Prairie Road Sediment Impact Report

South Fork Boise River Basin, Pierce Creek Watershed

Boise National Forest

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Introduction

Pierce Creek Watershed (Figure 1) is underlain by altered Idaho Batholith granitoids, which is capped by basalt flows about 50 ft thick and overlain by Quaternary stream and river terrace deposits, as well as lake deposits. Prairie Road is wide (8-10 m) and native surfaced, with an open un-vegetated ditch. The road is hardened and insloped in many places, directing water into the softer ditch, which is drained primarily by ditch relief culverts onto steep and erodible hillslopes. The average length of ditch between drainage features is 200 m, and the average slope below all of the drain points is 50%, averaged over 91 m of downhill slope length. The steep slopes and loose soils result in large gullies with the addition of road drainage in many places, which, coupled with the large amount of road surface generated sediment, bring an excessive amount of sediment into the Pierce Creek channel.

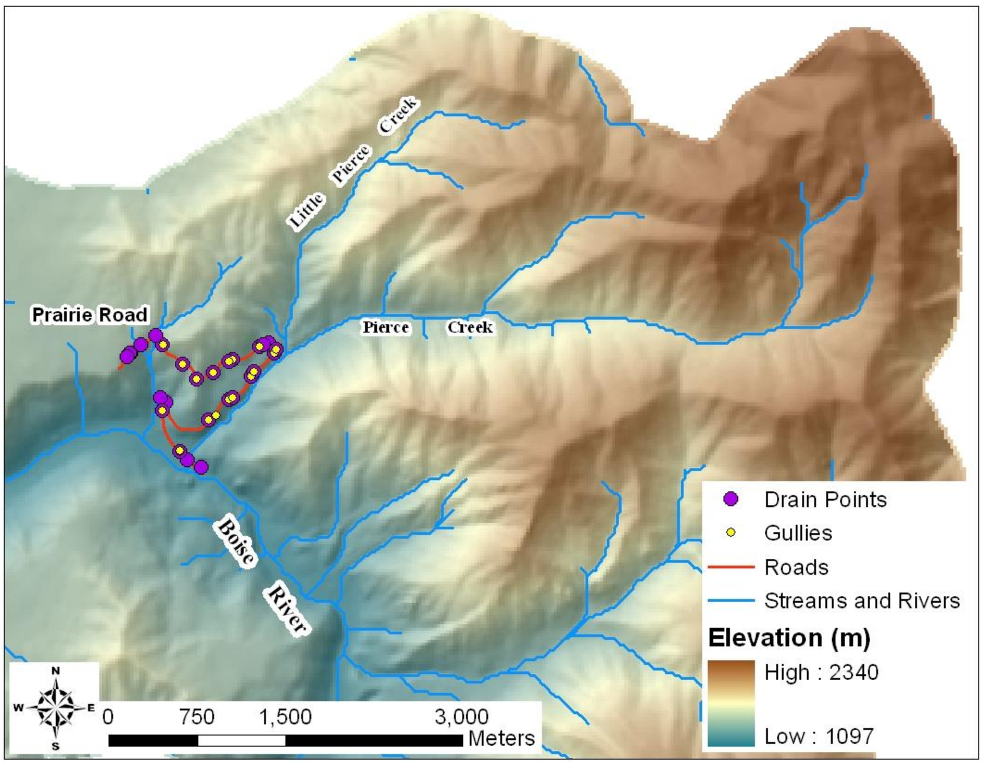

Figure 1. Location of inventoried section of Prairie Road in the Pierce Creek watershed.

Results

Road-Stream Hydrologic Connectivity

GRAIP calculates the hydrologically-connected portion of the road using the field assessment of drain point connection and a road segment flow routing system. The flow path below each drain point is followed until evidence of overland flow ceases or the flow path reaches a natural channel. In the Pierce Creek/Prairie Road watershed, 4024 m of road were surveyed. Of that, 3022 m, or 75%, of the road length was hydrologically connected to the channel. About 2000 m of the connected length is hydrologically connected by gullies.

Fine Sediment Production & Delivery

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

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

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

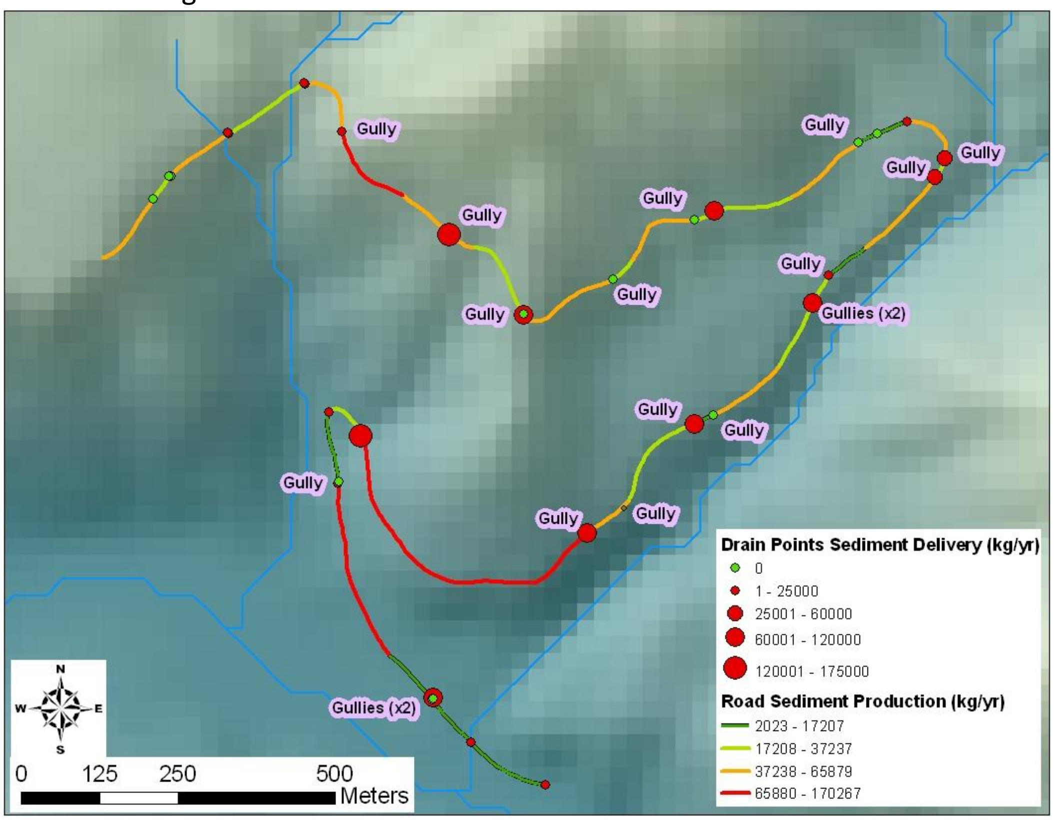

Figure 2. Fine sediment delivery to channels by road segment and drain point. The road line is colored to indicate the mass of sediment that is generated on the road surface (kg/yr). The size of the circle indicates the accumulated mass of sediment delivered to the channel through each drain point (kg/yr). The "Gully" label indicates that the labeled drain point drains into a gully.

[1] For this analysis, a base erosion rate of 790 kg/m of road length was assumed, based on numbers derived from the BOISED model (Reinig et al. 1991, Megahan and Ketcheson, 1996) for the Middle Fork Payette River watershed GRAIP study. Further work could determine if this rate is appropriate for this climate, geology and road system.

Delivery of eroded sediment to the channel network is determined by observations of each place that water leaves the road. Each of these drain points is classified as delivering, or not delivering. No estimate of fractional delivery is made, although some sediment storage was observed on the toe slopes. A map of the road surface sediment production and the accumulated sediment delivered through drain points is shown in Figure 2.

Delivery of fine sediment occurs through a mix of road drainage features including ditch relief culverts, non-engineered drain points, lead off ditches, and others. In Table 1, sediment delivery is broken out by drain type to assess their effectiveness in preventing sediment from entering the channel. However, the sample shown here is too small for extensive statistical analysis by drain point. Thirty-five drain points were documented, 66% of which were hydrologically connected to stream channels. These points delivered 1132 tonnes/year of sediment, or 75% of the sediment generated by the road surfaces and ditches.

The most common drain point types were ditch relief culverts, which delivered 992 tonnes/year (88% of all delivered sediment), and non-engineered drain points, which delivered 83 tonnes/year (7%). The ditch relief culverts drained 3202 m of road length, which is 80% of the total length, and the non-engineered points drained 439 m, or 11%.

Table 1. Summary of sediment production and delivery by drain points.

	Count	∑ Sediment Production (kg/yr)	∑ Sediment Delivery (kg/yr)	% Sediment Delivery	Length Connected (m)	% Length Connected
Broad Based Dip	3	44548	4887	11%	42	28%
Ditch Relief Culvert	15	1245823	991990	80%	2616	82%
Lead Off Ditch	4	36510	34742	95%	116	87%
Non-Engineered	10	157765	82920	53%	181	41%
Stream Crossing	2	17408	17408	100%	67	100%
Sump	1	6402	0	0%	0	0%
Totals:	**35**	**1508455**	**1131947**	**75%**	**3022**	**75%**

Existing Gullies

Gullying at drain points is a substantial source of sediment to the local stream channels. There were 19 recorded gullies, all road-related. 18 of those gullies were below actively draining features, and 14 gullies were observed to connect to the stream channels (including the gully that was not below an actively draining drain point). Estimations of lost sediment volume for all observed gullies were made (Figure 3). The estimated volume for all gullies was 33086 yd^3. The estimated volume for all delivering gullies was 32916 yd^3. Assuming an average soil density in Idaho granitic soils of 1.28 tonnes/m^3 (Froehlich et al. 1985), this is roughly equivalent to 30,000 tonnes. Averaged over 60 years, this is about 500 tonnes/year.

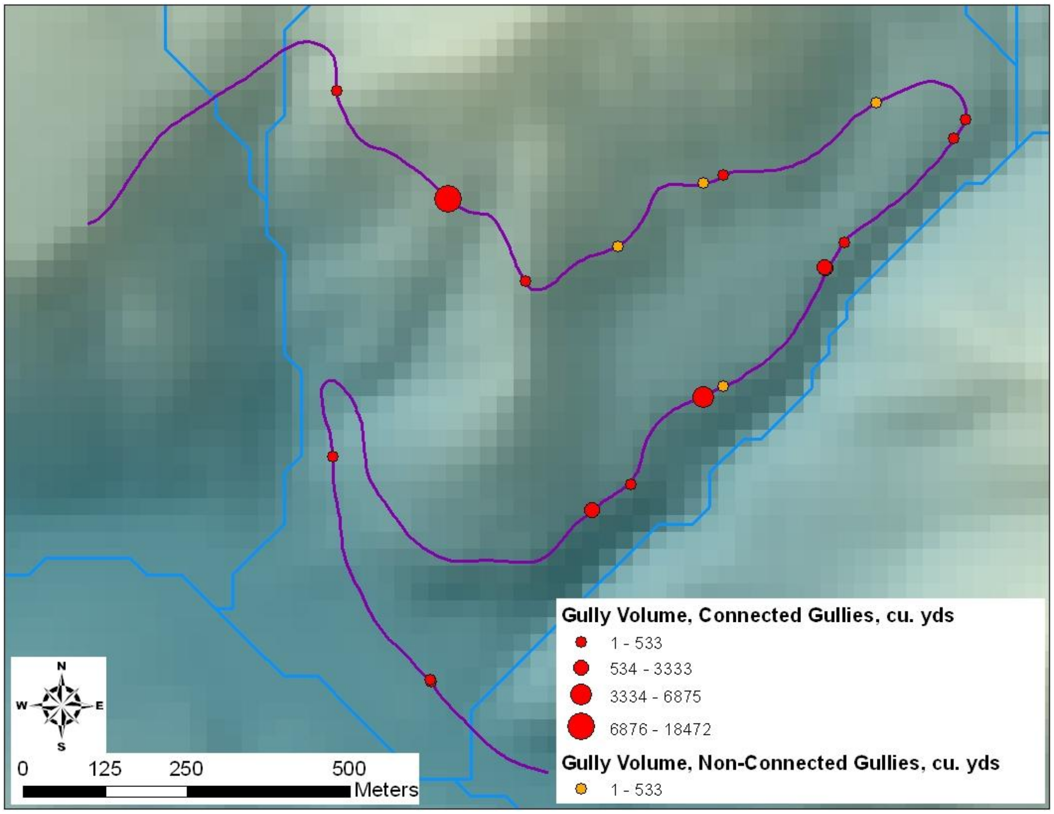

Figure 3. Location and volume for all gullies observed on Prairie Road. The size of the circle indicates the volume of the gully, and the color indicates its connection to the stream channel.

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.

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

L is the road length contributing to the drain point

S is the average slope of the hillslope below the drain point

In this location, it was found that, of the 11 gullies that initiated within 150 m of the stream channel, the mean initiation distance was 82 m. The DEM used had a resolution of 30 m x 30 m. So, in order to include at least three DEM grid cells in the average slope calculation, an averaging distance of 91 m was chosen. This reduced the error associated with slope averaging over too long a distance that arises if the shallower slopes from the valley bottom are included, while still providing a long enough distance for an accurate average to be obtained.

Calculated ESI values for each drain point were compared to a critical ESI threshold (ESI_{crit}) to identify areas with a high risk of gully formation (i.e., where ESI > ESI_{crit}). ESI_{crit} is empirically-derived using inventoried gullies, and is defined as the ESI value above which the risk of gullying increases significantly. Here, ESI_{crit} = 5.5, as the risk of gully initiation increases by a factor of 4.5 above that value (Table 2).

Table 2. ESI values for all drain points. ESI_{crit} = 5.5, as gully frequency increases significantly above that value.

ESI Value	< 0.5	0.5 – 5.5	5.5 - 30	> 30
# sites with gullies	2	1	7	7
# sites without gullies	6	2	5	4
% Gullied	12%	6%	41%	41%

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

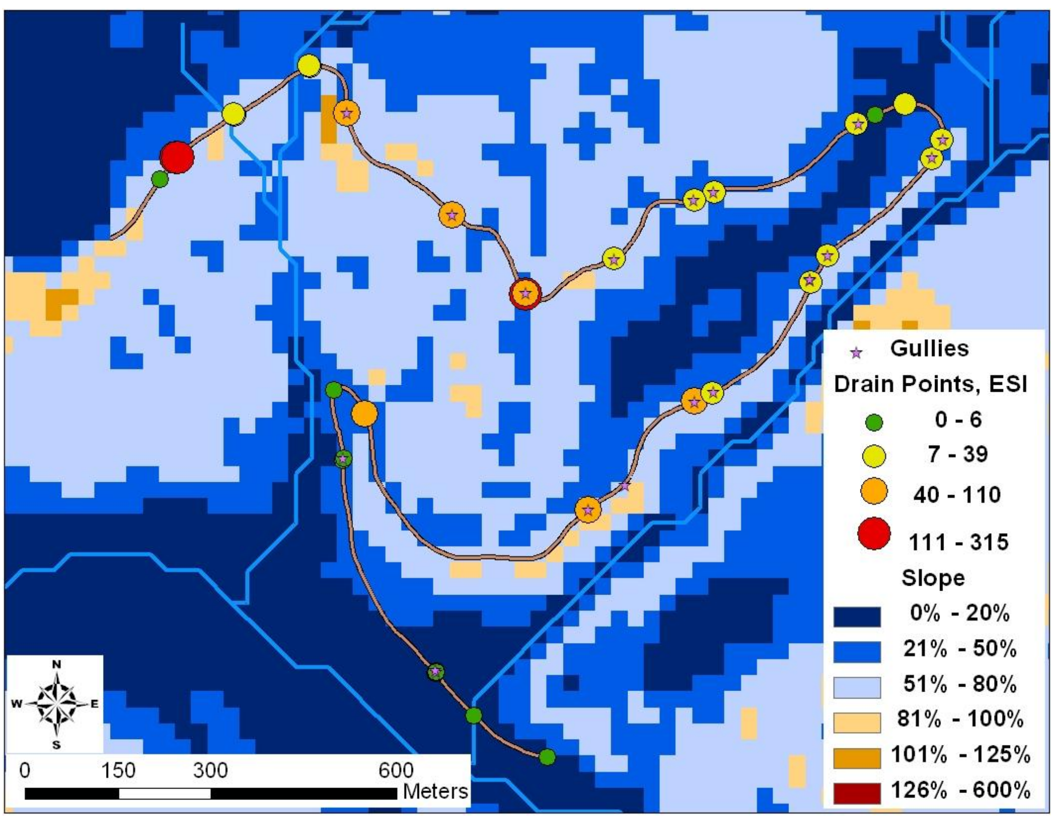

Figure 4. ESI values at drain points and gully locations. The slope map in the background indicates the component of gully risk due to hillslope gradient.

The average ESI was 39, with an average contributing road length of 128 m. 71% (22 of 35) of the points fell into this high risk group (Figure 4). These drain points drained 3143 m of road length, or about 78% of the total road length. Of the 22 drain points that had an ESI in excess of the ESI_{crit}, 14 already had gullies. This leaves 8 drain points that do not currently have a gully at risk of gullying. There were 3 gullies that occurred at drain points with an ESI below the ESI_{crit}, indicating that there is still a risk of gullying for almost all active drain points. Table 3 breaks out the average ESI by drain point.

Table 3. Average ESI values by drain point.

	Count	Average ESI
Broad Based Dip	3	41
Ditch Relief Culvert	15	58
Lead Off Ditch	4	4
Non-Engineered	10	18
Stream Crossing	2	7
Sump	1	0

Summary

Prairie Road was 75% connected to stream channels (3022 m connected), and 75% of the sediment generated on the road surface and in the ditch was delivered to the channel (1132 tonnes/year was delivered). 71% of the drainage points exceeded an empirically derived gully initiation threshold, and 14 of those points that were in excess already had observed gullies. Existing gullies had a volume of about 33086 yd^3, which is about 30,000 tonnes or 500 tonnes/year over 60 years.

Table 4. Summary of GRAIP road risk predictions for Prairie Road.

Impact/Risk Type	Effect of Road
Road-Stream Hydrologic Connectivity	75%, 3022 m
Fine Sediment Delivery	75%, 1132 tonnes/year
Gully Risk	
- ESI > ESI_{crit} (Points in excess of gully initiation threshold)	71%, 22 drain points, 14 of those drain points already have a gully
- Gully Volume	33086 yd^3, about 500 tonnes/year

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