffuse road segments on Highway 88 where flow discharged onto soft shoulder and fill, the contributing effective length was different than that of contributing length to a single discharge point. Streams have their own, and often non-road related controls on their propensity to incise, and do not flow onto hillslopes, and so cannot be treated the same as other drain points. Orphan drain points which have a contributing length of zero, and drain points with a zero slope below, have an ESI of zero, which disrupts a meaningful average and are therefore excluded.

In the entire project area, 3,487 drain points (198 with gullies, 6% gully rate) were used for ESI analysis, but as an entire data set, no meaningful ESI_{crit} value could be derived because there was no threshold pattern present. Areas where meaningful ESI_{crit} values could be derived were for drain points along Highway 88, and for drain points along paved roads within MGP geology types (Mehrten Formation, Glacial deposits, and undifferentiated Paleozoic rocks). In the two areas, ESI_{crit} values were 5.6 and 6.3, respectively. The risk of gully formation roughly doubles above that value (Tables 11, and 12).

Table 10. *Average contributing road lengths, and gully rate for drain points within areas of differing road surface and geology types.*

Road Type	Geology Type	Gully Rate (#DPs with Gully/#DPs)	Average Contributing Length for Drain Points with Gullies (m)	Average Contributing Length for Drain Points without Gullies (m)
Highway 88	**All Geologies**	**40%**	**108**	**69**
Paved	Mehrten, Glacial, undifferentiated Paleozoic	18%	104	82
	Granitics, Alluvium	*8%*	*131*	*85*
	All Geologies	**14%**	**109**	**83**
Native or Rocked	Mehrten, Glacial, undifferentiated Paleozoic	3%	122	77
	Granitics, Alluvium	*2%*	*121*	*72*
	All Geologies	**3%**	**122**	**74**
All Surface Types	Mehrten, Glacial, undifferentiated Paleozoic	8%	110	78
	Granitics, Alluvium	*3%*	*125*	*74*
	All Geologies	**5%**	**110**	**76**

For all drain points, contributing lengths on average to drain points with gullies were longer than to drain points without gullies for any geology type or road surface type (Table 10); 110 m (361 ft) versus 69 m (226 ft). For drain points with gullies in areas with lower gully rates (≤8%), contributing lengths on average were longer than in areas with higher (≥14%) gully rates; 120 m (394 ft) versus 107 m (351 ft). For drain points with gullies along native or rocked roads, contributing road lengths on average were longer than to drain points along paved roads; 122 m (400 ft) versus 109 m (358 ft). And for drain points with gullies in granitic and alluvium geology types, contributing lengths were longer to drain points along paved roads in Mehrten, glacial, and undifferentiated Paleozoic geology types (131 m [430 ft] versus 104 m [341 ft]), but nearly equal to lengths to drain points along native or rocked roads in MGP geology types; 121 m (397 ft) versus 122 m (400 ft).

Figure 30 shows the distribution of gully risk along Highway 88 in the northern portion of the project area, and Appendix B, Map 9 shows the same for the entire watershed. Along Highway 88, a total of 148 non-diffuse, non-stream crossing, non-orphan drain points were used in this analysis (Table 11). Of the 148 drain points, 59 had gullies for a gully rate of 40%. Among all 148 drain points, there were roughly an equal number of drain points with $ESI>ESI_{crit}$ (76, 51%) as with $ESI<ESI_{crit}$ (72, 49%). Of the 59 drain points with gullies, 66% had an $ESI>ESI_{crit}$. For drain points without gullies, fewer drain points (43%) had $ESI>ESI_{crit}$. The average ESI for drain points with gullies was 16.8, while the average ESI for drain points without gullies was 9.3.

Along paved roads in MGP geology types, a total of 549 non-diffuse, non-stream crossing, non-orphan drain points were used in this analysis (Table 12). Of the 549 drain points, 102 had gullies for a gully rate of 19%. Among all 549 drain points, there were roughly an equal number of drain points with $ESI>ESI_{crit}$ (270, 49%) as with $ESI<ESI_{crit}$ (279, 51%). Of the 102 drain points with gullies, 68% had an $ESI>ESI_{crit}$. For drain points without gullies, fewer drain points (45%)

had ESI>ESI$_{crit}$. The average ESI of drain points with gullies was 16.5, while the average ESI of drain points without gullies was 13.4.

ESI is useful predictor of gully formation along Highway 88 and along paved roads in MGP geology types in the Power study watersheds. Calibrations were completed using a logistical regression technique (local fit, locfit) in the R statistical computing environment (Figures 31 and 32) and a length-slope plot of the drain points with and without gullies (Figures 33 and 34). Note that each point on Figures 31 and 32, which represents the probability of a gully (no = 0, yes = 1) vs. ESI value, corresponds to a point with the same ESI value on Figures 33 and 34. In Figures 31 and 32, while there were a number of gullies at drain points with ESI below the chosen ESI$_{crit}$ threshold, the number of gullies vs. the number of non-gully drain points begins to increase significantly at roughly Log$_{10}$ESI = 0.75, which corresponds to an ESI$_{crit}$ value of 5.6 for Highway 88, and 6.3 for paved roads in MGP geology types.

Table 11. *Distribution of drain points along* ***Highway 88*** *by contributing length and various ESI values, Power study watersheds.* ***ESI$_{crit}$ = 5.6****.*

Drain points used in ESI	**All Drain Points**				**Drain Points with ESI>ESI$_{crit}$**		**Drain Points with ESI<ESI$_{crit}$**	
	Number	**Contributing Length (m)**		**Average ESI**	**Number**	**Gully Rate** (#DPs / #DPs used in ESI)	**Number**	**Gully Rate** (#DPs / #DPs used in ESI)
		Total	**Average**					
With Gullies	59	6,474	108	16.8	39	66%	21	34%
Without Gullies	89	6,046	69	9.3	37	42%	51	57%
All Drain Points	**148**	**12,520**	**85**	**12.4**	**76**	**51%**	**72**	**49%**
Gully Rate (#DPs with Gullies/Total #DPs in category)	**40%**				**51%**		**29%**	

Table 12. *Distribution of drain points along* ***paved roads in MGP geology types*** *(not including Highway 88) by contributing length and various ESI values, Power study watersheds.* ***ESI$_{crit}$ = 6.3****.*

Drain points used in ESI	**All Drain Points**				**Drain Points with ESI>ESI$_{crit}$**		**Drain Points with ESI<ESI$_{crit}$**	
	Number	**Contributing Length (m)**		**Average ESI**	**Number**	**Gully Rate** (#DPs / #DPs used in ESI)	**Number**	**Gully Rate** (#DPs / #DPs used in ESI)
		Total	**Average**					
With Gullies	102	10,710	104	16.5	69	68%	34	32%
Without Gullies	447	36,349	82	13.4	201	45%	245	55%
All Drain Points	**549**	**47,060**	**86**	**14.0**	**270**	**49%**	**279**	**51%**
Gully Rate (#DPs with Gullies/Total #DPs in category)	**19%**				**26%**		**12%**	

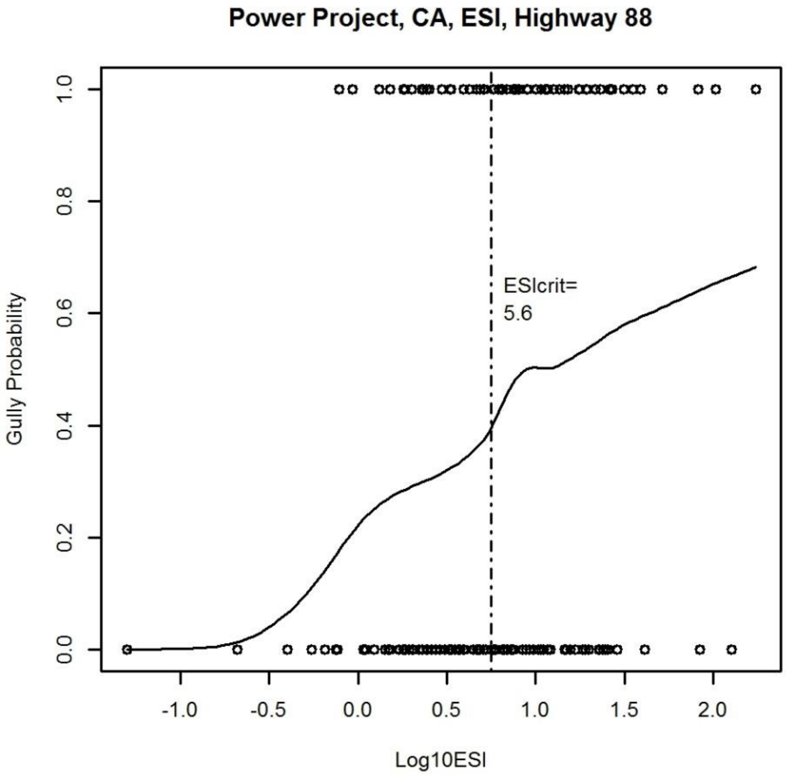

Figure 31. Calibration graph from the R local fit calibration for drain points along Highway 88. Gully Probability is a binary yes/no field. Log_{10} ESI corresponds to an ESI value. Although there are gullies below the chosen ESI_{crit} value of 5.6, their probability is less.

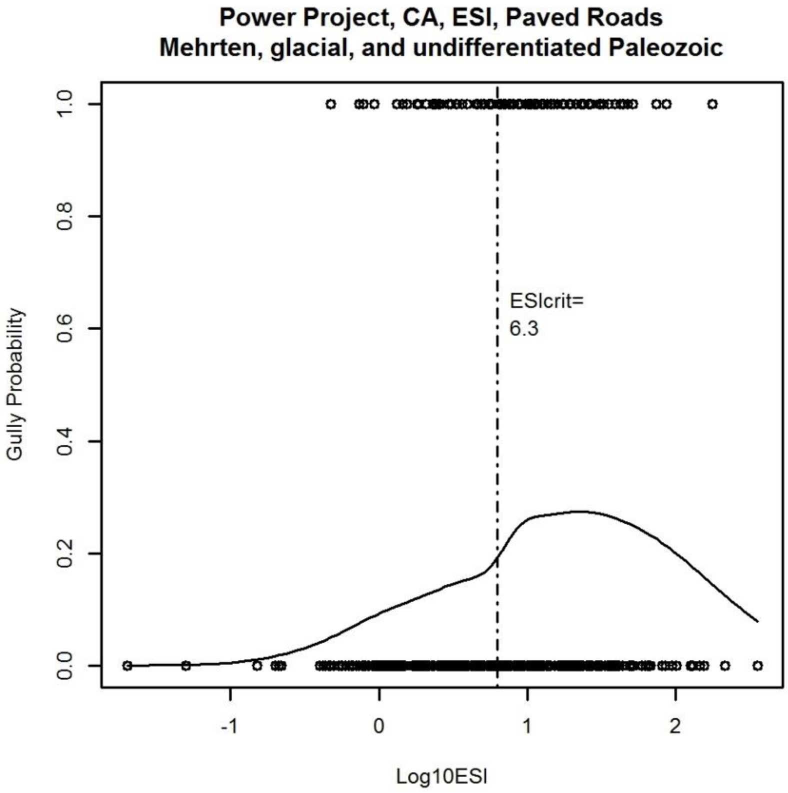

Figure 32. Calibration graph from the R local fit calibration for drain points along paved roads in the MGU geology types. Gully Probability is a binary yes/no field. Log_{10} ESI corresponds to an ESI value. Although there are gullies below the chosen ESI_{crit} value of 6.3, their probability is less.

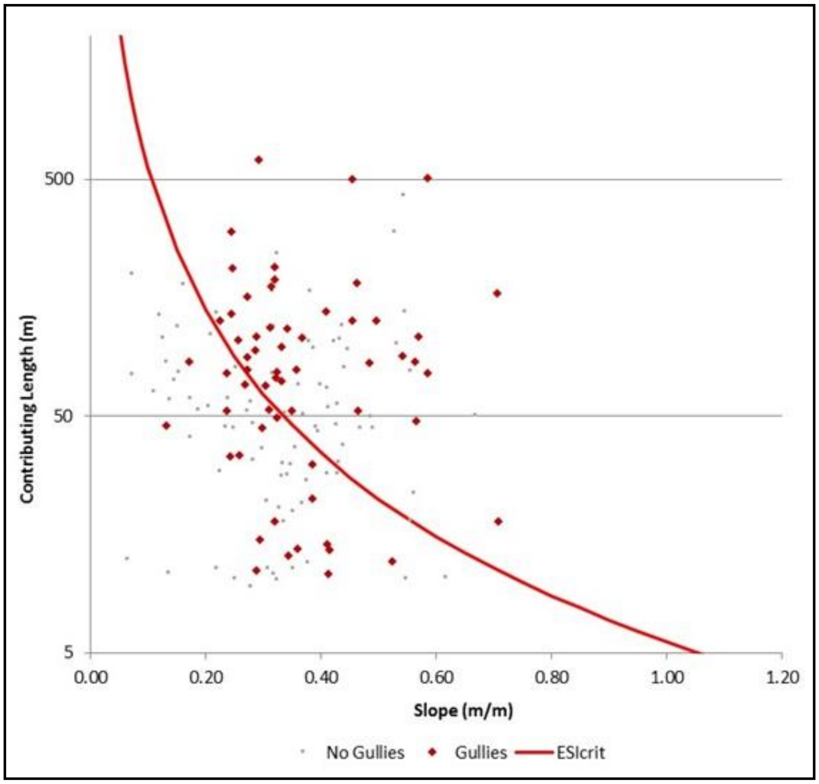

Figure 33. Length-slope plot that shows the distribution of gullied and non-gullied drain points along Highway 88. Notice that there are more non-gullied points towards the left of the graph. As the ESI increases (upper right part of the distribution), there about the same number of gullied points. Above the red ESI_{crit} = 5.6 line, there is a 51% chance of a point being gullied, while below the ESI_{crit} line, there is a 29% chance.

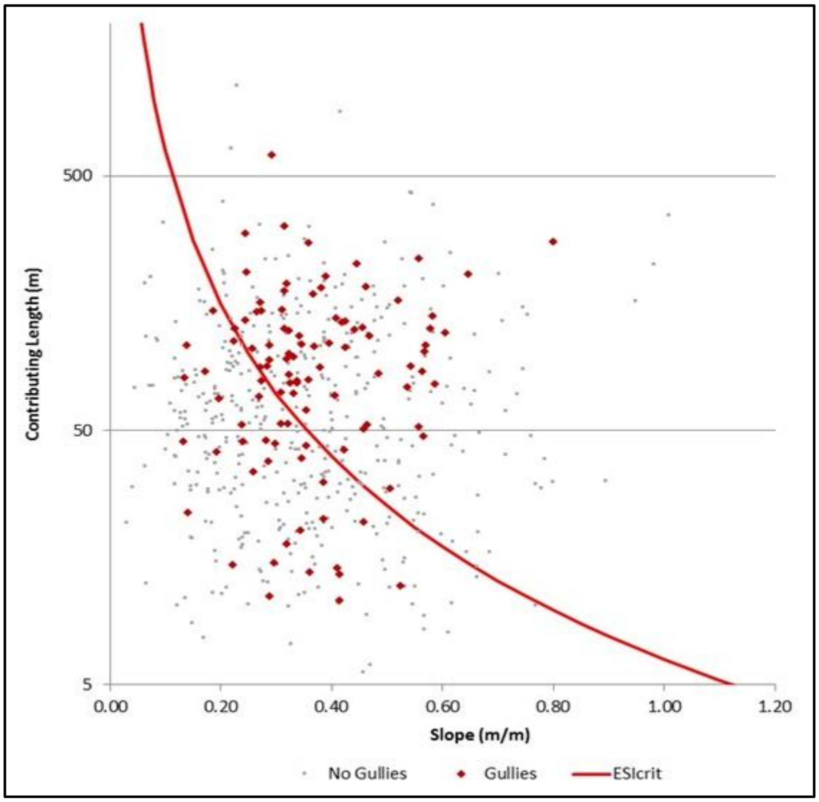

Figure 34. Length-slope plot that shows the distribution of gullied and non-gullied drain points along paved roads in MGP geology types. Notice that there are more non-gullied points towards the left of the graph. As the ESI increases (upper right part of the distribution), there about the same number of gullied points. Above the red ESI_{crit} = 6.3 line, there is a 26% chance of a point being gullied, while below the ESI_{crit} line, there is a 12% chance.

An easy way to conceptualize this is to think of these distributions as densities in length-slope space. That is, while the density of non-gully drain points decreases as ESI gets larger, the density of gullied points remains roughly the same. Therefore, along Highway 88, the ratio of gullied to non-gullied points increased as ESI increased. In this case, below ESI_{crit}, the ratio was 29%, but increased to 51% above ESI_{crit}. Along Highway 88, if the road was newly built or upgraded with 100 drains placed with spacing and hillslope slopes below that resulted in an ESI ($L\,XS^2$) for each drain point of less than 5.6, it would be expected that 29 drain points would develop a gully. If a different road was built or upgraded with 100 drains placed with spacing and hillslope slopes below that resulted in an ESI ($L\,XS^2$) for each drain point of greater than 5.6, it would be expected that 51 drain points would develop a gully.

Similarly for paved roads in MGP geology types, the ratio of gullied points to non-gullied points below ESI_{crit} was 12%, and increased to 26% above ESI_{crit}. If a road was newly built or upgraded with 100 drains placed with spacing and hillslope slopes below that resulted in an ESI ($L\,XS^2$) for each drain point of less than 6.3, it would be expected that 12 drain points would develop a gully. If a different road was built or upgraded with 100 drains placed with spacing and hillslope slopes below that resulted in an ESI ($L\,XS^2$) for each drain point of greater than 5.6, it would be expected that 26 drain points would develop a gully.

These results apply to the road design parameters observed at the time of survey combined with the history of storm events in the area. A change in road design that reduces ESI values by changing the combined factors of drain point spacing and hillslope slope below could have the benefit of reducing risk of gully formation in these two areas within the Power study area. In order to reduce gully risk, drain points must either be spaced close enough together to prevent too much water from discharging at a single point, or they must be removed from steep slopes and high risk locations. However, if drain point spacing is not close enough, risk may be reduced somewhat in one place, but then increased above the critical threshold in another, which may lead to further gully formation. Given the known ESI_{crit} for the watershed and the measurable hillslope slope at a given point on the landscape, it is then possible to calculate the theoretical maximum contributing stable road length (Table 13). These drain spacing values can be used in the planning phase of future projects. For more information on ESI in GRAIP, see Cissel et al. (2012A), specifically, pages 105-109 and page 126.

Table 13. *Maximum contributing road segment length for a given average hillslope required to prevent drain points from exceeding ESI$_{crit}$.*

	Highway 88 (ESI$_{crit}$=6.3)		Paved Roads in MGP Geology Types (ESIcrit=5.6)	
Average Hill Slope (%)	**Maximum Road Segment Length (m)**	**Maximum Road Segment Length (ft)**	**Maximum Road Segment Length (m)**	**Maximum Road Segment Length (ft)**
10%	560	1,840	630	2,065
20%	140	460	158	520
30%	62	200	70	230
40%	35	115	39	128
50%	22	72	25	82
60%	16	53	18	60
70%	11	36	13	43
80%	9	30	10	33
90%	7	23	8	26
100%	6	20	6	20

Though the frequency of gully occurrence had a wide range for the study area from only 2% to 40% of drain points in different areas, delivery rate for gullies was high (80%), and the annual delivered mass was significant at 7 times the annual road surface fine sediment delivery. While gully occurrence is a big concern in parts of the study area, it can be managed by designing road drainage with adequate spacing to reduce contributing road length, and avoiding placing drainage onto steep slopes. Road design which inhibits gully formation on road surfaces and in ditches such as outsloping and reducing drainage spacing can also significantly reduce sediment delivery.

5.6 Stream Crossing Failure Risk

Besides contributing fine sediment to streams through road surface erosion, stream crossings may fail catastrophically when blocked and deliver large sediment pulses to stream channels. Stream crossing failure risks were assessed using the Stream Blocking Index (SBI, Flanagan et al. 1998). The SBI characterizes the risk of plugging by woody debris by ranking two stream crossing characteristics: the ratio of the culvert diameter to the upstream channel width (d/w), and the measured skew angle between the channel and the pipe inlet. Culverts sized to be the same diameter as the channel width or larger have a diameter to channel width ratio greater than or equal to 1 (d/w ≥ 1), and received a value of 1. Culverts sized with a diameter slightly less than the width of the stream to half the width of the stream have diameter to channel width ratios between 1 and 0.5 (1 > d/w ≥ 0.5), and received a value of 2. Culverts sized with a diameter less than half the channel width have a diameter to channel width ratio, less than 0.5 (d/w < 0.5), and received a rank of 3. Skew angles greater than 45 degrees received a value of 1. SBI is a total of the two values. SBI values range from 1 to 4, where 1 suggests low risk of blockage, and 4 suggests a high risk of blockage.

255 stream crossings were recorded in the Power study watersheds. Crossings without culverts did not have SBI calculations. The 41 crossings that did not have a culvert were natural fords (28), bridges (10), and bottomless arch culverts (1), and excavated crossings (7). Risk of pipe plugging is not a factor at these crossings. Four stream crossings did have a culvert, but were not able to calculate SBI because they did not have a channel width or pipe diameter recorded, or were overtopped and flow was around the culverts.

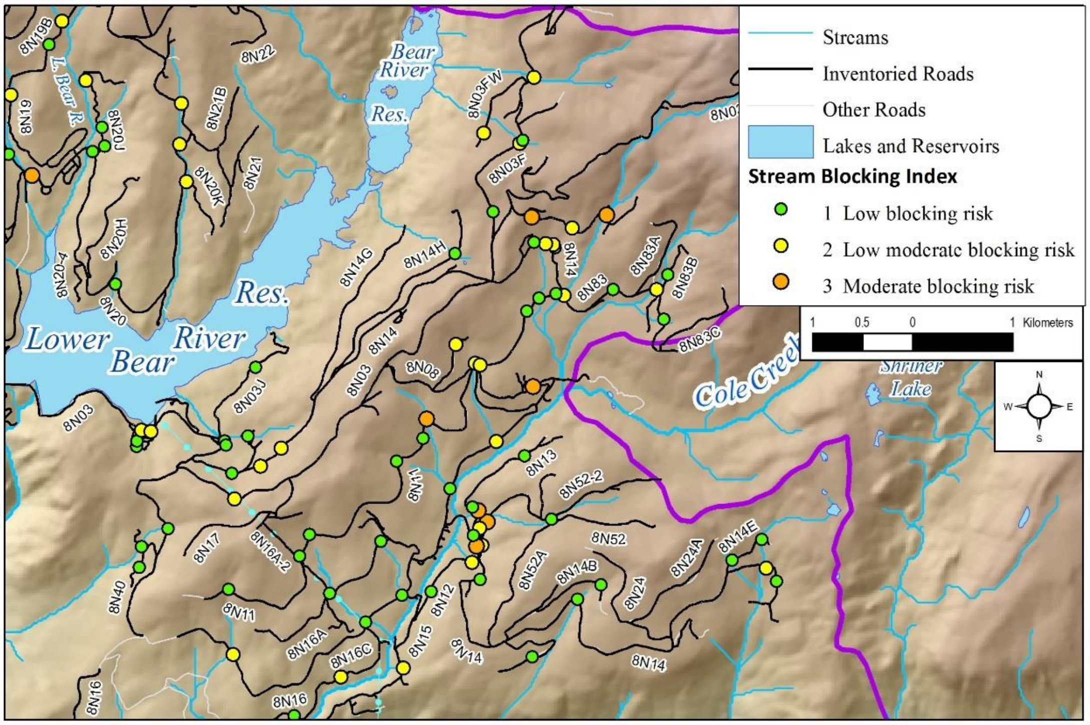

Figure 35. SBI values for the stream crossings in the northeastern part of the Power study watersheds.

Within the watersheds, culvert plugging at stream crossings posed low to moderate risk. For the 212 stream crossings with SBI values within the Power study watersheds there was an average of 1.5. There were no stream crossings with an SBI of 4. There were 16 crossings with SBI = 3 (8% of 212 crossings), 79 crossings with SBI = 2 (37% of 212 crossings), and 117 crossings with SBI = 1 (55% of 212 crossings; Figures 35 and 36; Appendix B, Map 10).

Plugging risk at crossings throughout the watersheds was due more to pipe diameters sized smaller than channel widths than to high skew angle. Of the crossings with SBI = 3, 9 (56%) had pipe diameter to channel width ratios less than 0.5 (as low as 0.14), so their SBI value and high plugging risk was due entirely to undersized culvert diameter and not to high skew angle. The remaining 7 crossings with SBI = 3 had pipe diameter to channel width ratios of 0.5 to 0.75; so were moderately undersized culverts coupled with plugging risk from a high skew angle to create high plugging risk overall. Of crossings with SBI = 2, most (76, 96%) had pipe diameter to channel width ratios between 1 and 0.5 (all less than 0.84); so their SBI value and moderate plug risk overall was due entirely to undersized culvert diameter and not to high skew angle. Only 3 crossings with SBI=2 had pipe diameter greater than or equal to channel width, so overall moderate risk of plugging at those crossings was due as much to high skew angle as pipe size. Of crossings with SBI = 1, all had a pipe diameter greater than or equal to channel width, low skew angle, and had low plugging risk.

The blocking rate is the number of culverts totally or partially blocked as a percentage of total number of crossings in each SBI value category. In the Power study watersheds the blocking rate was moderate. Of the crossings with SBI = 3, one had a partially blocked pipe, and one had a totally blocked pipe for a 12% blocking rate (Table 14). Of the crossings with SBI = 2, 13 were partially blocked and 5 were totally blocked for a 23% blocking rate. Of the crossings with SBI = 1, 15 were partially blocked and 4 were totally blocked for a 16% blocking rate. If only sites with totally blocked culverts were included, and partially blocked inlets are excluded, the rates are 6% for crossings with SBI = 3, 6% for crossings with SBI = 2, and 3% for crossings with SBI=1. These results suggest that SBI may be a moderately useful predictor of blocking condition in this and that a case by case approach to prioritizing remediation efforts is useful for stream

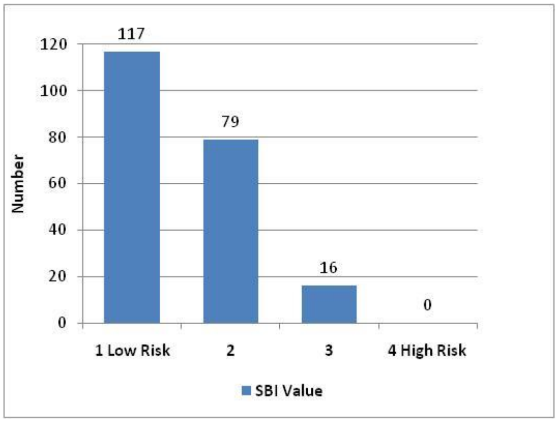

Figure 36. Distribution of SBI values for the Power study watersheds.

Table 14. *Blocking rate in percent for different culvert plug conditions by SBI category.*

Plug Conditions	Blocking Rate for each SBI (%)		
	1	**2**	**3**
Partially and totally blocked	16	23	12
Totally blocked pipes only	3	6	6

crossings with plugged pipes. See discussion below and Appendix C for a priority list for all stream crossings.

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. Though not likely at all crossings, we assumed the entire volume would be eroded in an overtopping type failure, and calculated the fill material of the entire crossing prism. Crossing fill depths and pipe gradients were surveyed, and volume of the prism of fill at risk was calculated assuming that the prism was bounded at the base by an area 1.2 times the channel width, with side slopes rising to the road surface at a slope of 33%. This type of fill failure will not occur at bridges, fords, or excavated stream crossings so no fill volume risk was calculated at these locations. Fill volumes ranged from 3 m^3 (4 yd^3, 5 Mg) to 3,350 m^3 (4,380 yd^3, 5,360 Mg), and had a mean volume of 132 m^3 (173 yd^3, 211 Mg). Fill volume at the bottomless arch was 105 m^3 (137 yd^3, 168 Mg). The total fill volume at risk for all the stream crossings with pipes was 27,970 m^3 (36,580 yd^3, 44,750 Mg). Though there is unequal chance of failure among all the crossings, and if any were to fail, delivery of entire prism fill may not be complete, this total mass represents a risk of potential sediment delivery of 64 times the annual delivered sediment from all other road related sources. At time of survey, a total of 648 Mg of fill was eroded at crossings with totally or partially failed fill.

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. 1998, Best et al. 1995). In these situations, volumes of sediment far exceeding those at the crossing can be at risk. GRAIP addresses this issue by classifying the potential for stream crossings to divert stream flow down the adjacent road as: no potential, potential to divert in one direction, or potential to divert in two directions. In the Power study watersheds, 104 of 255 stream crossings (41%) had the potential to divert in one or more directions. Eight crossings were actively diverting at the time of survey.

Stream Crossing Remediation Prioritization

Stream crossing failure risk factors were examined in order to evaluate crossings that pose the greatest risk of failure and, therefore, sediment contribution to streams. All stream crossings were assigned a priority rank to indicate sites with the greatest need for risk reduction treatments. The rank from high to low was based on the three main risk factors discussed above (plugging potential as SBI, diversion potential, and magnitude of fill), as well as additional risk factors based on observed conditions or problems at the crossing (degree of existing plugging, active diversion, active fill erosion, significantly rusted pipe, and evidence of past failure or debris flow). Of the total 255 stream crossings, 26 had a high or moderate-high priority. 54 had a moderate, moderate-low, or low-moderate-low priority, and 175 crossings had low priority. Crossings without culverts were typically low priority unless there were other significant risk factors present. A table listing all stream crossings in order of priority with risk factors at each crossings is in Appendix C. A map of their locations by priority category, and high priority roads is in Appendix B, Maps 11a, b and c. This detailed approach addresses the significant potential sediment delivery risk directly to streams posed by large fill volumes at stream crossings. If the 26 crossings with the highest risk of failure were to fail, a total of 2,340 Mg could potentially deliver to streams, or 3.5 times the total annual sediment delivered from all other road related sources in the study.

The highest risk crossings in the Power study watersheds were high risk in all three stream crossing risk areas (high SBI, more than 100 m^3 [160 Mg] of fill at risk, diversion potential in one or both directions, Figure 37). There were 7 crossings with an SBI = 3, but no diversion potential. Of those, 3 had more than 100 m^3 of fill at risk. There were 9 crossings with both an SBI = 3 and the potential to divert streamflow. Four had more than 100 m^3 of fill at risk. These 4 crossings had the highest combined stream crossing risk and are good candidates for risk reduction treatments.

Stream crossings should also be considered high priority for risk reduction treatments if they were actively diverting stream flow down the road outside the stream crossing area, were totally blocked, and/or had partially or totally failed fill, because with any of these conditions fill was at immediate risk of failure, or was actively delivering failing fill sediment to streams. There were 14 crossings with a totally blocked culvert. Eight stream crossings were actively diverting and had a total of 174 m^3 (228 yd^3, 278 Mg) of eroded, delivered fill sediment. Four of these crossings had a totally blocked culvert. Twenty one crossings had totally or partially eroded fill with 405 m^3 (530 yd^3, 648 Mg) of eroded, delivered sediment. Of these, 10 crossings had a totally blocked culvert.

Indicators of past or potential plugging were a sediment plume at the inlet, an organic debris pile at the inlet, or evidence of a debris flow. These conditions may create a high risk and priority if they are severe, but may pose a moderate risk if the indicators were not causing a problem at time of survey. There were 5 crossings with a sediment plume, two of which also had evidence of a debris flow. Two sites with a sediment plume were ranked as high priority because they were also actively diverting flow or had failed fill. Eighteen stream crossings had an organic debris pile. Most of these were ranked moderate-low to low priority, including two which also had evidence of a past debris flow. One was ranked high priority due to a variety of other problems. Of the 7 total sites with evidence of a debris flow, 3 not already mentioned were among the high ranking priority sites.

Other observed conditions of crossings with culverts that indicated a risk of plugging failure were significantly rusted culverts, partially blocked inlets, and totally crushed inlets. Of the 9 culverts that were significantly rusted, only 2 were ranked high priority. Of the 28 culverts that were partially blocked, 2 were ranked as high priority, 10 were ranked as moderate to moderate-low priority, and the others low. One site had a totally crushed inlet and was ranked moderate priority.

There were 2.7 km (1.7 mi, 0.8% of all road inventoried) of road surveyed with active stream flow from stream crossings diverting along the road. There were 38 drain points receiving flow from these segments of road (0.8% of all drain points), 25 of which were connected to streams. Stream flow diversion carries unpredictable risk of creating gullies, landslides, and large volumes of erosion, so that connectivity of drain points which routed diverted flow was high, and these road segments and drain points are good candidates for risk reduction treatments. See Appendix B, Maps 11 a-c for locations of road segments which were routing diverted stream flow.

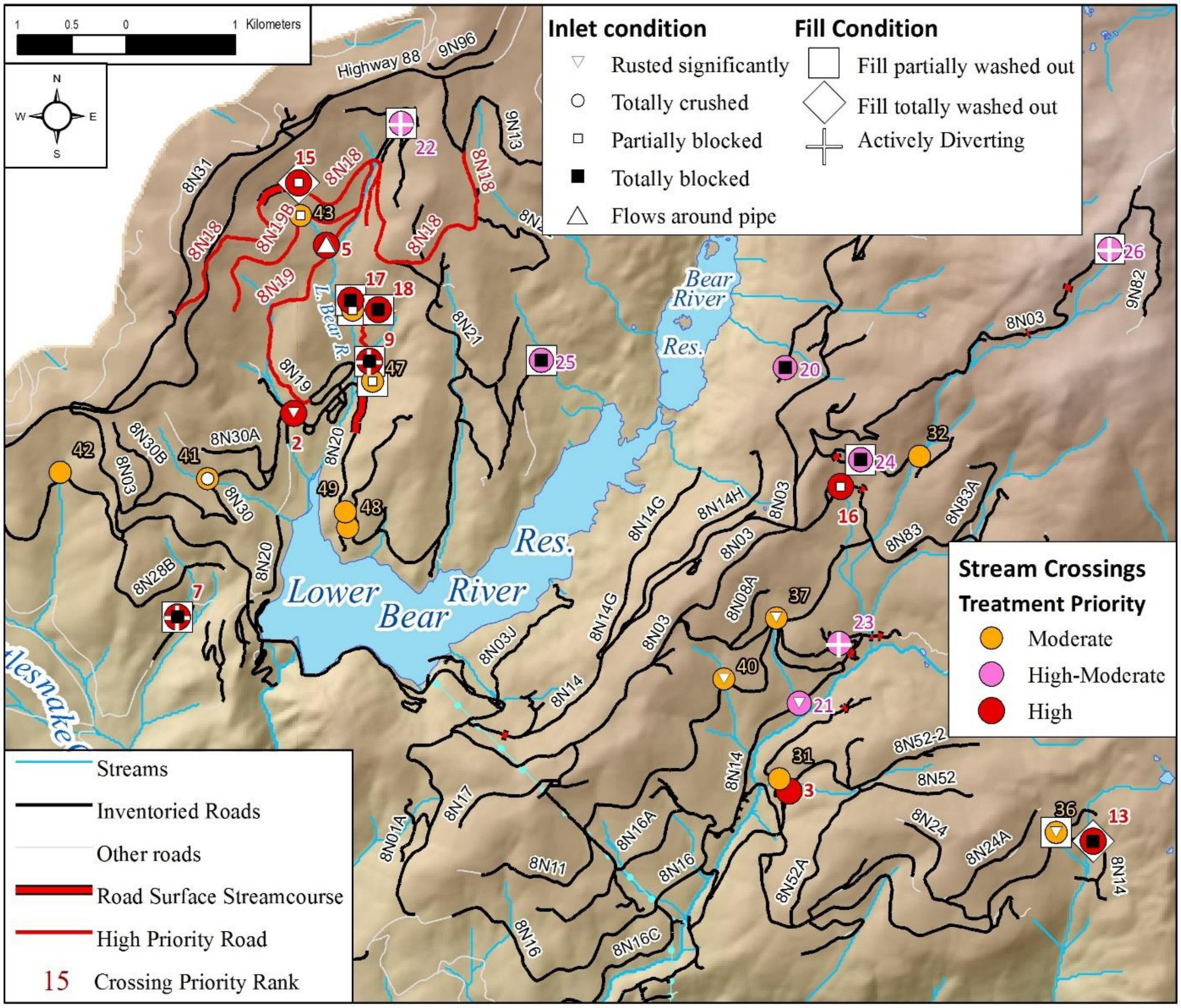

Figure 37. The stream crossings with the highest treatment priority in the northern part of the Power study watersheds.

5.7 Drain Point Condition and Fill Erosion

The GRAIP inventory assessed the condition of each drain point and made a determination of how well each was performing its intended function. Problems with drain point condition were pre-defined for each drain type. Broad based dips were considered to be in poor condition if they did not drain due to insufficient outslope, or ponded water on the road. Ditch relief culverts were defined to be in poor condition if they had more than 20% occlusion within the pipe or the inlet was totally buried by sediment, significant rust, or had a drop at the outlet of greater than one foot high. Ditch lead-offs were considered problematic if they had excess deposition or gullying. Non-engineered features were almost always a problem due to a diverted flow path, blocked ditch, gully, broken outside berm or fill erosion, but were not considered problematic if they occurred due to an outsloped road and did not have any fill erosion. Stream crossing culverts were considered to be a problem if the pipe inlet was partially or totally blocked by sediment or wood; totally crushed; if the pipe was rusted significantly; if flow scoured or washed out fill, or flowed around the pipe; or had SBI = 3, or SBI ≥ 2 with diversion potential (see previous section for more detail on SBI and diversion). Waterbars that

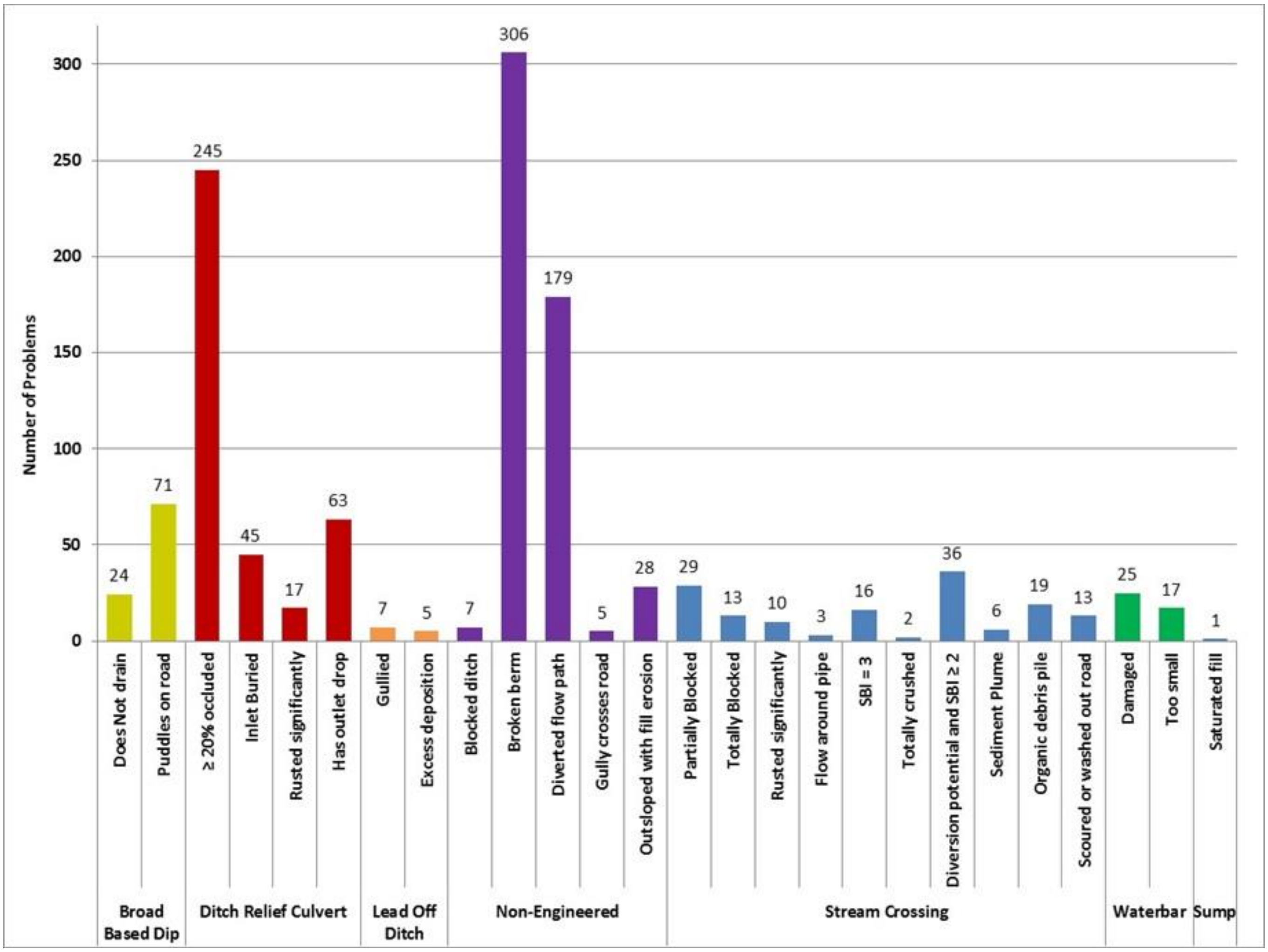

Figure 38. Number of problems by drain point type in the Power study watersheds.

were damaged, under-sized, or did not drain properly were defined as problematic. Sumps were a problem if they ponded water on the road surface or caused fill to be saturated. Diffuse drains (outsloped roads) were rarely observed to have problems. Figure 38 shows number of drain point problems by drain point type. Figure 39 shows locations of drain points with problems by drain point type for the northern portion of the study area, and Appendix B, Map 12 shows the same for the entire study area. Figure 40 shows some common ditch relief problems.

Within the Power study watersheds, 25% of all drain points (1,148 of 4,657) had one or more problem of some type (Table 15). Non-engineered drain points with problems comprised the highest percentage of all drain points with problems (525 of 1,148, 48%), and ditch relief culverts were a close second (368 of 1,148, 14%). Along with stream crossings (105 of 1,148, 18%), these three drain point types comprise the majority of drain points with problems (998 of 1,148, 87%). When examined as frequency of problems within each drain point type, non-engineered drain points, ditch relief culverts, and stream crossings each had problems at nearly half of their drain points (44%, 42%, and 41% respectively). Other drain point types had far fewer problems. Diffusely drained road segments (416) had few problems but many along Highway 88 had fill erosion on the outboard soft shoulder. Only one sump had saturated fill. Excavated stream crossings (7) had no problems.

Table 15. *Drain point condition problems, fill erosion at drain points, and contributing road surface gully erosion for each drain point type in the Power study watersheds.*

		Number of Drain Points			% Within each Drain Type[*]			% Each DP Type is of DPs with a Problem[†]		
Drain Type	**Number of Drain Points**	**Problems**	**Fill Erosion at Site**	**Road Surface Gully Erosion to Drain Point**	***Problems***	***Fill Erosion at Site***	***Road Surface Gully Erosion to Drain Point***	***Problems***	***Fill Erosion at Site***	***Road Surface Gully Erosion to Drain Point***
Broad Based Dip	1,189	95	34	22	*8%*	*3%*	*2%*	*8%*	*22%*	*29%*
Diffuse Drain	416	0	16	4	*0%*	*4%*	*1%*	*0%*	*10%*	*5%*
Ditch Relief Culvert	872	368	21	16	*42%*	*2%*	*2%*	*32%*	*14%*	*21%*
Lead Off Ditch	84	12	5	5	*14%*	*6%*	*6%*	*1%*	*3%*	*7%*
Non-Engineered	1,190	525	73	23	*44%*	*6%*	*2%*	*46%*	*48%*	*30%*
Stream Crossing	255	105	28	4	*41%*	*11%*	*2%*	*9%*	*18%*	*5%*
Sump	5	1	0	0	*20%*	*0%*	*0%*	*0%*	*0%*	*0%*
Waterbar	639	42	4	2	*7%*	*1%*	*0%*	*4%*	*3%*	*3%*
Excavated Crossing	7	0	0	0	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
All Drains	**4,657**	**1,148**	**153**	**76**	***25%***	***3%***	***2%***	***100%***	***100%***	***100%***

[*] #DPs with problem in each DP Type/Total #DPs for DP Type
[†] #DPs with problem in each DP Type /# of All DPs with a problem

Table 16. *Fill erosion below drain points, volumes and masses, in the Power study watersheds.*

Drain Type	Site Fill Erosion Mass Produced (Mg)	Site Fill Erosion Mass Delivered (Mg)	Road Surface Gully Mass Produced (Mg)	Road Surface Gully Mass Delivered (Mg)	Total Mass Sediment Produced (Mg)	Total Mass Sediment Delivered (Mg)	Total % Delivery	Average Delivery Rate Over 20 Years (Mg yr^{-1})
Broad Based Dip	40	20	190	100	220	110	50%	6
Diffuse Drain	10	0	5	0	20	0	0%	0
Ditch Relief Culvert	165	100	130	90	290	190	66%	10
Lead Off Ditch	5	0	70	20	70	20	29%	1
Non-Engineered	330	80	160	50	490	130	27%	7
Stream Crossing	1,150	1,150	30	30	1,180	1,180	100%	59
Sump	0	0	0	0	0	0	0%	0
Waterbar	50	10	10	5	60	10	17%	1
Excavated Stream Crossing	0	0	0	0	0	0	0%	0
All Drains	**1,750**	**1,360**	**595**	**295**	**2,330**	**1,640**	**70%**	**82**

Fill erosion was present at 229 (5%) of all drain points, and produced a total of 2,330 Mg (1,460 m^3, 51,410 ft^3; Table 16). Estimated total fill erosion sediment delivery was 1,640 Mg (1,030 m^3, 36,410 ft^3), or about 70% of total fill erosion mass produced. Stream crossings accounted for the largest percentage of all sediment delivered at 72% of the 1,640 Mg of eroded fill delivered. Ditch relief culverts, non-engineered drains, and broad based dips together accounted for 26% of all fill erosion sediment delivered.

Two types of fill erosion were recorded at drain points. The first was site fill erosion that occurred within the fill at the location of the drain point site. The second was erosion generated from gullies within the road surface that routed along a gullied road surface flow path to a drain point. The GRAIP model does not account for diffusive erosion processes on the road fill such as rain splash, rill erosion, and soil creep. These processes may generate significant sediment on new road construction near streams.

Site fill erosion sediment was 75% of all fill erosion mass produced, and 83% of all fill erosion mass delivered. Road surface gully sediment delivered was 25% of all fill erosion mass produced, and was 17% of all fill erosion mass delivered. Site fill erosion was observed at 153 (3%) of all drain points (Table 16). Site fill erosion produced 1,750 Mg (1,100 m^3, 38,660 ft^3), and delivered 1,360 Mg (78%, 850 m^3, 30,050 ft^3). Road surface gully fill erosion was observed routing along one or both flow paths to 76 (2%) drain points. Road surface gully fill erosion produced 595 Mg (360 m^3, 12,750 ft^3), and delivered 295 Mg (50%, 180 m^3, 6,360 ft^3).

Using the same approach as for landslides in Section 5.4, episodic fill erosion delivery was compared to annual road surface fine sediment delivery by averaging total fill erosion delivery mass over a 20 year period. For all fill erosion mass delivered this estimated average annual delivery rate was 82 Mg yr^{-1}, or 1.2 times the fine sediment delivered from road surfaces. 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. Actual annual sediment delivery from fill erosion is likely higher or lower than these estimates in any given year.

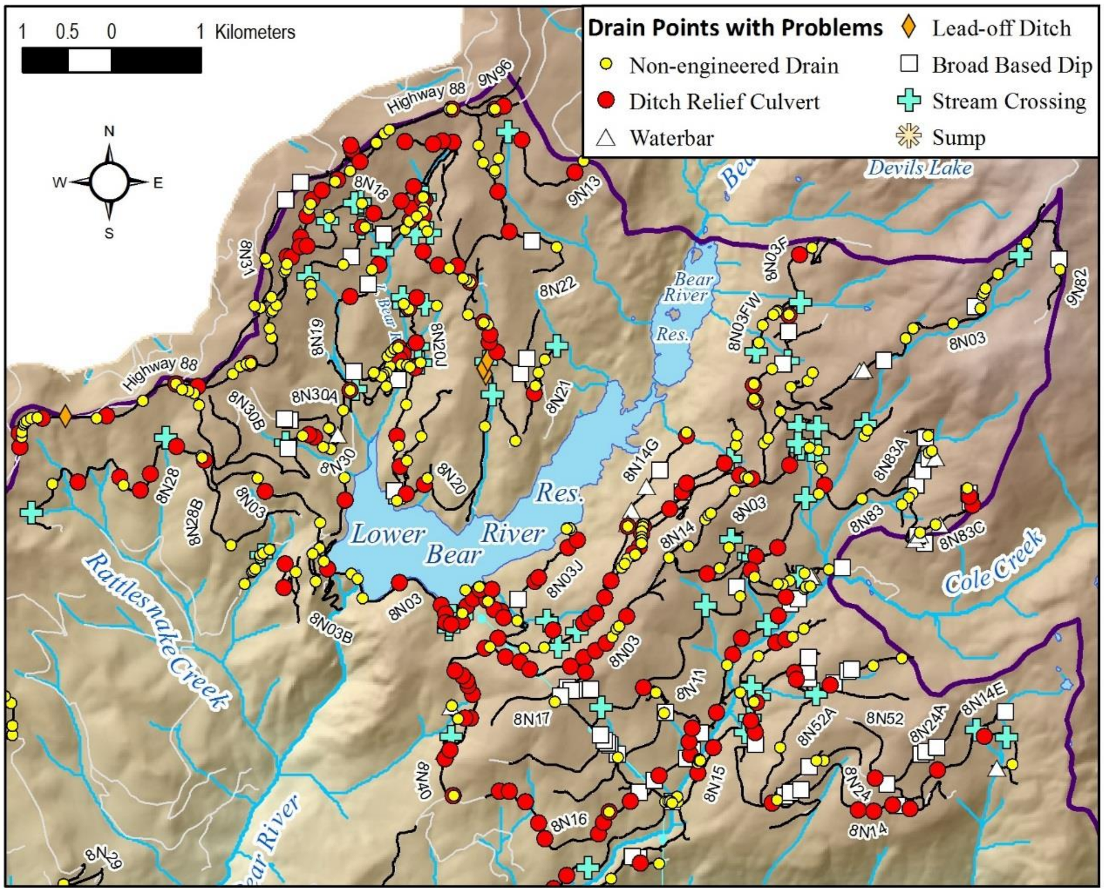

Figure 39. Locations of problems by drain point type in the northern portion of the Power study watersheds.

Figure 40. Problems with ditch relief culverts. The left culvert is rusted through. The middle culvert is set high in the fill. The right culvert has an occluded inlet.

6.0 Comparison to Other Studies

The most direct comparisons of road surface sediment production and delivery normalized by watershed area are to other GRAIP watershed studies (Table 17). Specific sediment production rate in the Power study was 7 Mg km^{-2} yr^{-1}, which was well within the range of rates (5 - 10 Mg km^{-2} yr^{-1}) found in geologically similar areas in the Sierra Nevada (Cabrera et al. 2015) and in the Idaho Batholith (Fly 2010, Black et al. 2012). The Power project specific sediment production rate was much higher compared to rates found in areas with dominantly volcanic geology types in the Oregon Klamath Mountains (0.4 Mg km^{-2} yr^{-1}, Turaski 2004) and Eastern Oregon (0.2 Mg km^{-2} yr^{-1}, Nelson et al. 2010), but about three times higher than the rate found in the Oregon Coast Range on dominantly ridgetop roads (2.2 Mg km^{-2} yr^{-1}, Cissel et al. 2012). Specific sediment delivery rates followed roughly the same pattern as for production. This Power study sediment delivery rate of 0.4 Mg km^{-2} yr^{-1} was most similar to studies in granitic geology types which were 0.7 Mg km^{-2} yr^{-1} in the nearby Sierra Nevada study (Cabrera et al. 2015), and 0.5 Mg km^{-2} yr^{-1} and 1.9 Mg km^{-2} yr^{-1} in the Idaho Batholith studies (Fly 2010, Black et al. 2012). Specific sediment delivery rates in the Oregon studies were far lower (0.03 - 0.06 Mg km^{-2} yr^{-1}).

A useful method of comparison to other studies is of percent road length connected. The Power study had a road length percent connectivity of 16%, which lies at the middle of the range among Sierran studies (3 - 30%, Cabrera et al. 2015, Coe 2006, Stafford 2011), the Oregon

Table 17. *Comparison of various road surface sediment rates between Power study and other regional studies.*

Road Surface Sediment Categories	Power	Sierra Nevada (GRAIP)	Sierra Nevada (non-GRAIP)	Idaho Batholith (GRAIP)	Oregon Klamath Mountains (GRAIP)	Eastern Oregon (GRAIP)	Oregon Coast Range (GRAIP)	Western OR and WA (non-GRAIP)
Specific Sediment Production by watershed area (Mg km^{-2} yr^{-1})	7	6	–	5, 10	0.4	0.2	2.2	–
Specific Sediment Delivery by Watershed Area (Mg km^{-2} yr^{-1})	0.4	0.7	–	0.5, 1.9	0.03	0.04	0.06	–
Percent Connected Road Length	16	13	3 – 30	13, 17	14	27	5	23 - 60
Specific Sediment Production by Road Surface Area, All Surface Types (Mg km^{-2} yr^{-1})	660	845	130 – 1,800	1,790, 2,140	32	22	335	–
Specific Sediment Production by Road Surface Area, Native Surface Roads (Mg km^{-2} yr^{-1})	1,290	1,100	130 – 1,800	1,790, 2,140	61	–	–	–

GRAIP studies (5 - 27%, Turaski 2004, Nelson et al. 2010, Cissel et al. 2012), and GRAIP studies in the Idaho Batholith (13 - 17%, Fly 2010, Black et al. 2012). All of these studies were lower than the 23 - 60% percent connectivity by road length in areas of western Oregon and Washington where roads were constructed in the 1950s through 1970s and total annual precipitation amounts were higher (Robichaud et. al 2010).

Assuming an average road width of 5 m, sediment production rates from GRAIP watershed studies can be converted to the more commonly reported sediment production rates normalized by road surface area. Average sediment production by road surface area for all roads in the Power study, 660 Mg km^{-2} yr^{-1}, was within the range of mean rates (130 - 1,800 Mg km^{-2} yr^{-1}) among the nearest studies in the Sierra Nevada (Cabrera et el. 2015, Coe 2006, Stafford 2011), and higher than the range of rates (32 - 335 Mg km^{-2} yr^{-1}) in the Oregon studies (Turaski 2004, Nelson et al. 2010, Cissel et al. 2012). However, the Power rate for all roads included only 20% native surface roads, whereas the average rates in the other Sierra Nevada studies were from nearly 100% native surface roads. The sediment production rate for native roads alone in Power was 1,290 Mg km^{-2} yr^{-1}. This is similar to the rate for native surface roads in the GRAIP Sierran project (1,097 Mg km^{-2} yr^{-1}, Cabrera et al. 2015), to the GRAIP studies in the Idaho Batholith (1,788 Mg km^{-2} yr^{-1}, Black et al. 2012; 2,142 Mg km^{-2} yr^{-1}, Fly 2010), and to a southern Sierran study in a rain dominated basin (1,800 Mg km^{-2} yr^{-1}, Stafford 2011). It was 1.5 to 10 times greater than the mean sediment production rate for native roads in two Sierran studies (320 - 810 Mg km^{-2} yr^{-1}, Coe 2006; 130 - 740 Mg km^{-2} yr^{-1}, Stafford 2011).

The nearest reservoirs with accumulated sediment data were Upper Bear River Reservoir (Spraberry 1964) in the northwest section of the Power study area, Tiger Creek Afterbay (Buckley et al. 2014), which intercepts all streams from the Power project plus Tiger Creek basin. Including all sediment sources (road surface, gullies, landslides, fill erosion) specific sediment delivery rate for the Power study area was 1.8 Mg km^{-2} yr^{-1}. This is 20% of the sediment accumulation rate in Bear River Reservoir (9 Mg km^{-2} yr^{-1}), which represents sediment delivery from all hillslope erosion sources including roads. The survey represents 46 years of sediment accumulation from construction of the dam in 1935 to 1946, a period prior to the majority of road construction. The catchment area of Bear River Reservoir was mostly outside the Power project area and comprised mostly of granite bedrock with likely low hillslope erosion rates. Tiger Creek Afterbay reservoir was surveyed in 2013. The sediment accumulation rate there represents 82 years of accumulation and was 155 Mg km^{-2} yr^{-1}. Sediment delivery from road sources in the Power study was 1.2% of sediment accumulated from all hillslope and other sources from watersheds to Tiger Creek Afterbay reservoir.

7.0 Summary and Conclusions

Among road related sediment sources, gullies produced and delivered the most sediment (Table 18, Figures 41 and 42). Road surfaces produced nearly the same amount of sediment mass as gullies, but delivered less sediment. Fill erosion and landslides delivered similar amounts of sediment as road surfaces. Stream crossing fill mass for high and high-moderate risk crossings was 2,430 Mg, or 3.5 times the mass of sediment delivered annually from all other road related sources.

Table 18. *Summary of mass of sediment produced and delivered by all road related sediment sources in the Power study watersheds.*

Source	**Sediment Produced (Mg yr^{-1})**	**% of Total Sediment Produced**	**Sediment Delivered (Mg yr^{-1})**	**% of Total Sediment Delivered**
Road surface sediment	503	37%	70	10%
Landslides (averaged over 20 year time period)	165	12%	87	12%
Gullies (averaged over 20 year time period)	580	43%	465	66%
Fill Erosion (including road surface gullies, averaged over 20 year time period)	117	9%	82	12%
Total	**1,365**	**100%**	**704**	**100%**

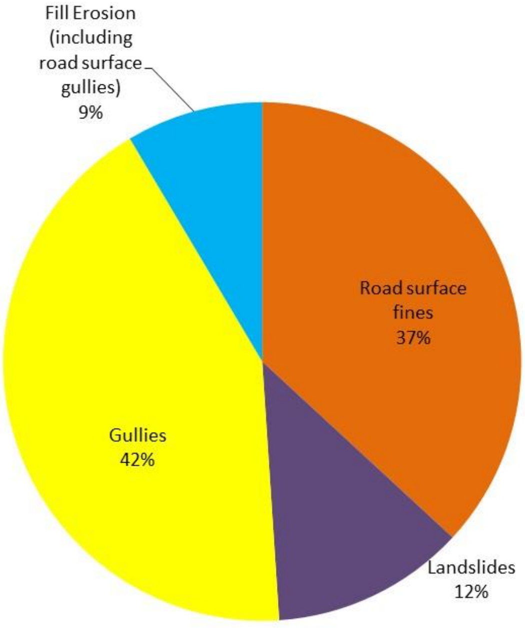

Figure 41. Percent of total sediment produced from each road related sediment source in the Power study watersheds.

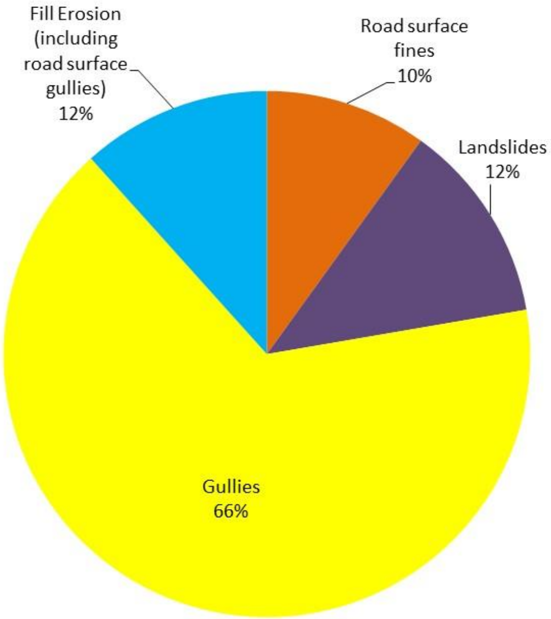

Figure 42. Percent of total sediment delivered to streams from each road related sediment source in the Power study watersheds.

The GRAIP model results provide a useful set of tools to help focus road related restoration efforts in the Power study watersheds. When making prioritization decisions there are at least two approaches. One is based on hydrologic connectivity. Since native roads with rocky surfaces, and non-engineered drains, broad based dips, stream crossings, and ditch relief represent the largest percentage of total road surface sediment delivered, managers can focus on these for remediation by reducing contributing road length and, upon road upgrade or new construction, install the drain point types that have been shown to be most effective. Also, addressing the large amount of sediment delivered by stream connected gullies was a high priority in the Power study area. Another approach is to focus remediation efforts throughout the road system where there are potential threats to infrastructure access and usability from erosion at certain locations. With this approach managers can focus on drain point problems such as blocked or partially blocked ditch relief and stream crossing culverts, dips that do not drain, any areas with flow diversion along the road surface, or where important roads are blocked or compromised by landslides or gullies. The study data provided abundant information regarding the conditions of road infrastructure in the study area that can be used in a myriad of ways to suit management needs.

Areas with the highest gully occurrence rates, substantial gully initiation risk, and the highest gully sediment production and delivery were along Highway 88 and along paved roads in Mehrten Formation, glacial deposits, and undifferentiated Paleozoic geology types. These areas may benefit from changes in drain point spacing and location as per Table 13. Road design which inhibits gully formation on road surfaces and in ditches such as outsloping can also significantly reduce sediment delivery.

Though road surfaces can produce large masses of sediment, sediment delivery is governed by the drain points through which road surface flow is routed. In the Power study watersheds, 90% of delivered road surface sediment was delivered through 5% (233) of drain points (Figure 15, Appendix B, Map 2). This can help focus remediation efforts on a limited set of drain points in the area. Diffuse drains were the most effective drain point type at reducing hydrologic connectivity. Waterbars and lead off ditch drains were also very effective. Native road surfaces produced and delivered the majority of road surface sediment (Figure 17). Rocky surfaces represented the highest percentage (41%, Figure 16, Table 3) of total road surface fine sediment produced. Road surfaces with good, rilled/eroded, or rutted condition all together produced 59% of the total fine road surface sediment. Road surface sediment delivery was highest on surfaces in rocky condition (52% of normalized total). Surfaces with rilled/eroded condition delivered 29% of the normalized total, followed nearly equally by surfaces that had a good or rutted condition (11% and 9%, respectively). The same pattern existed when the analysis was performed with only native surface roads.

Areas where delivery of road surface sediment created the highest specific sediment in streams were in the area north of Lower Bear River Reservoir, Rattlesnake Creek, and East Panther Creek. These would be ideal areas to target drain points which delivered the most sediment.

Landslides in the study area were concentrated in the East Panther Creek watershed. Several older features along the main paved road had been repaired and required no treatment at the time of the study. Other active landslides on 8N36 were less accessible in the area, and the active delivering features were small. Large landslides encompass the road on 8N65 and 8N05B. Though they blocked both roads, they were not caused by the road and presented a maintenance issue.

The risks associated with stream crossings were focused on risks to existing fill. If the stream crossings with the greatest risk of failure, and those that were failing at the time of study were to deliver the entire mass of fill present at those crossings, the total mass would be 3.5 times the annual delivered amount of all the other sediment sources combined. Risk was determined by a combination of factors focusing on plug potential and existing problems. Managers can use risk factors presented in this report, the priority ranked list of stream crossings in Appendix C, and Appendix B, Maps 11a, 11b, and 11c to inform their own priorities in the watersheds.

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Appendix A: Glossary of Selected Terms

Below is a list of terms, mostly of drainage point types, but also of some other commonly used terms, for the purpose of clarification. Adapted from Black, et al. (2011), Fly, et al (2010), and Moll (1997).

Broad based dip*. Constructed:* Grade reversal designed into the road for the purpose of draining water from the road surface or ditch (also called dip, sag, rolling grade, rolling dip, roll and go, drainage dip, grade dip). ***Natural:*** A broad based dip point is collected at the low point where two hillslopes meet, generally in a natural swale or valley. This is a natural low point in the road that would cause water on the surface of the road to drain out of the road prism.

Cross drain. This is not a feature collected specifically in GRAIP, and it can refer to a number of other drainage features. It is characterized by any structure that is designed to capture and remove water from the road surface or ditch. Ditch relief culverts, waterbars, and broad based dips can all be called cross drains.

Diffuse drain. This is a point that is characterized by a road segment that does not exhibit concentrated flow off the road. Outsloped roads or crowned roads often drain half or all of the surface water diffusely off the fillslope. Although collected as a drain point, this feature is representative of an area or a road segment rather than a concentrated point where water is discharged from the road prism. A drop of water that lands on a diffuse road segment will not flow down the road or into the ditch, but more or less perpendicular to the centerline off the road surface and out of the road prism. Also called sheet drainage or inter-rill flow.

Ditch relief culvert. This drain point is characterized by a conduit under the road surface, generally made of metal, cement, or wood, for the purpose of removing ditch water from the road prism. This feature drains water from the ditch or inboard side of the road, and not from a continuous stream channel.

Flow path. This is the course flowing water takes, or would take if present, within the road prism. It is where water is being concentrated and flowing along the road from the place where it enters the road prism, to where it leaves the road prism. This can be either on the road surface, or in the ditch.

Lead off ditch. This drain point is characterized by a ditch that moves flow from the roadside ditch and leads it onto the hillslope. Occurs most often on sharp curves where the cutslope switches from one side of the road to the other. Also known as a daylight ditch, mitre drain, or a ditch out (though this term can also describe other types of drainage features).

Non-engineered drainage. This drain point describes any drainage feature where water leaves the road surface in an unplanned manner. This can occur where a ditch is dammed by debris, and the water from the ditch flows across the road, where a gully crosses the road, where a wheel rut flow path is diverted off the road due to a slight change in road grade, or where a berm is broken and water flows through. This is different from a diffuse drain point, which describes a long section of road that sheds water without the water concentrating, whereas this point describes a single point where a concentrated flow path leaves the road.

Orphan drain point. This is any drain point that does not drain any water from the road at the time of data collection. Examples include a buried ditch relief culvert, or a water bar that has been installed on a road that drains diffusely.

Stream crossing. This drain point is characterized by a stream channel that intersects the road. This feature may drain water from the ditch or road surface, but its primary purpose is to route stream water under or over the road via a culvert, bridge, or ford. A stream for the purposes of GRAIP has an armored channel at least one foot wide with defined bed and banks that is continuous above and below the road and shows evidence of flow for at least some part of most years.

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

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

Appendix B: Additional Maps

Larger-scale maps (11” x 17”) were created that show risk distributions across the entire project area.

List of Maps

Appendix C: Stream Crossings by Treatment Priority

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
15083014212	Steel culvert round	24	5	1	**High**	3	Yes	24	Totally blocked	No	No	Intact	Yes	0	0	8N50	Lots of debris from granite hillslope above totally buries inlet and flow is actively diverting down road to gully fillslope at next two non-engineered drains that are stream connected.
14092909092	Steel culvert round	36	22	2	**High**	3	Yes	373	Rusted significantly	Organic debris pile	No	Intact	No	0	0	8N20	Main road up Lower Bear River just past resort. In terrible shape. Also partially blocked with wood and debris. Excavated debris of past plugging and diversion. Cobble lined stream. Completely rusted pipes. Rip rapped fill.
14101110434	Steel culvert round	18	3	3	**High**	3	Yes	18	Open and Sound	No	No	Intact	No	0	0	8N52	Culvert undersized. Not intended to be a stream crossing. Stream is in road above. Overtops and goes to waterbar down the road.
15071610502	Steel culvert round	30	4	4	**High**	2	Yes	627	Totally blocked	No	No	Intact	No	0	0	8N05	Southwest of East Panther Ck. on ascending arm of main paved road. In gully and slump prone area. Rip rap both fills. Flow path on outlet is diverting slightly, stays in channel below. This is one of the sites that had a large landslide identified in Dec 2005, since repaired.
14092710472	Steel culvert oval	60	7	5	**High**	2	None	116	Flows around pipe	No	No	Intact	No	0	0	8N19	Rocky, eroded road at bottom of cascading gully hillslope area. Flow is under pipe! Ephemeral stream, but large flows.
15091412322	Steel culvert round	48	4	6	**High**	1	None	68	Totally blocked	Washed out road	No	Washed out	No	233,077	6600	8N25D	Road is fine, but crossing is blown out. Still large volume of fill remains with active erosion potential. Pipe is broken in 2. Most flow is around pipe. Major incision and bank erosion upstream. Heavily cow trampled. In an active tree thinning and planted area.
15091315362	Steel culvert round	18	3	7	**High**	2	Yes	18	Totally blocked	Scoured road	Yes	Partially Washed out	Yes	100	3	8N10	In Mehrten formation? On an isolated leg past timber property. Small stream. Debris flow buries inlet. Flow is diverting currently down and across road. Also receives eroded road surface gully.
14092814141	Steel culvert round	24	1	8	**High**	1	Yes	0	Totally blocked	No	Yes	Partially Washed out	Yes	0	0	8N36	Debris flow has buried entire crossing. In landslide prone area around 8N36. Stream runs down road to non-engineered drain point.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
14100915182	Steel culvert round	48	2	9	**High**	1	Yes	24	Totally blocked	No	No	Partially Washed out	Yes	706	20	8N20J	High volume of sediment is routing from hillslopes and eroded road surface. Large culvert is well armored. Ephemeral stream. Inletis nearly 100% buried.
14101311573	Steel culvert round	18	3	10	**High**	2	Yes	0	Flows around pipe	Sediment Plume	No	Partially Washed out	No	900	25	8N65	Debris flow prone area in E. Panther Ck. Basin. No debris flow here, but there is a sediment plum. High rate of transport instream. Stream is incised and steep. Pipe is bypassed by flow, but not plugged. 5-10 feet of fill depth cannot be surveyed. Fill volume is an underestimate. Orphan.
15071713202	Steel culvert round	24	3	11	**High**	2	Yes	12	Partially blocked	Washed out road	Yes	Partially Washed out	No	280	8	8N05G	Has debris flow evidence, failing fill, blocked culvert, debris and wood at inlet, washed out inboard fill. Is orphan. Native, abandoned road.
14101316061	Steel culvert round	18	1	12	**High**	1	None	21	Totally blocked	Scoured road	No	Partially Washed out	No	150	4	8N39	Road is below private timber land in Lower Bear River valley. Road is high clearance grass and herbs with no problem. There is a seep spring and scoured road at crossing. Culvert is buried and now acts as a natural ford.
14100912023	Steel culvert round	24	4	13	**High**	2	None	19	Totally blocked	Washed out road	No	Washed out	No	0	0	8N14	No fill erosion recorded. Far east side in granite. Road is high clearance rock and native with no problem, but some nearby diverted stream flow on road. Culvert is overtopped, and road is washed out. Logs thrown in outlet.
14092611411	Steel culvert round	18	2	14	**High**	2	None	0	Totally blocked	Scoured road	No	Partially Washed out	No	75	2	8N25A	Flow is over the road. Pipe is buried and crossings is now a natural ford. Stream is small with abundant organic debris. Road is high clearance, and native with no problem.
15073109492	Steel culvert round	18	3	15	**High**	2	Yes	16	Partially blocked	Washed out road	No	Washed out	No	25	1	8N18	This is midslope in the cascading gully area. This is a ponded big spring area. Small crossing is washed out over road surface of shallow fill. Top of pipe exposed in fil. Wash out is a past event. Orphan on short side spur to pond.
14102410533	Aluminum culvert	24	2	16	**High**	1	Yes	31	Partially blocked	No	No	Intact	No	0	0	8N14	Main road is paved with no problem. Stream is ephemeral, and cascading with mossy cobbles. Partially buried inlet.
14100916052	Steel culvert oval	N/A	2	17	**High**	0	Yes	-	Totally blocked	Scoured road	No	Partially Washed out	No	970	27	8N20J	Scoured road. Actively eroding and eroded fill. Heavily eroded road surface in granite with most crossings problematic and eroded. Buried culvert inlet so crossing now acts as a natural ford. Stream is steep, and cobble lined.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
14100916252	Steel culvert oval	N/A	1	18	**High**	0	Yes	-	Totally blocked	Scoured road	No	Partially Washed out	No	450	13	8N20J	Scoured road. Actively eroding and eroded fill. Heavily eroded road surface in granite with most crossings problematic and eroded. Buried culvert inlet so crossing now acts as a natural ford. Stream is steep, and cobble lined.
14101012581	Natural ford		-99	19	**High**	0	2 Direction	-	Open and Sound	Sediment Plume	Yes	Partially Washed out	Yes	1875	53	8N65	Large volume of fill erosion with direct stream delivery. Debris slide area. Crossings and any pipe is totally buried by sediment plume and unobservable. Major debris flow buries any pipe and splits flow. Very steep fill.
14092711064	Steel culvert round	36	4	20	**Hi-Mod**	2	Yes	0	Totally blocked	Scoured road	No	Intact	No	0	0	8N03FW	Crossing is overtopping fill but has minor scour. Pipe is totally blocked by a sediment plume. Culvert is undersized. There is evidence of water going over road. Fill volume is small; not much higher than top of the 18 inch diameter pipe. On a remote road near northeast edge of project area. Road is high clearance with crushed rock and no problem. Inlet is blocked and buried.
14102514253	Steel culvert round	24	4	21	**Hi-Mod**	2	None	136	Rusted significantly	No	No	Intact	No	0	0	8N14	Pipe is rusted through. Flow might flow under pipe. Culvert is undersized. Main paved road is fine. Area is just north of the campground area surveyed in 2015. Stream is cascading, armored.
14100910292	Natural Ford	N/A	2	22	**Hi-Mod**	0	None	-	Open and Sound	No	No	Partially Washed out	Yes	750	21	8N07A-3	Fill erosion is along road surface as flow is diverted down road. Eroded path is armored with cobble. Stream is cobble lined, ephemeral, and has a moderately steep grade
14100714384	Steel culvert round	24	4	23	**Hi-Mod**	3	Yes	19	Open and Sound	Scoured road	No	Intact	Yes	0	0	8N08	Flow goes normally to inlet as well as is actively diverting to ditch. Small fill. Culvert is moderately undersized and has high skew. Stream has multiple braids, is ephemeral, and has diverted down ditch. Area is around eastern spurs.
14092811084	Steel culvert round	18	0	24	**Hi-Mod**	0	None	-	Totally blocked	No	No	Partially Washed out	No	0	0	8N03D	Stream overtops this fill. Fill depth is not large - not much more than 1-2 feet higher than top of pipe outlet. Existing scour is minor. Stream is ephemeral. Near far northeastern part of project area. road is high clearance, native, and has organic debris cover. No problem road.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
14092313422	Steel culvert round	18	0	25	**Hi-Mod**	0	None	-	Totally blocked	No	No	Partially Washed out	No	0	0	8N21	Stream has flowed around. Washed out portion looks armored. Worth another inspection. Orphaned culvert. Far north of Bear River Resort area and just north of private camp gate. Road is rocked and non-trafficable, abandoned. One photo only. Fill seems minor but uncertain.
14092413504	Natural Ford	N/A	1	26	**Hi-Mod**	0	Yes	-	Open and Sound	Scoured road	No	Partially Washed out	Yes	0	0	8N03	Flow diverts down road as well as crosses the road. No fill erosion. Small fill. Very small stream. Minor road scour. Rough eroded rocky road at far east end; non trafficable. Ephemeral stream barely meets stream criteria.
15083110272	Steel culvert round	72	30	27	**Mod**	3	Yes	554	Open and Sound	No	No	Intact	No	10	0.3	8N50	Two pipes! So Diameter/Channel Width should be 0.53 assuming an 8 ft diameter pipe. Or d/w=0.4 if assuming a 6 ft diameter pipe. Left SBI as is as calculated with two 6 foot diameter pipes. Paved road is fine. Inlets are beveled and mortared rock fills. Stream is a boulder channel and very wide. Channel width is valley width. Cole Creek. Major tributary. Road surface is dipped through crossing, but ditch is lower and therefore there is diversion potential.
15082909382	Aluminum culvert	36	7	28	**Mod**	3	Yes	127	Open and Sound	No	No	Intact	No	0	0	8N50	Pipe is set high. Fill volume is underestimated. Recent repair work. Bedrock channel may have over estimated channel width. Rocked headwall. Outlet is shotgun onto bedrock.
15073110392	Steel culvert round	24	3	29	**Mod-Low**	3	Yes	35	Open and Sound	No	No	Intact	No	0	0	8N18	Receives diverted streamflow via ditch. Moderately undersized culvert and high skew. In the cascading gully area. Creek is from open bedrock area above.
14092717424	Steel culvert round	18	2	30	**Mod-Low**	3	Yes	10	Open and Sound	No	No	Intact	No	0	0	8N03D	In remote northeast corner. Receives diverted streamflow via ditch. Culvert is moderately undersized and has high skew. Scour at outlet.
14101116524	Steel culvert round	66	8	31	**Mod**	3	None	153	Open and Sound	No	No	Intact	No	0	0	8N13	Moderately undersized pipe with high skew. Channel width is difficult to determine because it is bouldery. Orphan. An additional culvert is an overflow pipe. In southeastern area.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
14092811444	Steel culvert oval	48	10	32	**Mod**	3	None	102	Open and Sound	No	No	Intact	No	0	0	8N03D	Channel boulder cascade and width likely difficult to measure. NC changed the pipe diameter as per photos. Pipe mistakenly entered as 18" diameter. Is more like 48" diameter. So new PipeD/ChW=0.4 Because of uncertainties, please do reinspect! In remote northeastern area. Road is good.
15083009052	Concrete culvert	48	12	33	**Mod-Low**	3	None	88	Open and Sound	No	No	Intact	No	0	0	8N50	Beaver Creek! Nice place. Bedrock channel above makes channel width difficult. Old installation. In good shape. Culvert is a concrete square passage; 33in tall x4ft wide with cement wing walls up & down stream.
14101310104	Steel culvert round	18	2	34	**Mod-Low**	3	None	14	Open and Sound	No	No	Intact	No	0	0	8N14	Receives minor diverted stream flow via ditch. Moderately undersized pipe with high skew. Stream enters ditch before culvert. Southeast of Cole Creek Bridge.
14101310353	Steel culvert round	24	4	35	**Mod**	2	None	56	Open and Sound	Sediment Plume	Yes	Intact	No	1350	38	8N65	In debris flow and landslide prone area. Channel heavily scoured by debris flow, with a sediment plume, and outboard fill erosion. Outlet is rocked.
14100912513	Steel culvert round	18	1	36	**Mod**	1	None	3	Rusted significantly	Scoured road	No	Partially Washed out	No	15	0.4	8N14E	Crossing may have overtopped at one point. In a remote and rarely accessed area on far east side of project area.
14102415523	Steel culvert round	18	3	37	**Mod**	2	None	16	Rusted significantly	No	No	Intact	No	0	0	8N08	Culvert has large rust holes, and flow is likely under pipe. Undersized pipe on ephemeral stream. Road is a native passenger car road with no problem. Crossing is orphan.
15072209252	Steel culvert round	24	3	38	**Mod**	2	Yes	41	Partially blocked	Organic debris pile	No	Intact	No	0	0	8N65A	Inlet is half buried with an organic debris pile. Heavy cow trampling produces fine silt in stream. Road is abandoned, native, and non-trafficable with a diffuse surface and no problem. Outlet is rip rapped.
15071708182	Steel culvert round	72	17	39	**Mod**	3	None	2040	Partially blocked	Organic debris pile	No	Intact	No	0	0	8N05	East Panther Ck. Crossing. It has a large baffled pipe with inlet only 10-15% blocked by wood and cobble from what may be an old debris flow. Minimal erosion of stream banks upstream. Lots of material fills wide basin above inlet. There is abundant wood upstream too. Culvert is 12' diameter. It has fish baffles inside at base of pipe. Inboard fill is rip rapped.
14101111313	Steel culvert round	24	5	40	**Mod**	3	Yes	115	Rusted significantly	No	No	Intact	No	0	0	8N11	Has high rustline and other signs of being undersized. Native passenger car road is fine.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
14092510302	Steel culvert round	36	7	41	**Mod**	3	None	43	Totally crushed	No	No	Intact	No	0	0	8N30	Main road west of Bear River Resort is a paved passenger car road with no problem. Inlet may not actually be crushed.
14092410051	Aluminum culvert	36	4	42	**Mod**	3	None	50	Open and Sound	No	No			0	0		Bad channel angle. No flow present.
15080209242	Steel culvert round	24	3	43	**Mod**	2	None	25	Partially blocked	No	No	Intact	No	1100	31	8N19B	Fill erosion is large around culvert and ditch relief culvert right next to it. Erosion is active. 2nd lowest road in cascading gully area. There is gully and spring contribution. Inlet occlusion is by cobbles and minor from wide springy basin above. Outlet is shotgun.
15071811042	Steel culvert round	60	3	44	**Mod**	1	None	1694	Open and Sound	No	No	Intact	No	5350	151	8N05	Fill erosion is on inboard and outboard fills. West of main East Panther Creek crossings below 8N65. Inboard fill has rip rap.
15083010302	Concrete culvert	24	1	45	**Mod**	1	Yes	58	Open and Sound	No	No	Intact	No	3000	85	8N50	Just west of Beaver Ck. crossing. Fill volume is underestimated due to steep, dangerous outboard failing fill, and outlet set very high. Volume likely 3-4 measured. Boulder headwall.
14100915522	Steel culvert round	18	2	46	**Mod**	2	Yes	10	Partially blocked	No	No	Partially Washed out	No	580	16	8N20J	Fill Eroding! Culvert is undersized and on a steep ephemeral well armored stream. Road surface is heavily eroded granite.
14100914602	Steel culvert round	36	3	47	**Mod**	1	Yes	36	Partially blocked	No	No	Intact	No	650	18	8N20J	Inlet is rusted and blocked. A seep above inlet trickles underground. High degree of plugging is due to large amount of sediment from hillslopes and eroded road surfaces. Bees. 50 m3 of the fill erosion is from contributing road surface.
14092915572	Natural Ford	N/A	1	48	**Mod**	0	None	-	Open and Sound	No	No	Intact	No	85	2	8N20-4	See also crossing Drain ID 14092916132. Fill erosion is on contributing road surface which is streamcourse. This crossing is the same stream that crosses the natural ford at the top of the road above. Below the upper natural ford crossing, the stream is eroding the hillslope, then meets the road again where it is diverted along the surface to this crossing. The hillslope portion of gullying was not officially collected as it is not clearly road caused (1520 ft3 void space).

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
14092916132	Natural Ford	N/A	1	49	**Mod**	0	None	-	Open and Sound	No	No	Intact	No	85	2	8N20-4	See also crossing Drain ID 14092915572. Fill erosion is on contributing road surface which is streamcourse. This crossing is the same stream that crosses the natural ford at the bottom of the road below. Below this location, the upper natural ford crossing, the stream is eroding the hillslope, then meets the road again where it is diverted along the surface to the lower natural ford crossing. The hillslope portion of gullying was not officially collected as it is not clearly road caused (1520 ft3 void space).
15091512042	Steel culvert round	30	4	50	**Mod-Low**	2	None	473	Partially blocked	No	No	Intact	No	0	0	8N65	Has LOTS of wood. Occlusion is moderate, but stream is mostly duff and wood. Steep pipe, but stable. North end of a totally abandoned duff covered road near large landslide on road above. Southern most xing on this north section of road.
14102216223	Steel culvert round	18	2	51	**Mod-Low**	2	Yes	17	Rusted significantly	No	No	Intact	No	0	0	8N14	On rough, main paved road just up from Pardoes Campground. Inlet partially occluded. Waterfall above.
14092614561	Steel culvert round	18	2	52	**Mod-Low**	2	None	17	Rusted significantly	Organic debris pile	No	Intact	No	0	0	8N71	Organic debris pile at inlet. Channel is covered in organic debris. Orphan crossing. Road is native, high clearance and no problem. Stream is small, ephemeral.
14102310013	Steel culvert round	36	4	53	**Mod-Low**	2	None	45	Rusted significantly	No	No	Intact	No	0	0	8N14	On the main paved rough road just up from Pardoes campground. It receives spring flow. Is a weird pipe inside an old pipe installation.
14092710303	Steel culvert round	24	1	54	**Mod-Low**	1	None	37	Rusted significantly	No	No	Intact	No	0	0	8N06	In an area below private timber land. Passenger car road is fine, but lined with very, very dense whitethorn. Crossing is orphan.
15081310242	Steel culvert round	36	4	55	**Mod-Low**	2	None	160	Partially blocked	No	No	Intact	No	0	0	8N03	Has moderate occlusion. Stream channel above is a boulder cascade. Discharges through 100' of forest to lake. On main paved road below South Shore Campground.
15071807542	Steel culvert round	72	4	56	**Mod-Low**	1	None	3351	Partially blocked	Organic debris pile	Yes	Intact	No	0	0	8N05	Pipe is large with old debris flow creating old terrace. Has organic debris pile, lots of wood, very dense vegetation, inboard fill gullying to inlet and contributing debris, and moderate occlusion. On the main paved road just west of East Panther crossing.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
15071709342	Steel culvert round	24	2	57	**Mod-Low**	2	Yes	598	Open and Sound	No	No			0	0		Looks to plug easily. Recently dug out. Has a flared inlet at 90 degrees to cmp length. Channel above is a steep cascade.
15071609112	Steel culvert round	30	2	58	**Mod-Low**	1	Yes	236	Partially blocked	No	No	Intact	No	0	0	8N05	Receives diverted stream flow from cutslope, not the next xing! Flared inlet. Large woody debris at inlet. Main paved road in the southwest section of project area.
14092911251	Steel culvert round	36	3	59	**Mod-Low**	1	None	105	Partially blocked	No	No	Intact	No	0	0	8N05B	Partially occluded inlet. Lots of wood. In densely vegetated slopes in burn area. Road is high clearance with grass and herbs on surface and no problems. Culvert is on edge of landslide. Orphan.
15092109272	Steel culvert round	48	3	60	**Mod-Low**	1	Yes	282	Open and Sound	Organic debris pile	Yes	Intact	No	0	0	8N36	Inlet is open but the wood and debris are very abundant. Debris flow evidence, sediment plume, and organic debris pile. Spring contribution. Abandoned road with very dense vegetation on road surface, .
14101010471	Steel culvert round	24	2	61	**Mod-Low**	1	None	21	Open and Sound	Organic debris pile	No	Intact	No	500	14	8N65	South of the landslide area. Cow trampled. Partially crushed. Very dense whitethorn. Has flow and spring contribution.
15071912332	Steel culvert oval	72	4	62	**Mod-Low**	1	Yes	108	Open and Sound	No	No	Intact	No	300	8	8N05J	Fill Erosion location is uncertain. Flared inlet. Wood at outlet is ok. 48 inch pipe height. Located just up the west slope from main Panther Ck crossings on 8N05.
14100915551	Steel culvert round	24	1	63	**Low**	1	None	5	Open and Sound	No	No	Intact	No	0	0		Pipe undersized; 95% buried and, rusted.
15072210122	Aluminum culvert	36	4	64	**Low-Mod-Low**	2	Yes	71	Partially blocked	Organic debris pile	No	Intact	No	0	0	7N05	Organic debris pile, but plugging is moderate. Cow trampled!! Road is high clearance, and crushed rock with no erosion. Cow are a mess.
15080214102	Steel culvert round	36	4	65	**Low-Mod-Low**	2	Yes	40	Partially blocked	No	No	Intact	No	0	0	8N18A	Stream is a boulder cascade. On a closed, native, grassy, non-trafficable road with no problem. It is the lowest road on the east side of the gully cascade area,
15062010182	Steel culvert round	36	4	66	**Low-Mod-Low**	2	Yes	37	Partially crushed	No	No	Intact	No	0	0	9N13	Flared inlet. Channel splits into several small channels above pipe. Road is a rocked, passenger car road with no problems off Ellis up by Highway 88 intersection.
15080211292	Steel culvert round	18	2	67	**Low-Mod-Low**	2	Yes	32	Partially blocked	No	No	Intact	No	0	0	8N19B	Shotgun culvert. Pipe is set too high. Orphan crossing. 2nd lowest road in cascading gully area.

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15073109412	Steel culvert round	24	3	68	**Low-Mod-Low**	2	Yes	32	Partially blocked	No	No	Intact	No	0	0	8N18	Middle section of cascading gully area in big, ponded spring area just below crossing on 8N18B. Pipe above is overtopped and eroded. Rip rap around pipe inlet and outlet.
15080308172	Steel culvert round	24	3	69	**Low-Mod-Low**	2	None	28	Partially blocked	Organic debris pile	No	Intact	No	0	0	8N08	Mostly fine. Inlet is not blocked much, but pipe installation is at a higher grade than stream and causes minor sediment and wood deposition. Road is native, grassy, non-trafficable and no problem.
14092911401	Aluminum culvert	18	3	70	**Low-Mod-Low**	2	None	16	Partially blocked	No	No	Intact	No	0	0	8N05B	Debris flow. Partially occluded. Lots of wood above and in inlet. Road native, high clearance and fine. North of landslide zone.
14092914051	Steel culvert round	24	2	71	**Low-Mod-Low**	1	None	27	Partially blocked	No	No	Intact	No	0	0	8N09	Moderate to low plugging. Lots wood. Organic debris pile at inlet. Southwest corner of area, non-trafficable road with woody debris. Abandoned road
14101215053	Steel culvert round	24	1	72	**Low-Mod-Low**	1	None	20	Partially blocked	No	No	Intact	No	0	0	8N01A	Partially buried inlet, moderate degree of plugging. CMP has a 40% rust line. Orphan. Road is native with live woody vegetation.
14102417273	Aluminum culvert	24	2	73	**Low-Mod-Low**	1	None	18	Partially blocked	Organic debris pile	No	Intact	No	0	0	8N01A	Moderate to low degree of plugging; arm sized logs sticking out of outlet. Stream is ephemeral with little flow and lots duff and wood covering channel. Main road paved with no problems.
15081309142	Steel culvert round	24	1	74	**Low-Mod-Low**	1	Yes	17	Partially blocked	No	No	Intact	No	0	0	8N03C	Low to mod plugging. There are 3 xings in a row on this very small stream. Stream is a boulder cascade above. In South Shore campground. Road is paved and fine.
15081309382	Steel culvert round	24	1	75	**Low-Mod-Low**	1	Yes	15	Partially blocked	No	No	Intact	No	0	0	8N03C	Low plugging on outlet. There are 3 xings in a row on this very small stream. Rip rap on fillslopes around inlet & outlet. In South Shore campground. Road is paved and fine.
15081308422	Steel culvert round	24	1	76	**Low-Mod-Low**	1	Yes	12	Partially blocked	No	No	Intact	No	0	0	8N03C	Moderate plugging on outlet. There are 3 xings in a row on this very small stream. Boulders make natural rip raped around outlet. In South Shore campground. Road is paved and fine.
15072210522	Steel culvert round	18	1	77	**Low-Mod-Low**	1	Yes	12	Partially blocked	Organic debris pile	No	Intact	No	0	0	7N05	Low to moderate-low plugging. Lots of spring flow. Densely vegetated springy area upstream with low gradient to inlet with cow tramples!! Narrow erosional pool at outlet. Road is high clearance with no erosion, and crushed rock.

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15070115362	Steel culvert round	24	2	78	**Low-Mod-Low**	1	None	12	Partially blocked	No	No	Intact	No	0	0	8N14H	Moderate plugging with wood and rocks and a boulder at inlet. Ponding at outlet. High clearance native road with no problems.
15083109382	Steel culvert round	18	1	79	**Low-Mod-Low**	1	2 Direction	10	Partially blocked	No	No	Intact	No	0	0	8N50	Moderate to moderately high plugging. Just below low burn area. Small channel. Orphan crossings. Main paved road through North Fork Mokelumne gorge.
15090109522	Steel culvert round	24	1	80	**Low-Mod-Low**	1	None	9	Partially blocked	No	No	Intact	No	0	0	8N50	50% plugged outlet. Old pipe. Outlet blockage is old. Rocked headwalls. Just below low burn area with very steep topography above. Main paved road through North Fork Mokelumne gorge.
14092814432	Plastic culvert	24	2	81	**Low-Mod-Low**	1	None	11	Open and Sound	No	No	Intact	No	40	1	8N25	Crazy triple snorkel inlet! It is a new installation. This and other nearby sites have been recently dug out. Some erosion of inboard fill to inlet from lead off, but moderate to mod-low for plugging risk based on debris flow prone area. Evidence of debris flow is sediment plume at this site, and a previously buried, now excavated snorkel inlet at next DRC to west. Main paved road near bottom almost to 8N50 in NF Mokelumne River canyon. Deeply incised channel.
14101317221	Steel culvert round	48	2	82	**Low**	1	None	61	Open and Sound	Scoured road	No	Intact	No	30	1	8N39	Flared inlet. Small ephemeral stream. In area below private timber land down in Lower Bear River valley downstream of dam. Road is high clearance, rocked, and no problem. Scoured road is minor
15071908122	Steel culvert round	48	4	83	**Low**	1	Yes	1324	Open and Sound	Organic debris pile	No	Intact	No	0	0		Organic debris pile is minor. 54 inch pipe, not 48. Heavily cow trampled stream with bank and instream erosion. Channel is split. Very, very dense brush.
14092510192	Steel culvert round	18	2	84	**Low**	2	None	12	Open and Sound	No	No	Intact	No	0	0	8N30	On main paved road west of Bear River Resort. Passenger car road is fine.
14092412341	Aluminum culvert	24	2	85	**Low**	1	None	72	Open and Sound	Organic debris pile	No	Intact	No	0	0	8N28	Lots of wood but crossing is fine. Ephemeral stream channel covered by logging debris.
14092711123	Steel culvert round	48	4	86	**Low**	1	None	157	Open and Sound	Organic debris pile	No	Intact	No	0	0	8N06	Very minor debris pile. Very dense whitethorn makes reaching outlet difficult; survey was taken 3 ft left of channel. Flowing now. Steep, boulder channel.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m³)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft³)	Fill Erosion (m³)	Road	Notes
14092811143	Steel culvert round	18	1	87	**Low**	1	None	6	Open and Sound	Organic debris pile	No	Intact	No	0	0	8N16C	Minor organic debris pile at inlet. Very small ephemeral stream. Road is south of new PG&E station.
14101112044	Steel culvert round	24	2	88	**Low**	1	None	8	Open and Sound	Organic debris pile	No	Intact	No	0	0	8N52	In the southeast area of granite roads. Just a rotting fallen tree at inlet.
14101113453	Steel culvert round	36	3	89	**Low**	1	Yes	59	Open and Sound	Organic debris pile	No	Intact	No	0	0	8N11	Flared inlet. Steep cobble channel. Lots of wood in channel. Minor stream. Has lots wood but not enough flow to raft its large size. In eastern area near new PGE station.
14101215201	Steel culvert round	36	2	90	**Low**	1	None	27	Open and Sound	Organic debris pile	No	Intact	No	0	0	8N29	Minor organic debris pile. Ephemeral stream.
15082513192	Steel culvert round	48	2	91	**Low**	1	Yes	35	Open and Sound	Sediment Plume	No	Intact	No	0	0		Sediment plume and organic debris at inlet. In group campground past Pardoes campground. Orphan.
15091212242	Natural Ford		5	92	**Low**	0	None	-	Open and Sound	No	No	Washed out	No	70	2		Has a second, side channel through fill. Width is for main channel.
15072808002	Steel culvert round	24	3	93	**Low**	2	Yes	1856	Open and Sound	No	No	Intact	No	0	0		Large stream crossing. Goes down into snorkel. Connects with stream.
15082913192	Steel culvert round	48	5	94	**Low**	2	None	1325	Open and Sound	No	No	Intact	No	0	0		Very old, possibly historical stone in headwalls. Walls have 90 degree angles. Drop is over rocks. Dams upstream have a separate photo point.
14101112171	Steel culvert round	72	10	95	**Low**	2	None	836	Open and Sound	No	No	Intact	No	0	0		Active flow in channel/pipe. Non-fish bearing stream.
15091510272	Steel culvert round	24	4	96	**Low**	2	Yes	386	Open and Sound	No	No	Intact	No	0	0		Steep pipe. Dense brush. Stable crossing.
15081114542	Steel culvert round	24	3	97	**Low**	2	None	290	Open and Sound	No	No	Intact	No	0	0		Flared inlet and outlet. Rocked stream through wide landing around inlet basin. Rust stained rocks in channel below. Rip rap on inboard and outboard.
14092412151	Aluminum culvert	36	4	98	**Low**	2	None	245	Open and Sound	No	No	Intact	No	0	0		Rattlesnake creek. No present flow or snakes.

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14092711561	Steel culvert round	72	10	99	**Low**	2	None	242	Open and Sound	No	No	Intact	No	0	0		Has big concrete sediment trap.
15083110492	Steel culvert round	60	6	100	**Low**	2	Yes	228	Open and Sound	No	No	Intact	No	0	0		Armored mortared stone fills. Boulder channel. In lots of poison oak.
14102412373	Steel culvert round	72	8	101	**Low**	2	None	208	Open and Sound	No	No	Intact	No	0	0		Larger stream. No present flow. Low grade channel at crossing. 7' diameter pipe.
14100815574	Steel culvert round	48	5	102	**Low**	2	Yes	178	Open and Sound	No	No	Intact	No	0	0		Ephemeral channel. No problems.
14092515524	Aluminum culvert	72	12	103	**Low**	2	Yes	153	Open and Sound	No	No	Intact	No	0	0		Aluminum oval pipe. At hill crest. Incised steep slope.
14101110171	Steel culvert round	24	3	104	**Low**	2	None	146	Open and Sound	No	No	Intact	No	0	0		Channel covered in organic debris. Ephemeral channel.
14092615451	Steel culvert oval	48	6	105	**Low**	2	None	131	Open and Sound	No	No	Intact	No	0	0		Undersized pipe. Flared inlet. No present flow.
14092816274	Steel culvert round	60	6	106	**Low**	2	None	124	Open and Sound	No	No	Intact	No	0	0		No problems.
15073115352	Steel culvert oval	36	5	107	**Low**	2	None	115	Open and Sound	No	No	Intact	No	0	0		Steel ephemeral channel.
15081112412	Steel culvert round	48	6	108	**Low**	2	None	103	Open and Sound	No	No	Intact	No	0	0		Flared inlet.
15091214232	Steel culvert oval	72	8	109	**Low**	2	Yes	87	Open and Sound	No	No	Intact	No	0	0		Top of past diversion. Pipe is too short. Potential to overtop fill due to lack of fill at sides. cmp W70H60.
14100814544	Steel culvert round	48	5	110	**Low**	2	Yes	81	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream.

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14092412381	Aluminum culvert	36	4	111	**Low**	2	None	80	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream.
14101110232	Steel culvert round	24	3	112	**Low**	2	None	76	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream.
14092411332	Steel culvert oval	60	7	113	**Low**	2	Yes	70	Open and Sound	No	No	Intact	No	0	0		Large intermittent, low gradient stream.
15073115502	Steel culvert oval	36	6	114	**Low**	2	None	69	Open and Sound	No	No	Intact	No	0	0		Large intermittent boulder lined stream.
15081310432	Steel culvert round	24	3	115	**Low**	2	Yes	63	Open and Sound	No	No	Intact	No	0	0		Boulder cascade channel above. Discharges through 100' of forest to lake.
14092612531	Steel culvert round	24	3	116	**Low**	2	None	62	Open and Sound	No	No	Intact	No	0	0		Small, stable, ephemeral stream.
14092411391	Aluminum culvert	36	4	117	**Low**	2	None	56	Open and Sound	No	No	Intact	No	0	0		Ephemeral, cobble/boulder channel. Non-fish bearing.
14101011544	Steel culvert round	24	3	118	**Low**	2	None	56	Open and Sound	No	No	Intact	No	0	0		Active flow. Active grazing. High vegetation.
14092411021	Aluminum culvert	24	3	119	**Low**	2	None	51	Open and Sound	No	No	Intact	No	0	0		Ephemeral, cobbled channel. Non-fish bearing.
14100814404	Steel culvert round	36	5	120	**Low**	2	Yes	41	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream. Steep channel grade. Possibly overtopped fill.
15083013602	Steel culvert round	30	4	121	**Low**	2	Yes	39	Open and Sound	No	No	Intact	No	0	0		Rocked headwall with 90 degree side walls. Freestone outlet wall. Rip raped outlet.
15090108332	Steel culvert round	36	4	122	**Low**	2	None	37	Open and Sound	No	No	Intact	No	0	0		42 inch diameter pipe. Rocked headwall.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
14101012364	Steel culvert round	24	4	123	**Low**	2	None	35	Open and Sound	No	No	Intact	No	0	0		Active flow. Dense vegetation.
15073012552	Steel culvert round	24	4	124	**Low**	2	Yes	35	Open and Sound	No	No	Intact	No	0	0		Rocky channel.
14092315352	Steel culvert oval	48	6	125	**Low**	2	None	33	Open and Sound	No	No	Intact	No	0	0		Intermittent, fish bearing, low gradient, well armored channel.
15080110522	Steel culvert round	18	3	126	**Low**	2	Yes	26	Open and Sound	No	No	Intact	No	0	0		Flow below diverts along 8N18A surface.
15080111412	Steel culvert round	24	3	127	**Low**	2	Yes	24	Open and Sound	No	No	Intact	No	0	0		Spring flow contribution to inlet.
14101116294	Steel culvert oval	48	1	128	**Low**	2	None	22	Open and Sound	No	No	Intact	No	0	0		Oversized culvert on multiple streams. Has not received flow in many years.
15083108352	Steel culvert round	18	3	129	**Low**	2	Yes	22	Open and Sound	No	No	Intact	No	0	0		Rocked headwalls. Bouldery, not deeply incised channel.
14100715263	Steel culvert round	36	2	130	**Low**	2	Yes	21	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream. Well vegetated.
15090109202	Steel culvert round	30	3	131	**Low**	2	Yes	19	Open and Sound	No	No	Intact	No	0	0		Old pipe is not corrugated.
14101109474	Steel culvert round	18	3	132	**Low**	2	None	18	Open and Sound	No	No	Intact	No	0	0		Steep channel grade.
14102415573	Steel culvert round	18	2	133	**Low**	2	Yes	17	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream. Low gradient, grassy channel. Orphan.
14102410453	Aluminum culvert	18	2	134	**Low**	2	Yes	14	Open and Sound	No	No	Intact	No	0	0		Stable incised channel. Ephemeral stream.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
14102410403	Aluminum culvert	18	2	135	**Low**	2	Yes	14	Open and Sound	No	No	Intact	No	0	0		Multiple channels above. One to this crossing directly and one diverts to ditch and crosses to lower crossing where it crosses road.
14092811194	Steel culvert round	18	2	136	**Low**	2	None	14	Open and Sound	No	No	Intact	No	0	0		No problems.
14092514014	Aluminum culvert	18	2	137	**Low**	2	Yes	12	Open and Sound	No	No	Intact	No	0	0		Does not run all year. Lots of debris above.
14092710002	Steel culvert round	18	2	138	**Low**	2	None	12	Open and Sound	No	No	Intact	No	0	0		Small, ephemeral, cobble lined stream.
15072911312	Steel culvert round	18	3	139	**Low**	2	None	10	Open and Sound	No	No	Intact	No	0	0		Lots of large boulders and wood in channel.
14092810333	Steel culvert round	18	2	140	**Low**	2	None	10	Open and Sound	No	No	Intact	No	0	0		Barely meets stream qualifications. Stream incised. Does not transport significant sediment.
14092614073	Steel culvert round	12	2	141	**Low**	2	None	6	Open and Sound	No	No	Intact	No	0	0		Small pipe is set high in fill. 4 ft deep inlet basin is clear.
14100813514	Steel culvert round	36	5	142	**Low**	2	None	0	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream.
15091009312	Steel culvert round	66	4	143	**Low**	1	Yes	1084	Open and Sound	Sediment Plume	No	Intact	No	1412	40		Tons of woody debris. Boulder rip rapped fill. Crazy 3 snorkels off top of inlet; see pics!!
15071710502	Steel culvert round	60	4	144	**Low**	1	Yes	591	Open and Sound	No	No	Intact	No	0	0		Large, 54 inch diameter pipe. Slopes are rip rapped. 36 inch diameter overflow pipe with 1/2 round downspout and large wood atop inlet.
15070309582	Steel culvert oval	36	3	145	**Low**	1	Yes	386	Open and Sound	No	No	Intact	No	0	0		36 inch diameter pipe and a 36 inch diameter overflow pipe near top of fill w/extension and bees in pipe.
15072810322	Steel culvert round	24	1	146	**Low**	1	Yes	312	Open and Sound	No	No	Intact	No	0	0		Steel grate drop inlet. Trenched outlet.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
15082510122	Steel culvert round	72	3	147	**Low**	1	Yes	165	Open and Sound	No	No	Intact	No	0	0		Flared inlet. Bouldered channel.
14092916361	Steel culvert oval	36	2	148	**Low**	1	None	134	Open and Sound	No	No	Intact	No	0	0		Flowing water! Sediment catchment. Cows.
14101111332	Steel culvert round	36	2	149	**Low**	1	None	123	Open and Sound	No	No	Intact	No	0	0		Big pipe. Some fill armor. Lots of fill.
14092916141	Steel culvert oval	36	2	150	**Low**	1	None	119	Open and Sound	No	No	Intact	No	0	0		Sediment catch.
14102513493	Steel culvert oval	60	4	151	**Low**	1	Yes	117	Open and Sound	No	No	Intact	No	0	0		Sand bags at inlet.
14092813491	Steel culvert round	24	2	152	**Low**	1	None	111	Open and Sound	No	No	Intact	No	0	0		Small ephemeral stream. Channel covered in pine needles.
14092711011	Steel culvert round	60	5	153	**Low**	1	None	106	Open and Sound	No	No	Intact	No	0	0		No problems. Orphan.
14092916261	Steel culvert oval	36	2	154	**Low**	1	None	100	Open and Sound	No	No	Intact	No	0	0		Flowing water! Sediment catchment. Cows.
14100715573	Steel culvert round	36	1	155	**Low**	1	Yes	98	Open and Sound	No	No	Intact	No	0	0		Steep headwall boulder channel with nice grassy meadow. Little trickle of flow.
15070308422	Steel culvert oval	72	4	156	**Low**	1	None	94	Open and Sound	No	No	Intact	No	0	0		Top of pipe cut off at inlet and outlet. Some bank erosion at outlet.
14092712533	Steel culvert round	60	4	157	**Low**	1	None	90	Open and Sound	No	No	Intact	No	0	0		Log in culvert, does not block. Flared inlet. 54 inch diameter culvert. Outlet half crushed.
14100911391	Steel culvert oval	72	6	158	**Low**	1	None	88	Open and Sound	No	No	Intact	No	0	0		78 inch wide pipe. Flared inlet. Log jam waterfall outlet onto bedrock. Stream bank erosion below drop & on right of base of fill. Orphan.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
15082509582	Steel culvert round	60	3	159	**Low**	1	Yes	84	Open and Sound	No	No	Intact	No	0	0		Flared inlet. Bouldered channel.
14101014374	Steel culvert round	36	3	160	**Low**	1	None	72	Open and Sound	No	No	Intact	No	0	0		Active flow. No Problems.
14100816334	Steel culvert round	36	3	161	**Low**	1	Yes	69	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream. No problems.
14101015401	Steel culvert round	36	1	162	**Low**	1	Yes	69	Open and Sound	No	No	Intact	No	0	0		40 inch diameter culvert.
14092516011	Steel culvert oval	72	5	163	**Low**	1	None	64	Open and Sound	No	No	Intact	No	0	0		Armored stream. Sediment catch.
14092412211	Aluminum culvert	24	2	164	**Low**	1	None	64	Open and Sound	No	No	Intact	No	0	0		Small ephemeral, cascading stream.
15080210492	Steel culvert oval	60	3	165	**Low**	1	Yes	64	Open and Sound	No	No	Intact	No	0	0		Channel is bedrock; carries lots of fine silt. Oval pipe is 5' wide x 3' tall.
14101111161	Steel culvert round	36	2	166	**Low**	1	None	59	Open and Sound	No	No	Intact	No	0	0		Mossy ephemeral channel.
14101314563	Steel culvert round	36	3	167	**Low**	1	Yes	59	Open and Sound	No	No	Intact	No	0	0		Flared inlet. Flow now.
14092411571	Aluminum culvert	24	2	168	**Low**	1	None	55	Open and Sound	No	No	Intact	No	0	0		Small cascading ephemeral stream.
14092512271	Steel culvert oval	72	4	169	**Low**	1	None	54	Open and Sound	No	No	Intact	No	0	0		Sediment catch.
14092612331	Steel culvert round	24	2	170	**Low**	1	None	54	Open and Sound	No	No	Intact	No	0	0		Small stable ephemeral stream.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
15070308242	Steel culvert round	24	2	171	**Low**	1	Yes	53	Open and Sound	No	No	Intact	No	0	0		Recently cleaned out. Lots of vegetation uphill.
15082910172	Steel culvert round	24	1	172	**Low**	1	None	52	Open and Sound	No	No	Intact	No	0	0		Very old, thick but not corrugated pipe. Narrow rocked inlet and outlet. Lots poison oak!
14101214073	Steel culvert oval	66	4	173	**Low**	1	None	52	Open and Sound	No	No	Intact	No	0	0		Flared inlet.
15083010512	Concrete culvert	48	3	174	**Low**	1	Yes	51	Open and Sound	No	No	Intact	No	0	0		Mortared rock headwall. Bedrock channel.
15071913302	Steel culvert oval	60	2	175	**Low**	1	None	49	Open and Sound	No	No	Intact	No	0	0		Flared inlet. 5 ft pipe width. Black silted stream above because cows!
14092509303	Steel culvert oval	60	3	176	**Low**	1	None	46	Open and Sound	No	No	Intact	No	0	0		Heavily used/abused by cattle. Steel flared inlet.
14092516222	Steel culvert round	36	3	177	**Low**	1	None	41	Open and Sound	No	No	Intact	No	0	0		No problems.
15080211162	Steel culvert round	24	2	178	**Low**	1	Yes	39	Open and Sound	No	No	Intact	No	0	0		Shotgun culvert. Gullies from above. Boulder cascade channel; hard to measure width.
14101112403	Steel culvert round	24	2	179	**Low**	1	None	38	Open and Sound	No	No	Intact	No	0	0		Steep cobble channel.
15082808272	Steel culvert oval	36	2	180	**Low**	1	None	37	Open and Sound	No	No	Intact	No	0	0		24 in tall and 42 in wide pipe. Boulder cascade stream.
14102215533	Steel culvert round	36	3	181	**Low**	1	Yes	36	Open and Sound	No	No	Intact	No	0	0		Well armored stream.
14092912012	Aluminum culvert	36	3	182	**Low**	1	None	36	Open and Sound	No	No	Intact	No	0	0		Boulder cascade stream has irregular channel width.

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14101310314	Steel culvert round	24	2	183	**Low**	1	Yes	36	Open and Sound	No	No	Intact	No	0	0		Newer channel. Scoured channel.
14100811023	Steel culvert oval	60	2	184	**Low**	1	None	35	Open and Sound	No	No	Intact	No	0	0		Flared inlet.
14092415102	Steel culvert round	36	3	185	**Low**	1	None	32	Open and Sound	No	No	Intact	No	0	0		No problems.
14092610271	Steel culvert round	48	3	186	**Low**	1	None	32	Open and Sound	No	No	Intact	No	0	0		Beginning of a larger stream. Multiple channels meet at small confluence just below.
14092514144	Aluminum culvert	36	3	187	**Low**	1	Yes	28	Open and Sound	No	No	Intact	No	0	0		Aluminum oval pipe. Incised, steep slope.
14092912443	Aluminum culvert	24	2	188	**Low**	1	None	28	Open and Sound	No	No	Intact	No	0	0		Flared inlet.
14100817064	Steel culvert oval	36	2	189	**Low**	1	Yes	28	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream. No problems.
14092814192	Steel culvert oval	48	3	190	**Low**	1	None	27	Open and Sound	No	No	Intact	No	0	0		32 inch width, not 48.
14092409491	Aluminum culvert	24	2	191	**Low**	1	Yes	27	Open and Sound	No	No	Intact	No	0	0		Ephemeral, non-fish bearing, cobble channel.
14100913213	Steel culvert round	36	3	192	**Low**	1	None	25	Open and Sound	No	No	Intact	No	0	0		Flared inlet.
14102417103	Aluminum culvert	24	2	193	**Low**	1	None	24	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream. Channel covered by organic debris.
14092613361	Steel culvert round	24	2	194	**Low**	1	None	24	Open and Sound	No	No	Intact	No	0	0		Small stable ephemeral stream.

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14101112073	Steel culvert round	18	1	195	**Low**	1	Yes	24	Open and Sound	No	No	Intact	No	0	0		Channel scoured to bedrock.
14101011473	Steel culvert round	24	1	196	**Low**	1	None	22	Open and Sound	No	No	Intact	No	0	0		Stream has no sign of problems.
14102412463	Aluminum culvert	24	2	197	**Low**	1	None	21	Open and Sound	No	No	Intact	No	0	0		Low gradient ephemeral stream.
14092515351	Steel culvert round	36	2	198	**Low**	1	None	21	Open and Sound	No	No	Intact	No	0	0		Armored stream channel.
14092815584	Steel culvert round	24	2	199	**Low**	1	None	19	Open and Sound	No	No	Intact	No	0	0		No problems.
14102115463	Steel culvert round	24	2	200	**Low**	1	None	18	Open and Sound	No	No	Intact	No	0	0		Large inlet basin.
14092909344	Steel culvert round	36	2	201	**Low**	1	Yes	18	Open and Sound	No	No	Intact	No	0	0		Stream braids and some enters dtch for short distance.
14092517131	Steel culvert round	24	2	202	**Low**	1	Yes	18	Open and Sound	No	No	Intact	No	0	0		Stream feeds stream confluence. Armoured
14101210454	Steel culvert oval	30	2	203	**Low**	1	Yes	17	Open and Sound	No	No	Intact	No	0	0		Steep grade drop to inlet. Ephemeral stream.
14101111152	Steel culvert round	24	1	204	**Low**	1	None	17	Open and Sound	No	No	Intact	No	0	0		Ephemeral small stream.
14101115153	Steel culvert round	24	1	205	**Low**	1	None	17	Open and Sound	No	No	Intact	No	0	0		In burn area with dense vegetation.
14092517201	Steel culvert round	24	2	206	**Low**	1	Yes	16	Open and Sound	No	No	Intact	No	0	0		Stream feeds stream confluence. Armored.

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14102410363	Steel culvert round	24	2	207	**Low**	1	Yes	15	Open and Sound	No	No	Intact	No	0	0		Multiple stream channels above. One enters ditch and one is through this crossing.
15083115042	Steel culvert round	24	2	208	**Low**	1	None	14	Open and Sound	No	No	Intact	No	0	0		Channel flows through Pleistocene, cemented, terrace deposit. Rocked headwall.
14092912134	Aluminum culvert	24	2	209	**Low**	1	None	13	Open and Sound	No	No	Intact	No	0	0		Dense vegetation. Steep grade.
14101315581	Steel culvert round	18	1	210	**Low**	1	None	13	Open and Sound	No	No	Intact	No	0	0		Small ephemeral stream.
14100816554	Steel culvert round	24	1	211	**Low**	1	Yes	12	Open and Sound	No	No	Intact	No	0	0		Ephemeral. No problems.
14092716133	Aluminum culvert	24	1	212	**Low**	1	None	12	Open and Sound	No	No	Intact	No	0	0		Flared inlet. Mossy stream.
14092416433	Steel culvert round	24	2	213	**Low**	1	None	11	Open and Sound	No	No	Intact	No	0	0		Heavily vegetated. Downed trees.
14101212171	Steel culvert round	24	1	214	**Low**	1	None	10	Open and Sound	No	No	Intact	No	0	0		Active flow
14092513044	Aluminum culvert	18	1	215	**Low**	1	Yes	9	Open and Sound	No	No	Intact	No	0	0		No problems.
14101118073	Steel culvert round	24	2	216	**Low**	1	Yes	8	Open and Sound	No	No	Intact	No	0	0		Giant boulder at outlet. Cobble stream. Significant contributing flow.
14100816454	Steel culvert round	18	1	217	**Low**	1	Yes	8	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream. No problems.
14092710292	Steel culvert round	18	1	218	**Low**	1	None	6	Open and Sound	No	No	Intact	No	0	0		Small, steep, ephemeral, cobble lined stream.

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14100911353	Steel culvert round	18	1	219	**Low**	1	Yes	6	Open and Sound	No	No	Intact	No	0	0		Small seasonal stream.
15090109062	Steel culvert round	24	1	220	**Low**	1	Yes	6	Open and Sound	No	No	Intact	No	0	0		Rocked headwalls. Spring above inlet.
14100714503	Steel culvert round	18	1	221	**Low**	1	Yes	5	Open and Sound	No	No	Intact	No	0	0		Barely meets stream criteria.
14101117094	Steel culvert round	18	1	222	**Low**	1	None	4	Open and Sound	No	No	Intact	No	0	0		Barely meets stream criteria.
15082509142	Steel arch bottomless	72	3	223	**Low**	0	Yes	105	Open and Sound	No	No	Intact	No	0	0		Flared inlet with concrete apron. Rip rapped channel both sides up stream. Height is 72 inches.
14092411252	Natural Ford	N/A	1	224	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Stream is grassy, low gradient, armored and ephemeral.
14092410164	Natural Ford	N/A	5	225	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		No problems.
14092410302	Natural Ford	N/A	1	226	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Small ephemeral, steep, armored channel.
14092414554	Natural Ford	N/A	5	227	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		No problems.
14092509533	Natural Ford	N/A	1	228	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Very dusty road surface contribution.
14092511483	Natural Ford	N/A	2	229	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Ponding through road surface with reeds. Excavated waterbars each side.
14092511523	Natural Ford	N/A	1	230	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		A small side channel of adjacent crossing.
14092512581	Natural Ford	N/A	1	231	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		No problems.
14092710064	Natural Ford	N/A	2	232	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Steep grade channel near headwaters. Grazing evidence.
14092712214	Natural Ford	N/A	1	233	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Barely meets stream criteria. Headwaters.

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14092712244	Natural Ford	N/A	1	234	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Barely meets stream criteria. Headwaters.
14092717311	Natural Ford	N/A	1	235	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		No problems.
14092914284	Natural Ford	N/A	2	236	**Low**	0	Yes	-	Open and Sound	No	No	Intact	No	0	0		No problems.
14100710234	Natural Ford	N/A	6	237	**Low**	0	Yes	-	Open and Sound	No	No	Intact	No	0	0		Small branch of nearby stream. Receives fill erosion from gullied road upslope. Ephemeral stream.
14100710354	Natural Ford	N/A	8	238	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Active flow. No major issues.
14100710394	Natural Ford	N/A	8	239	**Low**	0	Yes	-	Open and Sound	No	No	Intact	No	0	0		Small braided branch of nearby stream, diverts down road for short distance 25ft. Ephemeral stream.
14100711054	Natural Ford	N/A	4	240	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Ephemeral stream
14100912463	Natural Ford	N/A	1	241	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Ford across road.
14101213061	Natural Ford	N/A	1	242	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Active flow.
14102411173	Natural Ford	N/A	2	243	**Low**	0	None	-	Open and Sound	Organic debris pile	No	Intact	No	0	0		Small ephemeral stream covered with logs and organic debris.
14092410164	Natural Ford	N/A	3	244	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Steep road approaches are stable.
14092410302	Natural Ford	N/A	3	245	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Odd. Might have been excavated but no spoils found. Steep sides.
14092516162	Bridge	N/A	18	246	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		No problems.
14092612233	Bridge	N/A	40	247	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Major bedrock and boulder channel. Stream gage just downstream. Creosote railroad tie surface with cement abutments.
14101310584	Bridge	N/A	8	248	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Bedrock stream. Channel width hard to determine due to bedrock.
14101311144	Bridge	N/A	45	249	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Bridge made in 1969. No cut and fill. On large bedrock stream.

Drain ID	Type	Pipe Diameter (in.)	Channel Width	Priority Rank	Priority	SBI	Diversion Potential?	Surveyed Fill Volume (m^3)	General Condtion	Problem	Debris Flow Evidence?	Fill Condition	Active Diversion?	Fill Erosion (ft^3)	Fill Erosion (m^3)	Road	Notes
14092411332	Bridge	N/A	65	250	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Metal bridge. There is a dam below outlet through constructed channel in bedrock with cement sidewalls.
14092414554	Bridge	N/A	50	251	**Low**	0	Yes	-	Open and Sound	No	No	Intact	No	0	0		Concrete wing wall footings. Guard rails. Concrete top. 20' to river, 15' to footings. 130' long. Orphan.
14092509533	Bridge	N/A	55	252	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		110' long bridge across NF Mokelumne R. 22' clearance to base of concrete, about 20' to base of support beam.
14092511483	Bridge	N/A	7	253	**Low**	0	Yes	-	Open and Sound	No	No	Intact	No	0	0		100' long concrete top, steel base support, 17' clearance to base of concrete, 14' to base of steel supports. Concrete and steel abutments.
14092511523	Bridge	N/A	15	254	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Flume crossing. 15' wide with 3' clearance to flume top.
14092512581	Bridge	N/A	70	255	**Low**	0	None	-	Open and Sound	No	No	Intact	No	0	0		Lower Bear River. Has dam doors that can close to make a small reservoir, open now; 70' wide.