Tributaries Forest Recovery Project
Road Survey Report

Hungry Creek and Little Grizzly Creek Subwatersheds

Overview, Hungry Creek Watershed

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Executive Summary

Surveys of road crossings were conducted in the Hungry and Little Grizzly Creek subwatersheds. Both streams lie within the Tributaries Forest Recovery Project. Each provide important spawning habitat for native trout in Indian Creek, and important recreational fishery.

Survey results found numerous road segments in need of improvement, with a small percentage of road crossings delivering a majority of sediment to channels. Road crossings where flow from channels had been diverted down roadways as a result of plugged culverts accounted for the greatest percentage of sediment delivery. Road surfaces with long delivery paths on relatively steep road grades were another primary sediment source. In Hungry Creek, over 90% of estimated sediment production came from 10 sites (of 59 surveyed). In Little Grizzly Creek, over 90% of estimated sediment production came from 11 of 94 sites surveyed. A high percentage of crossings (31% in both Hungry Creek and Little Grizzly Creeks) were identified that have the potential for road capture of streams if the crossing were to fail. No problems were identified in any of the ten low water crossings surveyed.

A high percentage of crossing approaches (67% in Hungry Creek, 50% in Little Grizzly Creek) exceed current California State Practice Rules guidelines for connected length of approaches. Cumulative connected approach lengths increased flow paths by 3.3 miles in Hungry Creek and 4.4 miles in Little Grizzly Creek.

Few crossings in either subwatershed meet the current direction of culvert sizing to pass 100 year return interval flows, bedload and debris. 21% of culverts in Hungry Creek and 25% in Little Grizzly Creek are adequately sized for 100 year storm events. Only one culvert (in Hungry Creek) is sized to carry bedload and debris along with a 100 year flow.

Twelve channels above road crossings were identified that could benefit from the addition of standing dead trees to provide downed large woody debris.

Priority Recommendations for improvement fall into three categories:

- Maintenance of crossings where culverts are completely or substantially plugged to prevent additional stormflow damage.
- Storm proofing of road crossings and approaches, including construction of critical dips and construction of additional drainage structures to reduce length of connected road surfaces.
- Development of an approach to upsize culverts, or replace culverts with low water crossings at priority crossings.
- Revision and implementation of revised road management objectives for road 24N08X, an ummantained spur in Little Grizzly subwatershed where numerous road crossing caused problems were found.

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Background: Plumas National Forest Tributaries Forest Recovery Project and Hungry Creek and Little Grizzly Creek Fisheries Context

The Tributaries Forest Recovery Project (NFFRP) is being developed to enhance, restore, protect, and recover natural resource values within a 166,889-acre project area, heavily impacted by the 2021 Dixie Fire, including some areas that were also impacted by the 2001 Stream Fire, the 2007 Moonlight Fire, and the 2019 Walker Fire.

The project is a landscape-scale forest restoration project on public lands managed by the Plumas National Forest (PNF) on the Mt. Hough Ranger District of the PNF. The proposed project area (Figure 1) extends roughly from Indicator Peak to the north to Lake Davis and Conklin Park, and from Grizzly Ridge on the west to Antelope Lake and Murdock Crossing to the east. Water flowing from and through the project area is used to generate power at hydroelectric facilities in the Feather River Canyon. The project area is a primary source watershed for the State Water Project that provides water for more than 27 million Californians.

Feather River Trout Unlimited's (FRTU) interest in Hungry Creek and Little Grizzly Creek stems from an assessment of rainbow trout distribution and habitat condition in the Feather River watershed upstream of Lake Oroville completed by FRTU and partners in 2017 (Rogers, et al, 2017). Both subwatersheds were among those identified as priority for native fisheries improvement and protection. The assessment used a combination of physical and biological attributes to evaluate the condition of all 111 sub-watersheds of the Feather River Basin.

The assessment rated the relative resilience of sub-watersheds by combining watershed condition and climate change exposure factors. Subwatersheds with the highest resilience were typically in the best condition and located at higher elevations where changes to snowpack and stream temperature are expected to be moderated. Future amounts of thermally suitable and optimal rainbow trout habitat were also projected. Climate change and watershed condition metrics were combined to rate the suitability of each sub-watershed. Both Hungry Creek and Little Grizzly Creek were rated highly for sustaining native trout habitat in the assessment, and are considered refugia for native fishes at the scale of the Feather River Basin.

The assessment pointed to roads and high severity wildfire as key threats to fish habitat. As the Tributaries project is intended to address both these concerns, FRTU welcomed the opportunity to conduct road crossing surveys in the Hungry Creek and Little Grizzly Creek subwatersheds.

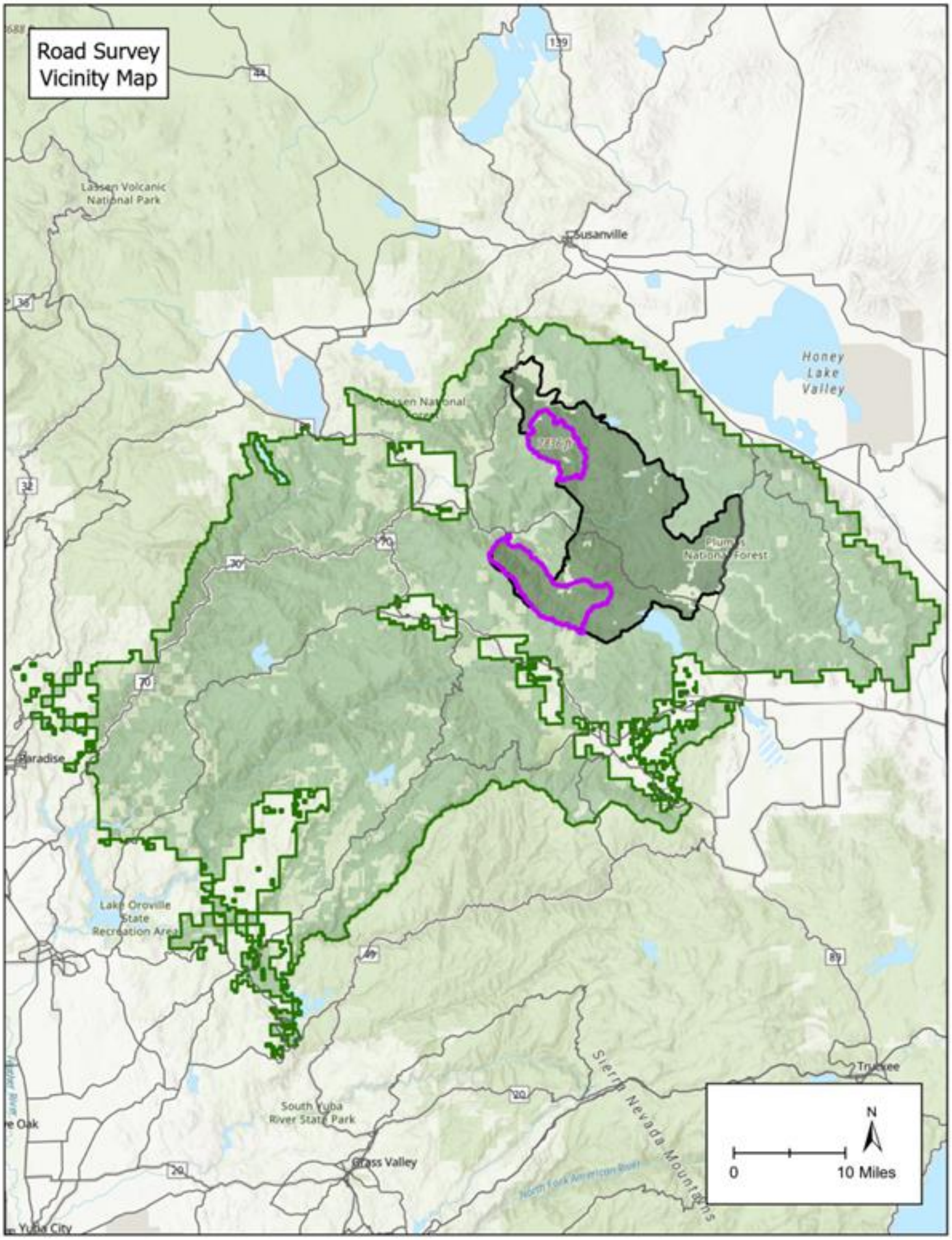

Figure 1. Location of Hungry and Little Grizzly Creeks (purple) in the Tributaries Project Area (dark shading) within the Plumas National Forest

Objective

The primary objective of this report is to summarize findings of road crossing surveys relative to the roads that impact water quality and fish habitat, and discuss possible road treatments to protect or improve water quality and fish habitat.

Road Impacts Review

Roads are important because of their potential to impact water quality, fish habitat and fish populations. Along with changes to hydrology and sediment production from wildfire, episodic and chronic, long-term contributions of fine sediment into streams from roads is a concern in the subject sub-watersheds. Mass failures from road cuts and fills are concerns on unstable landforms, but mass wasting is not a major concern in either Hungry Creek or Little Grizzly Creek.

Along with increased sediment delivery, roads affect hydrology. Roads can alter channel morphology directly or may modify channel flow paths and extend the drainage network into previously unchanneled portions of the hillslope. In terms of hydrology, road surfaces, cuts and fills intercept rainfall and subsurface flow moving down the hillslope. Some road designs concentrate flow, when surfaces or ditches connect to channels. Roads divert or reroute water from paths they would otherwise take if the road were not present. The effect of roads on peak streamflow is strongly influenced by the size of the watershed. In large catchments, roads constitute a small proportion of the land surface and have relatively limited effects on peak flow. In smaller, especially urbanized watersheds, roads are major considerations in flood routing. The subject watersheds lie in between these two extremes.

Roads are of particular interest in assessing protection and improvement actions because modifications in the design and maintenance of roads can reduce road-related erosion at the scale of individual road segments. It follows that focused improvements at larger scales (e.g. subwatershed) would translate to improved habitat condition. Road problems are tractable. Cost effective, well proven improvement actions are available.

Evidence suggests that roads are likely to influence the frequency, timing, and magnitude of disturbance to aquatic habitat (Gucinski, et al, 2001). Increased fine-sediment composition in stream gravel is a common consequence of road-derived sediments entering streams and has been linked to decreased trout fry emergence, decreased juvenile densities and loss of winter carrying capacity.

Sediment delivery from stream diversions at road crossings is a major source of road related erosion. A stream crossing has diversion potential if the stream flows down the road, rather than across the road when stream crossing capacity is exceeded (i.e., the culvert plugs). Diversion potential exists on roads that have a continuous climbing grade across the stream crossing or where the road slopes downward away from a stream crossing in at least one direction (Figure 2).

Figure 2. The probability of failure is substantial for most crossings, so how they fail is of critical importance. In this sketch, the crossing has failed, and the road grade has diverted the streamflow out of this channel and down the road, resulting in severe erosion and downstream sedimentation. Such damage to aquatic habitats can persist for many years once begun (from Furniss, et al, 1997).

Crossings without diversion potential may erode or cut through the crossing fill if a culvert fails and the stream overtops the fill, but the stream remains in its natural channel at the base of the fill. Crossing failures that divert storm flow along the roadway deliver more sediment. This is a result of gullies cut by the flow which erode material along and across the road, and from the slope eventually that returns flow from the roadway to the channel. An example of such a gully is shown in Figure 3A-B.

Figures 3A-B. Example of crossing (site H7) where plugged culvert failed resulted in flow diversion, in this case a long run along the roadway (3A) with gullying where flow finds a return path to the stream channel (3B).

Road crossing failures with or without channel diversion are major sources of sediment delivery, and may also have significant economic and social consequences. Failures most often occur during floods, with most failures caused by deposition of organic debris and bedload at the crossing inlet.

Subwatershed Scale Road Indicators

The Feather River Basin Assessment used measures of near stream road density (the density of roads within 100 meters of stream channels) and the number of road channel crossings as indicators of watershed condition. Table 1 presents three road metrics relevant to characterizing potential impacts on hydrologic condition at the subwatershed scale.

Little Grizzly Creek has road density and near-stream road density and frequency of road channel crossings lower than the mean for Feather River subwatersheds. The subwatershed is fairly large (~35 square miles) and the lower portions of the subwatershed, draining Grizzly Ridge to the west and Peel Ridge to the east, are very steep and contain few roads, with the exception of County Road 113 which parallels the creek to the east. Other portions of the Little Grizzly Creek subwatershed have high road density, including most of the area south of Oliver Creek on the eastern slopes of Grizzly Ridge.

In the Hungry Creek subwatershed, all three road metrics are higher than the basin averages, with both road density and density of channel crossing nearly twice the basin mean. Much of the topography has moderate slopes that were attractive to timber harvest and associated road construction in the 1960s and 1970s. NFS Road 27N09 runs along Hungry Creek for most of its length in the subwatershed, contributing to the relatively high near stream density.

Road density values from the two subwatersheds are high as compared to other subwatersheds on the Plumas National Forest, and the average for National Forest System lands. Plumas National Forest has an overall road density of 2.92 miles/mi^2 (Plumas NF, 2018), which is high in comparison with most National Forests. The average road density for non-wilderness NFS lands is 1.52 mi/mi^2 (USDA, 1998).

Subwatershed	Road Density (mi/mi2)	Near Stream Road Density (mi/mi2)	Channel Crossings/stream mile
Hungry	5.54	3.85	1.2
Little Grizzly	3.04	1.29	0.7
Feather River Basin-Range	0.5-8.1	0-9.3	0-2.5
Feather River Basin-Mean	3.6	3.2	0.9

Table 1. Summary of subwatershed scale road related metrics

Field Methods

Road Crossings

The survey employed in this assessment focused on stream crossings. Information was collected to provide estimates of road influences on delivery of flow and sediment and the risk of channel diversion. We surveyed each crossing in the two subwatersheds. At each crossing, the following characteristics were determined:

Inlet type
Inlet Condition
Potential fish passage site
Type of road structure connected (surface, ditch)
Type of road surface (native, rock, pavement, etc.)
Potential for crossing to divert flow in case of failure

The following characteristics were measured:

Inlet size
Length of Connected road (left and right)
Width of connected road
Slope of connected road
If diversion potential present, length of potential diversion

Where rilling or gullying on road surfaces or ditches was evident, the site was noted and the length, depth and width of the rill or gully was estimated.

Where channel diversion had occurred, the length, depth and width of resulting gullies were estimated.

Cross Drains

Cross drains are road infrastructure that carry water collected in road ditches across the road in a dip or culvert. Where these features were encountered observations were made if flow from the cross-drain outlet had connection to a stream channel. The length, width and dominant slope of the contributing area was measured. Any gullying associated with a cross drain outlet was noted and gully dimensions were estimated.

Aquatic Organism Passage

The second objective of the road crossing inventories was to evaluate road channel crossings for aquatic organism passage (AOP). The criteria for conducting surveys were that at least a mile of perennial stream habitat be present above the crossing and that the crossing had not been previously surveyed for AOP. None of the road crossings surveyed met the two criteria.

Needs/Opportunities for Addition of Large Woody Debris in Channels

At each road crossing, visual observations were made of the stream channel upstream and downstream of the crossings. The objective was to identify channel reaches that might benefit from falling fire killed trees into channels to provide in channel Large Woody Debris (LWD). Criteria included in the determination of whether or not LWD would be beneficial were:

- channel of low to moderate gradient (<2% slope)
- channel with evidence of substantial bedload movement
- availability of dead, recruitable LWD

Data Analysis

Plumas National Forest Road Crossing Rating

Data from field observations was summarized to rate each crossing based on a system developed by the Plumas National Forest (Appendix A). The rating includes categories that address channel flow regime, diversion potential, surface connectivity, sediment delivery, and culvert inlet condition. The range of possible scores is from 2 to 38, with weights given to sites with diversion potential, long surface connections and plugged, damaged or undersized culverts. A parallel system was used to rate low water crossings.

Sediment Production

Estimated Surface Erosion

Sediment production from connected road segments was estimated using the model employed by Cabrera, et al (2015) in their assessment of road related erosion in the Moonlight Fire (Plumas National Forest) as shown here:

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

Where E is erosion in kg, annually; B is the base erosion rate (kg/m); L is the road length (m) contributing to the drain point; S is the slope of the road contributing to the drain point (m/m); V is the vegetation cover factor for the flow path and R is the road surfacing factor. We applied the base rates developed by Cabrera et al (ibid) of 78 kg/m/yr for roads on volcanic soils and 33 kg/m/yr for roads on granitic soils. As we looked only at road surfaces and ditches delivering directly to channels, a vegetative cover factor for the flow path was not applied. We assumed that delivery was measured on roads with a width of 20 feet and adjusted estimates for measured widths greater or less than 20 feet.

Observed Surface Erosion

The length, width and depth of rills and gullies on road surfaces were estimated. Volumes for each site were converted to cubic yards.

Channel Diversions

Evidence of past and potential for future stream diversion that might result from a crossing failure was assessed by estimating the length, width and depth of past diversions and the likely length of future diversions.

Culvert Sizing

To assess culvert failure risk, a culvert sizing analysis was performed by comparing the existing culvert diameter to the recommended 100-year culvert sizing, which is the standard design flow listed in the Record of Decision for the Sierra Nevada Forest Plan Amendment (2004). 100-year flows were estimated at each culverted crossing site using the USGS StreamStats mapping application. This tool utilizes a regional regression analysis to estimate streamflow statistics for ungauged watersheds (U.S. Geological Survey, 2019).

Site characteristics including the estimated 100-year peak flows, culvert configuration, and headwater depth ratio were then input into the Federal Highway Administration (FHWA) culvert capacity nomograph (FHWA, 1965, found in FHWA, 2010) to determine the culvert size required to pass the 100-year flow event. To estimate needed culvert size to pass bedload and debris in addition to flow, a headwater depth of .67 was used, as recommended by Cafferata, et al (2017).

The existing culvert diameter was divided by the recommended 100-year diameter to create a Culvert Size Ratio. The Culvert Size Ratio was then used to quickly assess the existing culverts variance from the recommended 100-year sizing.

Channel Extension and Runoff

Estimates of channel extension were made by comparing the length of connected road surface (including ditches) with the length of channel in each subwatershed. Channel lengths (both perennial and seasonally flowing) were derived from the National Hydrography Dataset (NHD) stream layer.

Results

Results of road crossing inventories are shown in Table 2. As in most forested watersheds, roads appear to be a substantial factor affecting watershed processes and influencing stream condition in the two subwatersheds. This based is on the large number of crossings with diverted channels and the length of road approaches with connectivity to stream channels.

Attribute	Hungry	Little Grizzly
Number of Road Crossings	52	83
Culverts	52	73
Low Water Crossings (LWC)	0	10
Number of Cross Drains with Channel Connectivity	7	6
Number of Diversion Potenial Sites (crossings)	16	26
Length of connected roadways (m)	5390	6447
Length of connected roadways (mi)	3.3	4.0
Stream Miles (NHD)	97	153
Channel Extension (%)	3.4	1.4
Area of connected roadway (acres)	7936	9280
Area of connected roadway (mi 2)	12.4	14.5
Basin Size (acres)	12097	22451
Basin Size (mi sq)	18.9	35.1

Table 2. Road Crossing Survey results, Hungry and Little Grizzly Creek subwatersheds (LWC are fords)

Plumas National Forest Road Crossing Rating

Crossing ratings using the PNF road crossing rating scheme are summarized in Table 3. The results are shown in Figure 4 which includes the location of all crossings surveyed. Roughly a fifth of crossings in Hungry Creek and a quarter of Little Grizzly Creek crossings were rated as having high risk of impacts to water quality.

Rating	Subwatershed	
	Hungry	Little Grizzly
High	11 (21)	22 (28)
Moderate	24 (46)	20 (25)
Low	17 (33)	38 (47)

Table 3. Road Crossing Ratings, Hungry and Little Grizzly Creek subwatersheds. Percentages are in parenthesis.

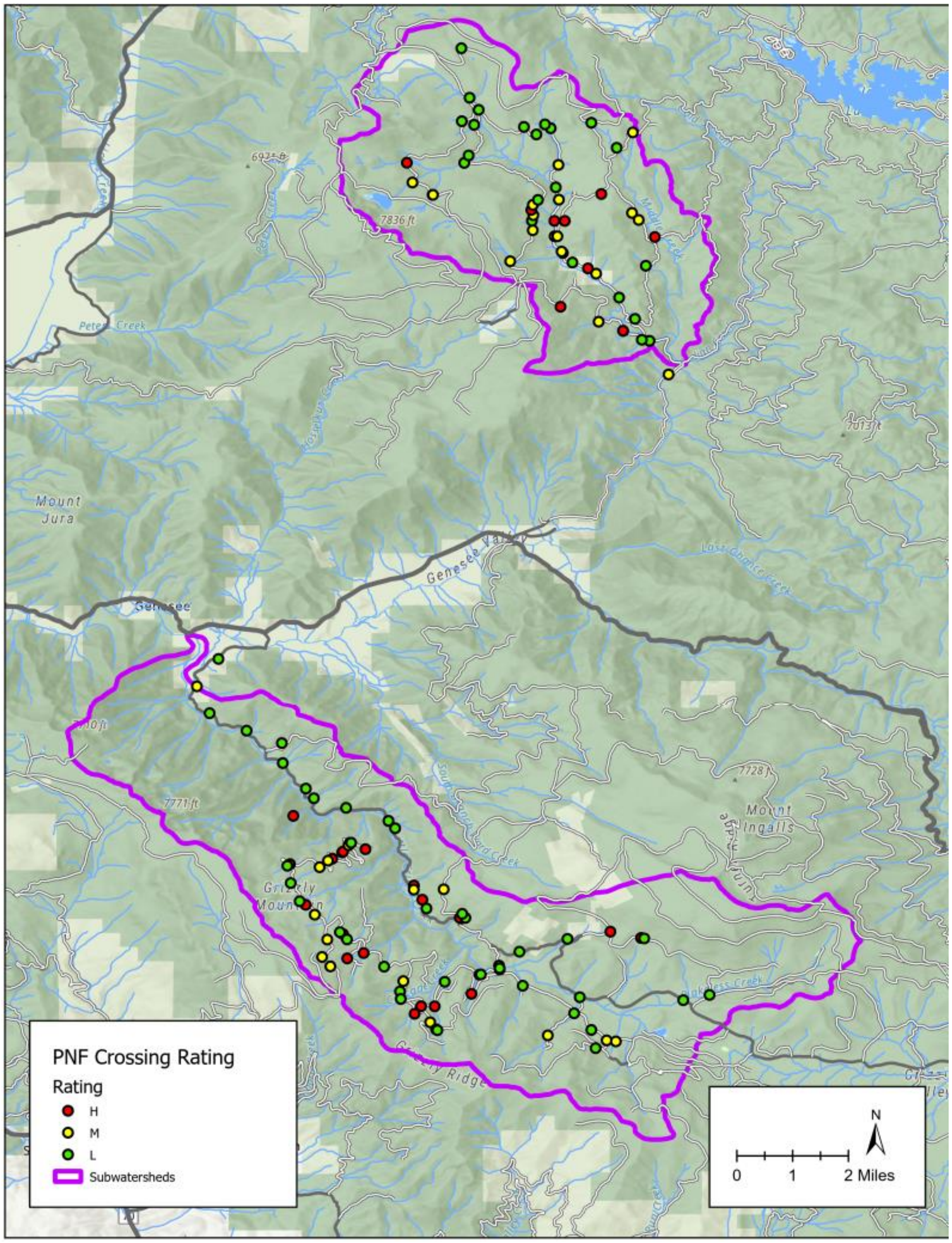

Figure 4. Location of Road Crossing Surveys with PNF Crossing Rating, Hungry and Little Grizzly Creek subwatersheds

Sediment

We looked at four types of road crossing sediment delivery to channels. In order of estimated sediment delivered (Table 4) these were gullies resulting from diverted channels, modeled surface erosion, surface rilling and ditch erosion.

Subwatershed	sediment	Source			
		gullies	surface	rills	ditch
Little Grizzly	CY	414.6	26.0	36.2	3.1
	percent	86.3	5.4	7.5	0.6
Hungry	CY	469.0	31.9	36.1	21.1
	percent	84	5.7	6.5	3.8

Table 4. Estimated sediment delivery by source, Hungry Creek and Little Grizzly Creek Subwatersheds (CY=cubic yards)

Results from Hungry and Little Grizzly Creeks are similar to other recent watershed surveys that include road surveys and summary of impacts, including those from the Moonlight Fire (Cabrera, et al, 2015), the Meadow Valley and Bear subwatersheds on the Plumas National Forest (Roby and Rogers, 2018) and from Butt Valley and Soldier Creek subwatersheds on the Lassen National Forest (Roby and Rogers, 2019). All these surveys found that high percentages of estimated sediment production were associated with relatively few road crossings. This is to be expected, as road crossings that are outliers in terms of having plugged culverts and diversion potential and those with the steepest slopes and greatest length of connected approaches can be expected to generate the most sediment if road designs do not account for these risks. Also, failure of drainage structures, though more likely during large flow events, is somewhat stochastic, and the greatest amount of sediment found during surveys is from sites with recent failures. While there is no doubt some error in our estimates of sediment volumes, we are confident in using the estimates in ranking of sites delivery of sediment to channels. Sites with greatest sediment delivery are listed in Tables 5 and 6 and shown in Figure 5.

Site	Road	% sediment	Latitude	Longitude
H7	27N53	27.90	40.12627	-120.673
H46	27N07	23.01	40.15547	-120.662
H8	27N53	15.94	40.12771	-120.676
HXD5	27N07	6.71	40.14989	-120.672
H32	27N45	4.37	40.15136	-120.68
HXD6	27N07	3.86	40.15556	-120.664
H1	27N09	2.82	40.10874	-120.645
H16	27N09	2.74	40.14018	-120.672
HXD4	27N09	1.32	40.15282	-120.673
HXD7	27N07	0.92	40.14781	-120.672

Table 5. Road crossings accounting for 90% estimate sediment delivered, Hungry Creek Subwatershed

Site #	Road	% sediment	Latitude	Longitude
LG80	24N08X	27.46	39.9872	-120.727
LG84	24N08X	20.99	39.99417	-120.742
LG17	24N42	12.61	39.94496	-120.709
LG79	24N08X	6.60	39.98714	-120.727
LG33	24N08X	6.05	39.97116	-120.739
LGX2	25N06Y	5.23	40.01152	-120.745
LG41	24N08X	4.50	39.98474	-120.729
LGX3	25N06Y	3.56	39.93612	-120.676
LG39	24N08X	2.80	39.98258	-120.733

Table 6. Road crossings accounting for 90% estimate sediment delivered, Little Grizzly Creek Subwatershed

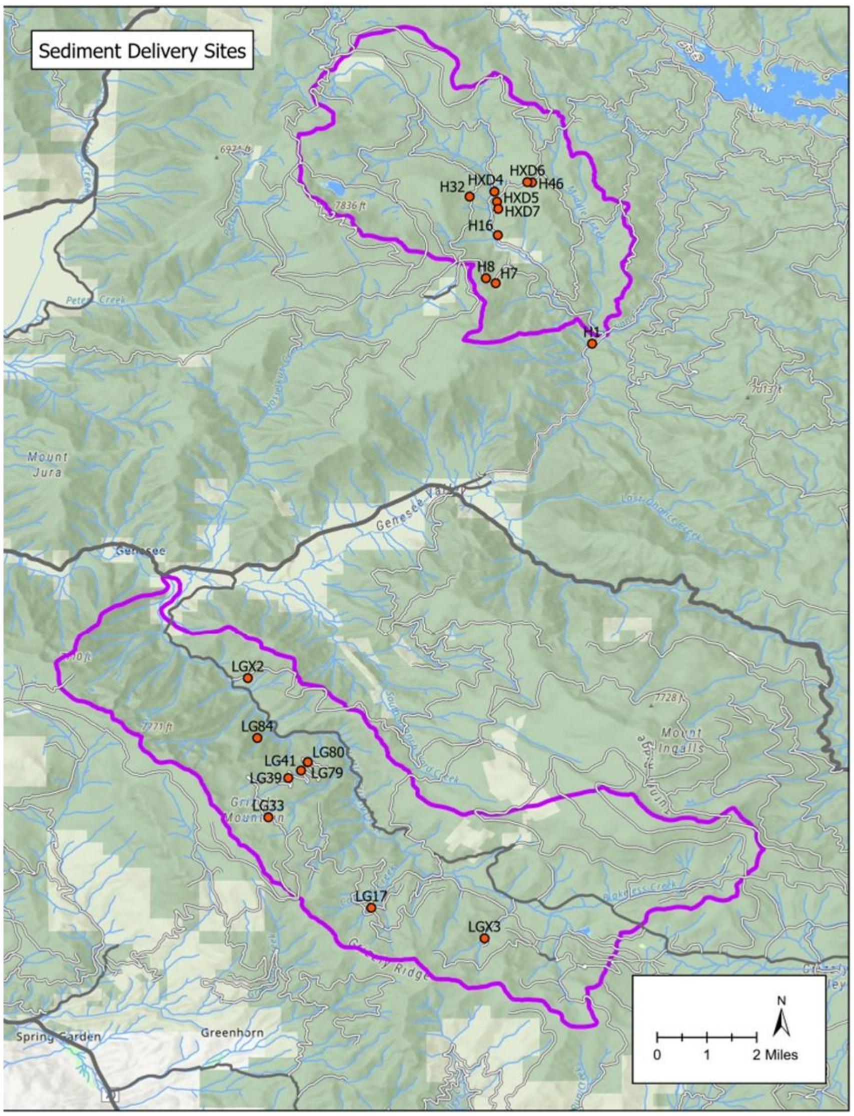

Figure 5. Location of road crossings with greatest sediment delivery, Hungry and Little Grizzly subwatershed

Crossings with Diversion Potential

Roughly a third of road crossings in both Hungry Creek and Little Grizzly Creek subwatersheds were found to have the potential to divert flow from channels should the crossings fail. These results are similar to findings in other surveyed watersheds (Roby and Rogers, 2018, Roby and Rogers, 2019). Frequency of crossings with diversion potential from these 4 subwatersheds on the Plumas and Lassen National Forests ranged from 19 to 46 percent, with an average of 31%. Lists of sites with diversion potential are presented in Tables 7 and 8. Locations of the sites are shown in Figure 6.

Site	Road	Latitude	Longitude	Site	Road	Latitude	Longitude
H1	27N09	40.10874	-120.645	H19	27N09	40.14851	-120.674
H2	27N09	40.11745	-120.65	H20	27N09	40.154	-120.673
H5	27N53	40.12007	-120.657	H28	27N45	40.13806	-120.686
H6	27N53	40.1224	-120.663	H32	27N45	40.15136	-120.68
H7	27N53	40.12627	-120.673	H42	27N06	40.15057	-120.654
H8	27N53	40.12771	-120.676	H46	27N07	40.15547	-120.662
H9	26N54	40.12313	-120.653	H47	27N07	40.14851	-120.672
H18	27N09	40.14453	-120.674	H50	27N10	40.16357	-120.713

Table 7. Location of crossings with diversion potential Hungry Creek subwatershed.

Gullies formed by diverted flows in roadways and return slopes to channels represented a high percentage (84% in Hungry, 86% in Little Grizzly) of all estimated road generated sediment. Eroded volumes ranged from 3 to 155 Cubic Yards (CY) and averaged just over 53 CY per site. Note that of the 16 crossings with diversion potential in Hungry Creek and 26 in Little Grizzly, only 5 in Hungry Creek (31%) and 9 in Little Grizzly Creek (35%) have failed and currently divert flow. Roughly two thirds of the remaining crossings with diversion potential pose a high risk of delivering large quantities of sediment to channels in the future. Examples of erosion following channel diversion are shown in Figure 7 A-B, and in Figure 3 above.

Site	Road	Latitude	Longitude	Site	Road	Latitude	Longitude
LG7	25N42	39.96219	-120.733	LG55	24N11	39.96262	-120.652
LG15	24N42	39.94879	-120.714	LG56	24N09	39.96423	-120.66
LG16	24N42	39.94683	-120.714	LG58	25N42	39.97518	-120.703
LG17	24N42	39.94496	-120.709	LG59	CR112	39.96765	-120.698
LG20	24N42	39.95311	-120.694	LG61	CR112	39.97023	-120.707
LG23	24N42	39.95449	-120.689	LG62	CR112	39.97248	-120.709
LG24	24N60B	39.94816	-120.696	LG64	CR112	39.97616	-120.711
LG33	24N08X	39.97116	-120.739	LG66	CR112	39.99288	-120.717
LG37	24N08X	39.9817	-120.743	LG74	CR112	40.02797	-120.767
LG40	24N08X	39.98309	-120.732	LG76	24N08X	39.98556	-120.723
LG41	24N08X	39.98474	-120.729	LG79	24N08X	39.98714	-120.727
LG42	24N08X	39.98494	-120.729	LG80	24N08X	39.9872	-120.727
LG46	24N42D	39.93875	-120.705	LG84	24N08X	39.99417	-120.742

Table 8. Location of crossings with diversion potential Little Grizzly Creek subwatershed.

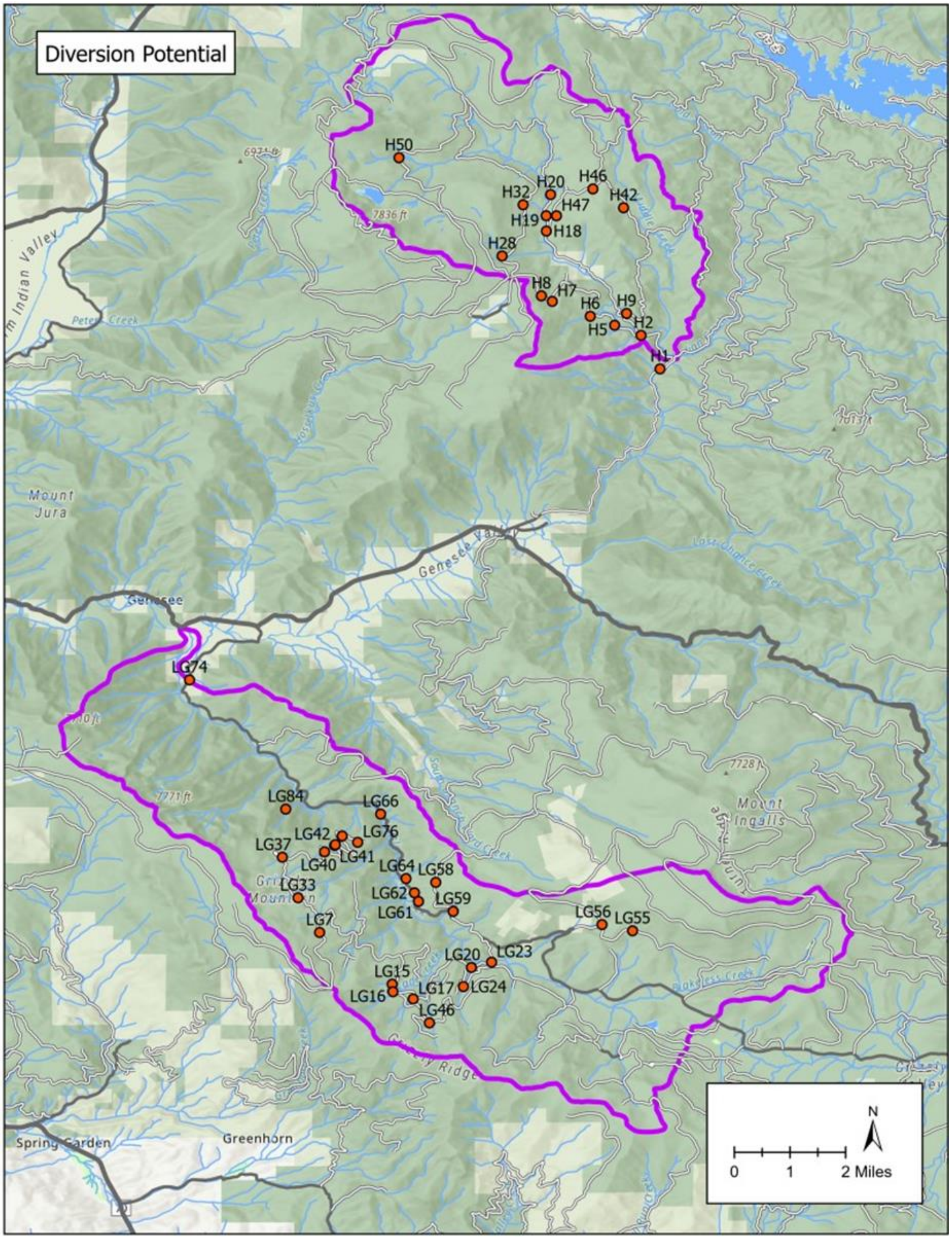

Figure 6. Location of crossings with diversion potential Hungry Creek and Little Grizzly Creek subwatersheds.

Figures 7A-B. Example of road surface erosion (7A) resulting from culvert failure and diversion of flow onto roadway. Erosion also occurs where flow leaves roadway and returns to channel, as shown in Figure 7B. Site is LG 33 on FS road 24N08X.

Rilling and Estimated Road Surface Erosion

We included both observations of rilling and modeled estimates of potential surface erosion in our assessment of surface erosion from road channel crossing approaches. Including both rilling and surface erosion modeling undoubtedly overestimates delivery at some crossings where rilling is present. We include both because several roads (including CR113, FS 27N09 and FS 25N42 had either been maintained (graded) or received enough traffic to obscure evidence of rilling. Therefore, the modeling estimates provide a way to look at all crossings using a fixed standard of comparison.

Surface erosion accounted for about 10% of sediment delivery estimates. Of the 268 crossing approaches surveyed, 51 (21%) had evidence of rilling. While an order of magnitude less than gullies from diverted channels in terms of volume of sediment delivered, surface erosion is important in that it represents a chronic source of increased sediment delivery to streams. Channel diversion results from plugged culverts, which usually occurs during a infrequent storm event. Road approaches deliver sediment to channels during every storm event large enough to result in road runoff, much more frequently than crossing failures. As such, treatment of these chronic sites is important. Examples of sites with road rilling are shown in Figures 8 and 9.

Applying rock to road surface as a way to reduce road surface erosion is a longstanding well accepted practice. Road rocking appeared to be very effective in reducing sediment delivery at crossings in the subject watersheds. Of the crossing approaches with evidence of rilling, only five were rocked this represents about 5% of the rocked approaches. In comparison, 46 (27%) of unrocked approaches exhibited rilling..

As might be expected from the Cabrera et al (2017) model described above, sites with long, steep approaches accounted for the most estimated surface erosion. As with other road erosion attributes, relatively few sites accounted for a majority of estimated road surface erosion. In Hungry Creek, 10 crossings accounted for 50% of estimated road surface erosion for the subwatershed. In Little Grizzly Creek, 9 sites accounted for over 50% of estimated road surface erosion for the subwatershed. These results and locations are listed in Table 9.

Site #	Road	Latitude	Longitude	CY	% subwshd
H39	27N56	40.19322	-120.698	1.99	14.7
H46	27N07	40.15547	-120.662	0.82	6.0
H31	27N45	40.14999	-120.68	0.75	5.5
H10	26N54	40.13689	-120.651	0.70	5.1
H11	27N09	39.93519	-120.879	0.54	4.0
H35	27N45	40.16352	-120.698	0.51	3.7
H50	27N10	40.16357	-120.713	0.51	3.7
H49	27N10	40.17432	-120.698	0.48	3.5
H41	27N06	40.14875	-120.652	0.39	2.8
H9	26N54	40.12313	-120.653	0.37	2.7

Site #	Road	Latitude	Longitude	CY	% subwshd
LG10	25N42	39.96223	-120.728	1.5	5.7
LG12	24N42	39.95871	-120.724	1.5	5.6
LG58	25N42	39.97518	-120.703	1.3	5.0
LG59	CR112	39.96765	-120.698	2.4	9.4
LG63	CR112	39.9751	-120.711	1.2	4.7
LG64	CR112	39.97616	-120.711	1.0	4.0
LG65	CR112	39.99096	-120.716	1.8	7.0
LG69	CR112	39.99872	-120.737	1.2	4.7
LG76	24N08X	39.98556	-120.723	1.9	7.4

Table 9. Location of crossings with the greatest modeled surface erosion (Hungry on left, Little Grizzly on right). % watershed values are the percentage the subwatersheds total projected surface erosion represented by each site.

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Figures 8 and 9. Examples of surface rilling from Hungry Creek Subwatershed (Site H11, Road 27N09) and Little Grizzly Creek (Site 56, Road 24N09).

Culverts

Culvert Sizing

Summary of results from analysis of culvert sizing are presented in Table 10 and Appendix B. We used USGS StreamStats regression analysis to estimate design flows of 100 years, 25 years and 2 years for the catchments upstream of each channel crossing. We also did rough analysis of culvert performance in passing bedload and debris for those return interval flows. We believe that StreamStats may overestimate flows, but because a consistent approach was used, the results are useful rating the relative capacity of the culverts in crossing surveyed.

Use of a 100 year flow for design, and allowance for passage of bedload and debris at crossings is a relatively recent design consideration. Such language is included as a road management standard and guideline in the Sierra Nevada Forest Plan Amendment:

> "To provide protection for watershed resources, the following standards should be met for new road construction reconstruction and relocation: (1) design new stream crossings and replacement stream crossings for at least the 100 year flood, including bedload and debris; (2) design stream crossings to minimize the diversion of streamflow out of the channel and down the road in the event of crossing failure; (3) design stream crossings to minimize disruption of natural hydrologic flow paths, including diversion of streamflow and interception of surface and subsurface water; (4) avoid wetlands or minimize effects to natural flow patterns in wetlands; and (5) avoid road construction in meadows."

We applied the StreamStats 100 year flow estimates to FHCA culvert sizing chart (Appendix C) to derive estimates of pipe sizes needed to pass a 100 year stormflow. We estimated culvert sizes necessary to pass both flow and bedload and debris by using a headwall depth of .67 on the FHCA chart. To summarize differences between existing and estimated culvert sizes, we divided the existing size by the "modeled" size to derive a Culvert Size Ratio (CSR), as described by Abramsom, et al (2023). By this measure, a CSR of 100% would be properly sized.

Culvert Ratio	Little Grizzly				Hungry			
	100 yr flow		100 yr Bedload & Debris		100 yr flow		100 yr Bedload & Debris	
	number	percent	number	percent	number	percent	number	percent
>.95	18	25	0	0	11	21.2	1	1.9
.75-.95	8	11.1	3	4.3	2	3.8	1	1.9
.50-.74	14	19.4	8	11.1	12	23.1	2	3.8
.25-.49	28	38.8	27	38	25	48.1	14	27
<.25	4	5.6	33	46.5	2	3.8	34	65.4

Table 10. Culvert Size Ratio assessment for Little Grizzly and Hungry Creek subwatershed culverts. CSR is the ratio of existing culvert sizes (area) against projected size needed for 100 year storm flows

As might be expected very few culverts currently pass a 100 year flow, with or without consideration of bedload and debris. In Hungry Creek, modeling estimated that roughly 20% (Table 10) of crossings would accommodate a 100 year flow and only one crossing would pass bedload and debris with that flow. In Little Grizzly Creek, about a quarter of inventoried crossing would pass the flow, none would pass bedload and debris with a 100 year flood. About half of culverts in both subwatersheds were estimated to have CSR of greater than .5 when considering 100 year flow. Far fewer culverts have culvert sizes even half as big as those projected to pass 100 year flow, bedload and debris (Little Grizzly, 15%, Hungry Creek, 8%). In Grizzly Creek, low water crossings were not assessed.

We included the 25 year return interval assuming that was likely the design standard when most of the surveyed road crossing were constructed. The 2 year interval was estimated to serve as a low bar criterion. Results were better for 25 year flood flows with 30.8% and 38.6% of culverts expected to pass the design flow in Hungry and Little Grizzly, respectively. As with the 100 year flow, few culverts would be expected to pass flow and bedload and debris with over half the culverts in both watersheds projected to handle less than 25% of the 25 year flow. Data for these analyses are in Appendix B.

Nearly all culverts are projected to pass the 2 year stormflow, but only 58% (Hungry Creek) and 64% (Little Grizzly Creek) are adequate to pass bedload and debris.

Culvert Plugging

Several culverts surveyed were completely plugged (example, Figure 10). While the composition of the material at the plug inlets was primarily fine sediment, it is likely that either bedload or bedload and debris contributed to clogging the pipe inlets. As might be expected there was a strong correlation between diverted stream flows at crossings and plugged inlets at those crossings. Tables 11 and 12 include lists of crossings with culvert inlets either plugged or with capacity reduced by greater than 50% in Hungry and Little Grizzly, respectively. Location of these culverts is shown in Figure 11.

Figure 10. Plugged culvert inlet at site H17, road 27N09

Site	Road	Size (inches)	% pluggged	Latitude	Longitude
H7*	27N53	18	100	40.12007	-120.657
H8*	27N53	18	100	40.12627	-120.673
H19	27N09	24	100	40.14851	-120.674
H20	27N09	18	100	40.154	-120.673
H32	27N45	18	100	40.15136	-120.68
H13	27N09	24	100	40.13484	-120.664
H14	27N09	18	100	40.1362	-120.666
H16	27N09	18	100	40.14018	-120.672
H17	27N09	18	100	40.14057	-120.672
H48	27N07	24	100	40.14452	-120.674
H33	27N45	18	100	40.15267	-120.68
H4	27N53	24	95	40.12002	-120.656
H11	27N09	18	90	39.93519	-120.879
H42	27N06	18	80	40.15057	-120.654
H31	27N45	18	70	40.14999	-120.68
H43	27N56	18	70	40.17392	-120.665
H40	26N54	36	65	40.14434	-120.648

*Table 11. Location of crossings with plugged culverts Hungry Creek subwatershed (*crossings with diversion potential)*

Plugged culverts generally had two things in common. They were either small diameter pipes (half were 18”, another 5 were 24”) or the culverts were on system spur roads that had not been used or maintained in several years (perhaps as long as a decade). Treatment of crossings with plugged culverts, especially those with diversion potential is a priority, as they are at high risk of diverting channel flows down and off the road way.

Site #	Road	Size (inches)	% Plugged	Latitude	Longitude
LG11	24N94Y	36	100	39.95731	-120.728
LG14	24N42	18	100	39.95145	-120.713
LG17*	24N42	18	100	39.94496	-120.709
LG43	24N42D	18	100	39.943	-120.711
LG46	24N42D	18	100	39.93875	-120.705
LG7*	25N42	18	100	39.96219	-120.733
LG79	24N08X	36	100	39.98714	-120.727
LG45	24N42D	18	97	39.93898	-120.705
LG38	24N08X	24	85	39.98091	-120.735
LG4	25N42	18	80	39.96883	-120.698
LG18	24N42	42	60	39.94493	-120.705
LG24*	24N60B	40	50	39.94816	-120.696
LG62	CR112	8	50	39.97248	-120.709

*Table 12. Location of crossings with plugged culverts Little Grizzly Creek subwatershed (*crossings with diversion potential).*

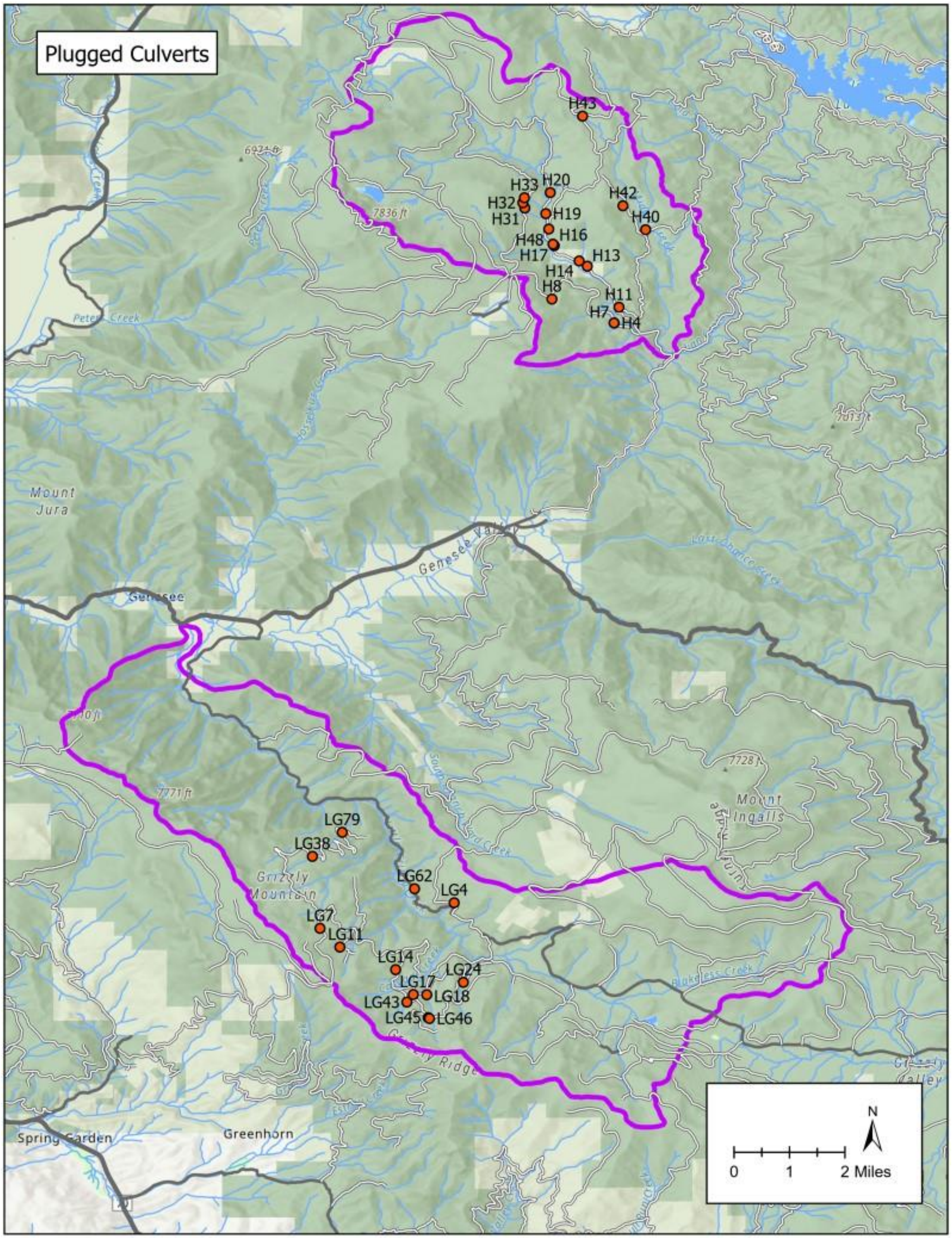


Figure 11. Location of crossings with plugged culverts Hungry Creek and Little Grizzly Creek subwatersheds.

Road Surface Connection

In addition to delivering sediment to channels as discussed above, connected road approaches also deliver flow, and in effect, increase the channel network routing flow during storms. Flow delivered by road surfaces during storms contributes to peak flows and does not infiltrate to contribute to baseflow or become available to forest vegetation. These impacts have gained appreciation in recent years. Current California Forest Practices Rules call for disconnection of forest roads. The Rules have a standard of 30-100 feet for road approaches, with a maximum approach distance of 200 feet.

Again, existing condition of roads in the two subwatersheds reflect designs that do not meet current thinking and standards. In Hungry Creek, about two thirds of surveyed crossings exceeded the 30-100 foot connected length standard, and a third exceeded the 200 ft maximum approach length (Table 13). Note that these results included cross drains as well as channel crossings. In Little Grizzly Creek, the percentage of crossings exceeding the 200 foot target was less (about a fifth of crossings) but the proportion of crossings with approaches greater than 100 feet was similar.

Approaches	Subwatershed	
	Hungry	Little Grizzly
Number (roads)	104	164
Number (cross drains)	7	6
#/w Connected Length >200'	36	33
% > 200'	32.4	19.4
#/w Connected Length >100'	39	50
% >100'	35.1	32.4
Total Connected Length (ft)	17679	21146
Total Connected Length (mi)	3.3	4

Table 13. Summary of road surface connection to stream channels, Hungry Creek and Little Grizzly Creek subwatersheds

As shown in Table 2, roads have resulted in increases in flow paths in the subject watersheds (3.4% in Hungry Creek, 1.4 % in Little Grizzly Creek). While these connected surfaces deliver sediment as discussed in the previous section, they also deliver flow during storm events and snowmelt. Hydrologic effects include increases in storm flows and corresponding reductions in flow that would otherwise infiltrate into the forest soils and reach channels later.

We did not calculate potential influences of the cumulative connected surfaces and flow paths on storm flows. Based on projections made in other nearby subwatersheds, we would not expect measurable increases in flow. In other subwatersheds, increased flow paths of 8 to 12% resulted in increases of 1% to 5% in the 2 year storm discharge. Given comparatively low increases in flow path in the subject watersheds, increases of less than 1% in the two year discharge would be expected.

LWD Channel Observations

We found it difficult to consistently identify channels that might benefit from addition of standing dead trees. In general, the vast majority of channels observed were steep (>2% channel slope), and we were certain channels were "too steep". Nevertheless, we did identify several locations (listed in Table 14, shown in Figure 12) that we feel met the criteria, and might benefit from addition of LWD. We caution that more evaluation of these sites should be conducted before treatment prescriptions are proposed.

Site #	Road	Latitude	Longitude	Site #	Road	Latitude	Longitude
H6	27N53	40.1224	-120.663	LG11	24N94Y	39.95731	-120.728
H13	27N09	40.13484	-120.664	LG12	24N42	39.95871	-120.724
H14	27N09	40.1362	-120.666	LG18	24N42	39.94493	-120.705
H20	27N09	40.154	-120.673	LG25	24N60	39.95025	-120.683
				LG27	24N60C	39.93741	-120.676
				LG30	24N57	39.93586	-120.658
				LG34	24N08X	39.97208	-120.74
				LG9	25N42	39.9636	-120.729

Table 14. Location of channels with possible LWD recruitment opportunities (Hungry on left, Little Grizzly on right).

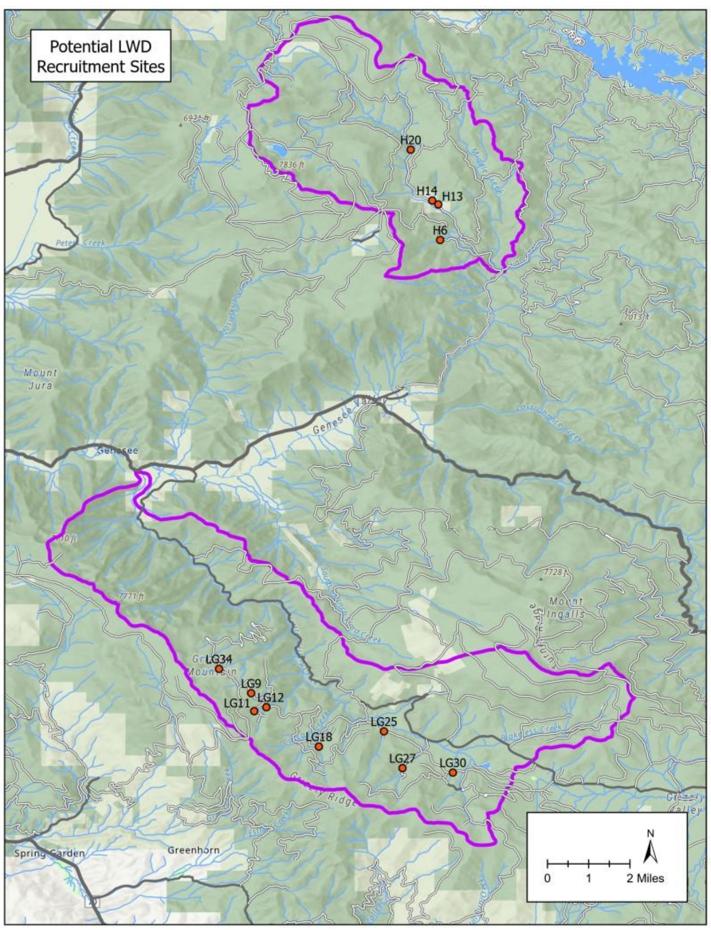


Figure 12. Location of channels with possible LWD recruitment opportunities.

Additional Observations

Impact of Dixie Fire. Hydrologic processes adversely affected by the Dixie Fire negatively impacted crossings in both sub-watersheds. In particular, runoff from precipitation events on June 9 and 10, 2023 resulted in substantial surface flow on steep slopes that had been severely burned as well as large flows in seasonally flowing channels. Over 1" of precipitation was measured on June 10 at both Kettle Rock and Quincy. Much higher amounts fell on portions of the Dixie Fire area, perhaps as much as 2-3" per hour in some locations (Kurt Sable, personal comment).

Impacts of this event were observed at sites H7 and H8. These sites were first surveyed on June 6th. Diversion potential was identified

at both sites, but culvert inlets were not obstructed. The sites were revisited on June 26th. Both culverts were completely blocked, and channel flow had been diverted down the roadway. Catchments upstream of both crossings were severely burned.

We suspect that the same storm event adversely affected stream road crossings east of H7 and H8, on the other side of Hungry Creek. Numerous culverts on road 27N09 were downstream of severely burned catchments. Hillslopes at these sites showed signs of extensive overland flow and surface erosion. We note also that PNF invested in storm proofing of road 27N09 following the Walker Fire in 2019. 27N09 is the primary throughfare in the Hungry Creek drainage. Though numerous culverts were plugged, no failed crossings resulted. The treatments reduced overall road damage, provided safe public passage and reduced impacts to Hungry Creek.

In addition to channel conditions, we observed many areas where steep, severely burned slopes had substantial rilling, gullying and surface movement. In several cases, flows from these slopes reached roadways and contributed to problems at road crossings and ditches. We believe that dropping fire killed trees at such slopes would reduce surface erosion.

Metal End Sections (MES) and other inlet structures. The overwhelming majority of culverts in the two subwatersheds had no inlet improvements and consisted of projecting pipes. Three headwalls and three MES were observed. None had failed, and none were partially blocked.

Low Water Crossings. Relatively few (10) low water crossings were encountered during the surveys. Typically, these crossings had far fewer sediment and flow delivery issues than the culverted crossings. Obviously, none had failed or plugged culverts. None had diverted channels, and nearly all had approaches that meet the Forest Practice Rules standards.

Effectiveness of Critical Dips . Also called diversion potential dips. We previously noted that storm proofing of crossings on FS Road 27N09 served to prevent channel diversions. FRTU conducted one additional road survey project this year, in the Upper Mill Creek subwatershed in Lassen National Forest. This subwatershed supports anadromous fish runs in Mill Creek and was the site of road storm proofing work about 10-15 years ago. This work included construction of critical dips. Of the 68 crossings surveyed, none had diversion potential.

Improvement Recommendations

Results of the surveys show that most of the sediment delivery from roads comes from a relatively few number of sites. We recommend that treatments be applied to reduce sediment delivery from these high delivery sites. Many of the sites are located on relatively low standard roads, where construction of additional dips (or waterbars) would reduce flow paths.

Treatment of the highest priority sites would serve the dual purpose of reducing channel extension (flow) and sediment delivery. The sites with the greatest length and sediment delivery also deliver the most flow due to their relatively large contributing surface areas.

Most of our recommendations amount to applying storm proofing treatments to project area roads at crossings at high risk of delivering substantial sediment to channels. Additionally we recommend more specific treatments of road 24N08X, and point out the need to develop an approach to determine which culverts should be upgraded.

Storm Proofing Elements (listed in priority order)

1. Plugged Culverts- Clean all plugged culverts to reduce occurrence of overtopping and channel diversion.

2. Diversion Potential- Treat all crossings with diversion potential by constructing critical dips.

3. Channel Connection- Disconnection of road approaches longer than 200 feet. Where practical reduce connection length to less than 100 feet.

4. Metal End Sections- When installing new culverts, include metal end sections where feasible. Also include consideration of MES in upgrade of existing crossings to improve flow capacity and better pass bedload and LWD.

5. Aggregate. Rocked approaches produced substantially less sediment then unrocked approaches. Consider aggregate in treating sites with rilling and high surface sediment delivery.

Low Water Crossings. Low water crossings encountered in the surveys demonstrated few problems, and avoided the significant issues encountered at culverted crossings. Many culverts in the project area were plugged and analysis found nearly all to be undersized. Given declining maintenance budgets and staffing, they are also attractive in that they require less maintenance. They should be considered in the crossing upgrade work.

Road 24N08X. This spur road is the site of several of the worst sediment producers encountered in the road surveys. The road has not been maintained, and is overgrown to the point where it is impassible by passenger vehicles. We recommend either decommissioning this road, or closing it after pulling culverts and constructing waterbars to prevent delivery or flow and sediment from road surfaces. We note also that roads 24N60B, 24N60C and 15N42D are unmaintained spurs with plugged culverts. Though problems on these roads are not as severe as those on 24N08X, they also need attention.

Upgrade High Priority Crossings. Very few of culverted crossings meet current standards for passage of flow, bedload and debris. Upgrade of all crossings is impractical, due to cost. This set of conditions calls for a strategic approach to crossing upgrade. Project roads that will need maintenance to provide access for project activities should receive priority. While this approach makes sense logistically, it will undoubtedly “miss” crossings that are high priority for other reasons (importance of the water body, AOP, risk of failure, etc.) so we recommend a mixed approach that includes both crossings on roads that will be maintained to provide access, and crossings that are high priority for other reasons. To facilitate this approach, a process to identify and rate crossings for upgrade is needed.

Once identified, culverts should be replaced with low water crossings whenever practicable.

References Cited

Abramson, N., Pritchard, V. and H. Reineking. 2023. West Lassen Watershed Infrastructure Assessment. Sierra Institute for Community and Environment. Taylorsville, CA. 49 p.

Cabrera, N., Cissel, R., Black, T and C Luce. 2015. Moonlight Fire GRAIP Watershed Roads Assessment Lights Creek and Indian Creek, Plumas National Forest, California. U.S. Forest Service Rocky Mountain Research Station. 85pg.

Cafferata, P., Lindsay, D., Spittler, T., Wopat, M, and G Bundros (2017) Designing Watercourse Crossings for Passage of 100-Year Flood Flows, Wood, and Sediment. State of California California Natural Resources Agency Department of Forestry and Fire Protection California Forestry Report No. 1. 126 p.

Furniss, M. J., Love, M. and Flanagan, S. A. 1997. Diversion potential at road-stream crossings, USDA Forest Service Technology & Development Program, USA, 12 p

FHWA (Federal Highway Administration). (2010). Culvert Design for Aquatic Organism Passage, Publication No. FHWA-HIF-11-008, U.S. Department of Transportation, Federal Highway Administration, Office of Infrastructure Research and Development, McLean, VA, 234 p

Gucinski H, Furniss MJ, Ziemer RR, and Brookes MH. 2001. Forest roads: a synthesis of scientific information. General Technical Report PNW-GTR-509. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. www.fs.fed.us/eng/road_mgt/science.pdf.

Plumas NF (2018). Calculation of Road Density. Ralph Martinez, GIS Coordinator.

Rogers, V., Roby, K., & Kossow, M. (2018). *Upper Feather River Basin Fisheries Assessment and Restoration Strategy*. Feather River Chapter, Trout Unlimited, Graeagle, CA.

Roby, K., & Rogers, V. (2018). Watershed Improvement Report Bear Creek and Meadow Valley Creek Subwatersheds: Plumas National Forest. Sierra Institute for Community and Environment. 52 p.

Roby, K., & Rogers, V. (2019). Watershed Improvement Report Upper Yellow Creek and Butt Valley Subwatersheds. Sierra Institute for Community and Environment. 30 p.

Sable, Kurt. Watershed Program Manager, Plumas National Forest. Personal comment. 2023.

USDA. 1998. National Forest Road System and Use. Forest Service. W.O. Engineering Staff. 31 p.

USDA Forest Service. 2004. Sierra Nevada Forest Plan Amendment Final Supplemental Environmental Impact Statement Record of Decision. 71 p.

USDA. Forest Service (2014). National Best Management Practices. National Core Best Management Practices. Forest Service Handbook -2509.19, Chapter 10. 19 p.

U.S. Geological Survey. (2019). The StreamStats program, online at https://streamstats.usgs.gov/ss/

Appendix A

PNF Crossing Rating

Category	Criteria	Score	Site Number
Channel	Seasonally Flowing	2	
	Perennial	3	
Diversion Potential	No Diversion Potential	0	
	Critical Dip Present but needs improvement	3	
	Critical Dip Present needed	7	
Surface Connectivity (length)	<30'	0	
	30-100'	3	
	> 100 '	5	
	>300'	8	
Sediment Delivery	very little	0	
	minor evidence of rilling or surface erosion (usually short connected length)	5	
	some rilling or surface erosion evident (usually moderate connected length)	6	
	substantial rillig or surface erosion evident (usually long connected length)	7	
CMP Issues	CMP not plugged, no issues	0	
	Low: i.e. culvert not set at or close to natural grade. Culvert not oriented parallel to flow direction. Culvert is less than 25% plugged	3	
	Moderate: i.e. signs of excessive corrosion (or separation). Culvert inlet blocked by sediment or debris, or damaged reducing flow capacity. Culvert is 25%-50% plugged. Outlets not armored or without energy dissipators.	5	
	High: i.e. Insufficient culvert size. Culvert is greater than 50% plugged. Evidence of culvert overtopping on erodible fill or road surface. Can included things from the moderate rating. Culvert outlet erosion that extends downslope of the outlet	8	
Low Water Crossing Issues	No issues found	0	
	Low: i.e. Unarmoured stream crossing	2	
	Moderate: i.e. Stream channel/banks need better defintion to prevent stream disconnect in the future. May include armoured crossing. Outlet not armoured or without energy dissipators	4	
	High: i.e. Stream is disconnected and runs down the inside ditch or road. Or substantial cutting in our downstream of the structure.	8	

Total Score (Check Applicable Rating)

Appendix B

CMP Scenario (return interval, flow, flow and bedload, inlet condition)	Portion of Design Flow Passed (number and percent of CMP)									
	100		75		50		25		<25	
	#	%	#	%	#	%	#	%	#	%
100 yr open	5	9.6	5	9.6	10	19.2	22	42.3	10	19.2
100 yr current	5	9.6	5	9.6	7	13.5	9	17.3	27	51.9
100 yr BD open	1	1.9	0	0.0	2	3.8	14	26.9	35	67.3
100 yr BD current	1	1.9	0	0.0	2	3.8	7	13.5	42	80.8
25 yr open	16	30.8	6	11.5	16	30.8	9	17.3	5	9.6
25 yr current	14	26.9	3	5.8	7	13.5	8	15.4	20	38.5
25 yr BD open	3	5.8	3	5.8	9	17.3	19	36.5	18	34.6
25 yr BD current	3	5.8	2	3.8	7	13.5	9	17.3	31	59.6
2 yr open	51	98.1	0	0.0	0	0.0	0	0.0	1	1.9
2 yr current	38	73.1	1	1.9	0	0.0	1	1.9	12	23.1
2 yr BD open	46	88.5	2	3.8	2	3.8	1	1.9	1	1.9
2 yr BD current	30	57.7	3	5.8	4	7.7	1	1.9	14	26.9

App B1. Results of culvert sizing evaluation for culverted crossings in Hungry Creek subwatershed. First entry in table (5 in 100 yr. open) indicates that 5 crossings passed 100% of the 100 yr. design flow. An additional 5 crossings passed at least 75% of the estimated flow. "Open" assumes pipe diameter with no obstructions; "current" reflects reduction in pipe inlet area due to observed obstructions or damage; BD reflects passage of bedload and debris in addition to design flow.

CMP Scenario (return interval, flow, flow and bedload, inlet condition)	Portion of Design Flow Passed (number and percent of CMP)									
	100		75		50		25		<25	
	#	%	#	%	#	%	#	%	#	%
100 yr open	10	14.3	4	5.7	15	21.4	17	24.3	24	34.3
100 yr current	10	14.3	4	5.7	12	17.1	13	18.6	31	44.3
100 yr BD open	0	0.0	2	2.9	5	7.1	12	17.1	51	72.9
100 yr BD current	0	0.0	2	2.9	3	4.3	13	18.6	52	74.3
25 yr open	27	38.6	12	17.1	3	4.3	21	30.0	7	10.0
25 yr current	25	35.7	7	10.0	5	7.1	17	24.3	16	22.9
25 yr BD open	5	7.1	4	5.7	9	12.9	22	31.4	30	42.9
25 yr BD current	4	5.7	3	4.3	8	11.4	18	25.7	37	52.9
2 yr open	66	94.3	1	1.4	1	1.4	0	0.0	2	2.9
2 yr current	55	78.6	2	2.9	1	1.4	2	2.9	10	14.3
2 yr BD open	54	77.1	6	8.6	5	7.1	2	2.9	3	4.3
2 yr BD current	45	64.3	4	5.7	4	5.7	4	5.7	13	18.6

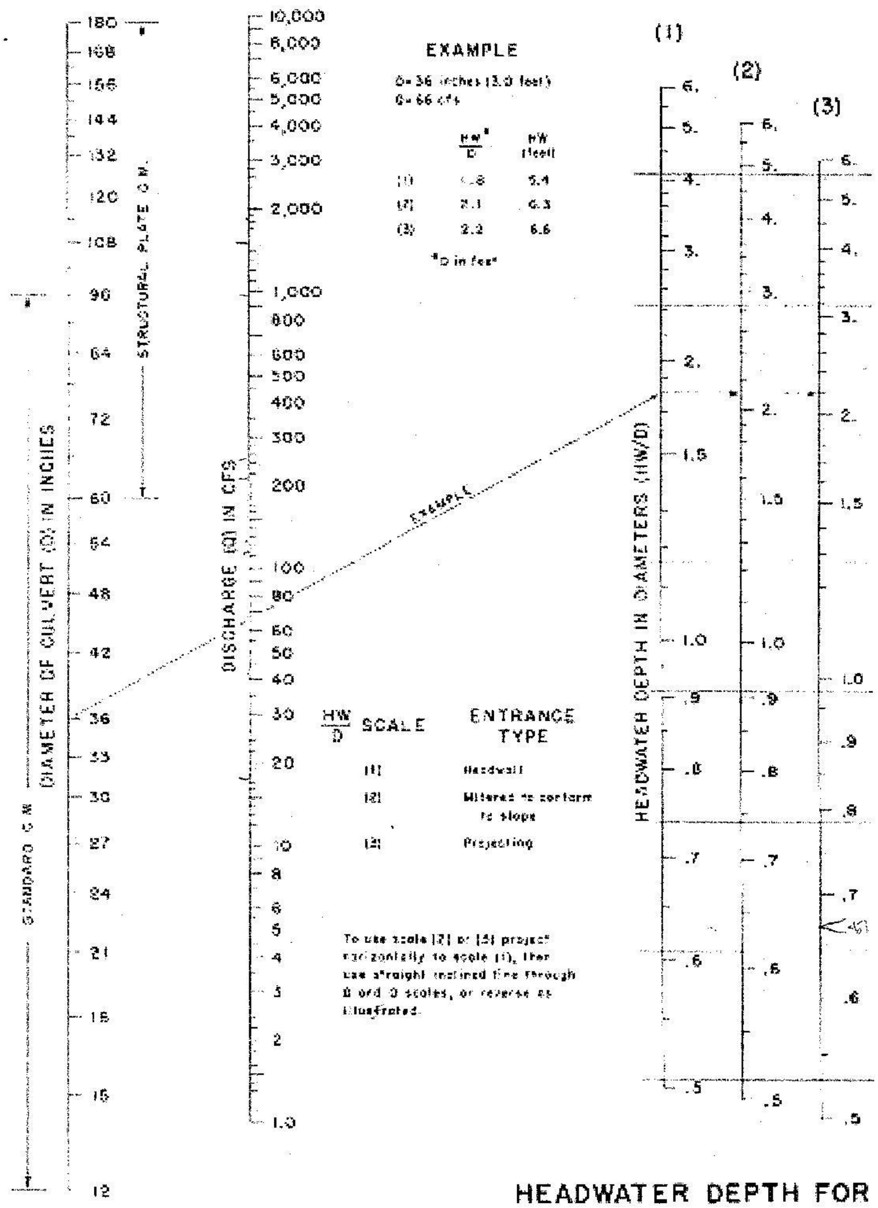
Table App B2. Results of culvert sizing evaluation for culverted crossings in Little Grizzly Creek subwatershed. First entry in table (10 in 100 yr. open) indicates that 5 crossings passed 100% of the 100 yr. design flow. An additional 4 crossings passed at least 75% of the estimated flow. "Open" assumes pipe diameter with no obstructions; "current" reflects reduction in pipe inlet area due to observed obstructions or damage; BD reflects passage of bedload and debris in addition to design flow.

Appendix C

Go Back to Part II

Go to Chart 6

CHART 5



HEADWATER DEPTH FOR
C. M. PIPE CULVERTS
WITH INLET CONTROL

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