ASSESSMENT OF SEDIMENT DELIVERY FROM THE RUBICON JEEP TRAIL

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1.0. INTRODUCTION

The following assessment is to determine the magnitude of water quality impacts from off-highway vehicles (OHVs) on the Rubicon Jeep Trail (RJT). The assessment was prompted by stakeholder complaints and by field observations from Regional Board employees. Stakeholder complaints included a wide variety of concerns, including water quality impacts from excessive sediment, human waste, and from petroleum leaks/spills. Field observations confirmed that the RJT is a source of water quality impacts to waters of the state. However, the magnitude of the water quality impacts is generally unknown. The focus of this assessment is on erosional impacts from the RJT, as the relative magnitude of these impacts can be assessed through rapid assessment. Hence, the objectives of this assessment are to:

1. Document the relative magnitude of sediment production from portions of the Rubicon Jeep Trail;
2. Document the relative magnitude of sediment delivery from portions of the Rubicon Jeep Trail that are hydrologically connected to stream channels; and
3. Determine the relative impacts of trail derived sediments on the beneficial uses of water.

1.1. Background

A growing body of literature suggests that OHV trails are significant sources of chronic erosion (MacDonald et al., 2004; Foltz, 2006; Welsh et al., 2008). OHV trails exhibit similar erosion processes to unpaved roads. Unpaved roads have been shown to increase turbidity and suspended sediment concentrations, alter channel substrate and morphology, and adversely affect water quality (Cedarholm et al., 1981; Bilby et al., 1989; Waters, 1995). While the magnitude of trail-induced surface erosion is often much less than that of episodic erosion processes (i.e., mass wasting), aquatic ecosystems are typically not adapted to chronic low magnitude disturbance (Yount and Niemi, 1990).

Sediment delivery from OHV trails is inextricably tied to trail related runoff generation and redistribution processes (Luce, 2002). The hydrological impacts of OHV trails include: 1) a highly compacted trail surface, which results in a preponderance of Horton overland flow; 2) the interception of subsurface runoff by trail cutbanks; 3) the interception of surface flow at unimproved stream crossings; and 4) the lateral redistribution and concentration of this runoff by trail surfaces. These hydrologic process alterations increase the erosive force applied to the trail surface and increase the sediment transport capacity of trail runoff. Furthermore, the redistribution and concentration of runoff increases the likelihood that the trail network becomes integrated with the channel network – a term referred to as "hydrologic connectivity". The hydrologic connectivity of trail networks ultimately controls the magnitude of sediment delivery to the channel network (MacDonald and Coe, 2007), so assessing hydrologically connected OHV trail segments is critical in assessing erosional impacts from the RJT.

Vehicular traffic enhances sediment production by generating surface material that is easily transported by overland flow events (Luce and Black, 2001; Ziegler et al., 2001). Increases in trail surface erodibility can be attributed to soil detachment by tire traffic, in addition to crushing and churning forces that alter the trail surface's aggregate size distribution (Ziegler et al. 2001). Research suggests that interrill erodibility[1] (K_i) on OHV trail surfaces can be 9 times higher than the K_i from road surfaces (Foltz, 2006).

Erosion on an OHV trail can be described by the following equation (Megahan, 1974):

$$E_t = E_b + E_s \quad (1)$$

Where E_t represent the total erosion rate on an OHV trail, E_b is the baseline erosion rate of the trail surface in the absence of OHV traffic, and E_s is the accelerated erosion due to OHV traffic (Figure 1). E_b is related to the erodibility of the trail surface, trail gradient, and the force applied to the trail surface by rainfall, overland flow, etc. E_b can be relatively small when the trail surface is consolidated and/or armored because the trail surface can be resistant to the erosive forces of rainsplash, sheetwash, or rill erosion. However, E_b can be a substantial portion of total erosion when gullying, rutting, or extreme precipitation events occur (Ziegler et al., 2001) (Figure 1). E_s is a function of the amount of surface material generated by OHV traffic and can be approximated by gravimetric or volumetric estimates of the loose sediment on the trail surface (i.e., the "dust layer" method) (Ziegler, et al. 2001) (Figure 2). Estimating the volume of the dust layer can be accomplished by measuring the depth of dust (d) on the trail surface and applying it to the surface area (A) of hydrologically connected trail segments. This will provide a minimum estimate of E_t, and therefore a relative estimate of sediment delivery to the channel network.

2.0. METHODS

Sediment production was estimated for a portion of hydrologically connected RJT segments. Trail segments were determined to be hydrologically connected when: 1) Trail segments discharged runoff and sediment directly into a stream at a trail-stream crossing; 2) Runoff and sediment from trail segments traveled diffusely across hillslopes and subsequently delivered to the stream channel; 3) Runoff and sediment from trail segments was discharged into gullies that were connected to the channel network; 4) Runoff and sediment from trail segments was discharged into unchanneled swales that were visibly connected to the channel network; and 5) Low order stream channels were intercepted onto the trail and subsequently rerouted back into the channel network.

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[1] A soil's susceptibility to detachment and transport from rainsplash and sheetwash erosion.

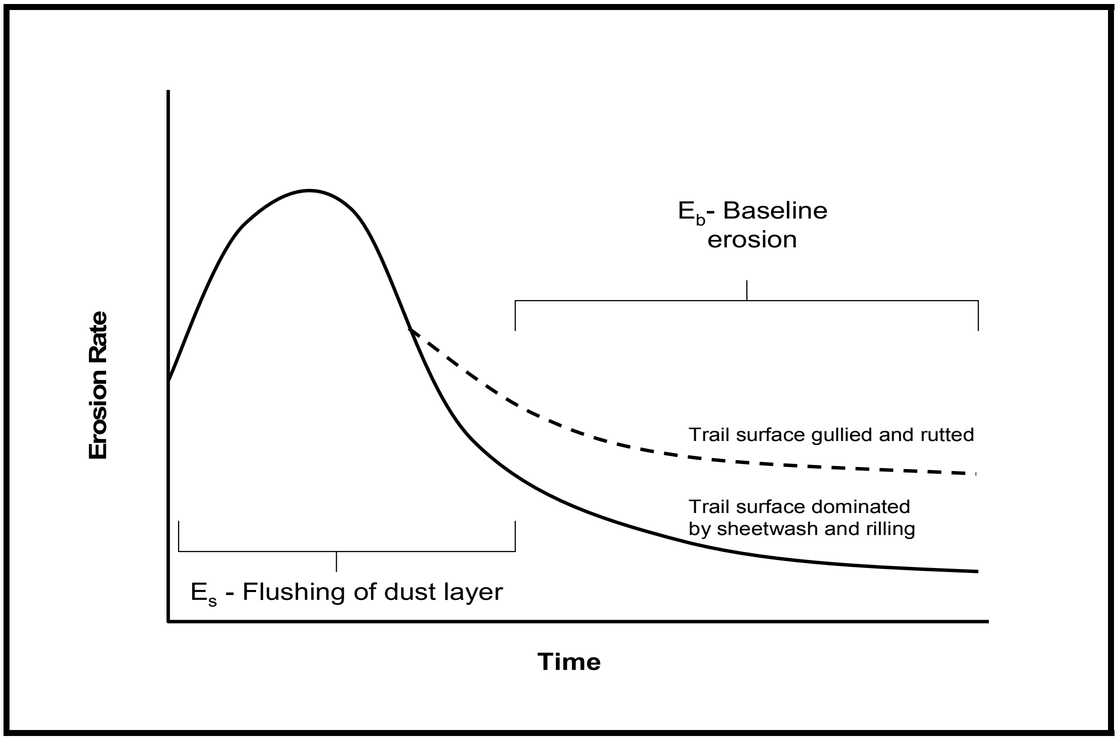

Figure 1. A conceptualized schematic of erosional response by an OHV trail over time. Erosion increases quickly as the easily erodible dust layer is flushed from the trail surface. As the supply of dust is exhausted, the erosion rate decays to a baseline erosion rate. The baseline erosion rate can be relatively low for trail surfaces dominated by diffuse erosion processes, or can be relatively high for trail surfaces subjected to gullying, rutting, or extreme storm events.

Volumetric sediment production (E_t) in cubic yards per year (yd^3yr^{-1}) was estimated for portions of the RJT that are currently delivering sediment to the channel network. For purposes of this study we assume that E_b is equal to zero and that E_t is equal to E_s. E_s is estimated by the following relationship:

$$E_s = dA \tag{3}$$

where d is the average or median dust depth and A is the area of trail segment hydrologically connected to a channel.

To measure the trail segment area and dust depth, the length (L) of the hydrologically connected road segment was first measured. Ten orthogonal transects were selected for each 100 linear feet of trail by multiplying the trail length by a randomly generated number (i.e., 0<random number<1.0). At each orthogonal transect, the trail width (W) was measured. Trail segment area was calculated by the following equation.

$$A = \left(\frac{\sum W_i}{n} \right) L \qquad (4)$$

Along each orthogonal transect a point was randomly chosen to measure the depth of the dust layer to the nearest 1/100th of a foot. Histograms of dust depths for each trail segment were generated to determine if dust depths were normally distributed. If dust depths were not normally distributed, the median value was used in equation 3.

Sediment delivery was estimated for each hydrologically connected trail segment. Annual sediment delivery was assumed to 100% when the trail drained directly into the stream channel. Annual sediment delivery is assumed to be less than 100% for trail segments connected to the channel network via sediment plumes.

Surface grain sizes were estimated above and below the Ellis Creek-RJT crossing to determine if beneficial use impairment was occurring. Surface grain size distributions were estimated by performing pebble counts on Ellis Creek above-and-below where trail segment one crosses the creek. Separate pebble counts were done above and below the crossing using a gravel template which bins grain size by phi (φ) classes.

3.0. Results

3.1. Trail Segment Connectivity

Approximately 8 miles of the RJT were assessed for water quality impacts by Water Board staff in August of 2008 (i.e., 8/13-8/14; 8/26; 8/28). Eight trail segments were assessed for sediment production and sediment delivery. However, these trail segments are not the only segments delivering to waters of the state. Of the 8 trail segments, 7 were determined to have hydrologic connectivity to the channel network. The 7 trail segments accounted for approximately 5485 feet of connected trail length, and approximately 1.9 acres of trail surface area (Table 1).

3.2. Trail Sediment Production

Sediment production is dependent on the depth of the dust layer and trail surface area (equation 3). Dust depth measurements were done for all surveyed trail segments with the exception of trail segment 7. On trail surfaces, measured dust depths ranged from 0 to 0.28 feet, with a median of 0.03 feet, a mean of 0.04 feet, and a coefficient of variation of 114 percent. Overall, the distribution of dust depths was right skewed, indicating that the median dust depth was a better indicator of central tendency than the mean. As a result, sediment production and delivery estimated were calculated using the median dust depth for the each trail segment.

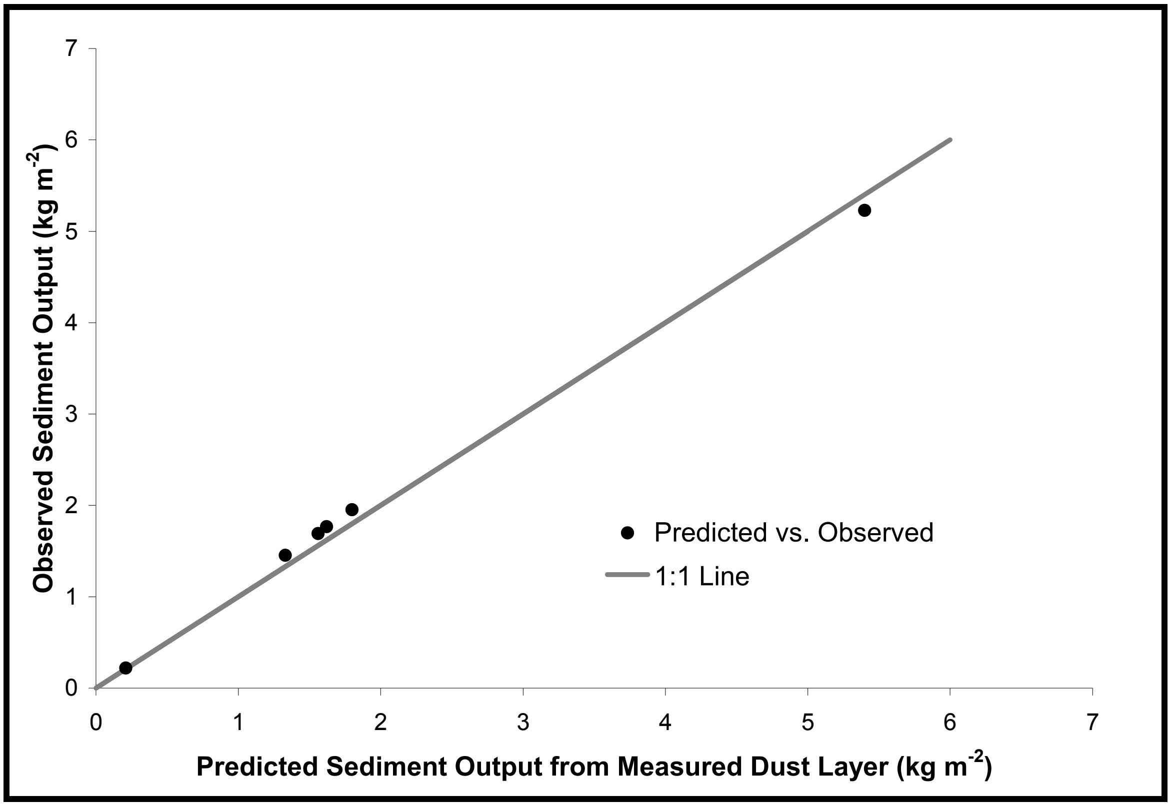

Figure 2. Predicted sediment output from dust layer measurements versus observed sediment output for 6 road plots subjected to simulated rainfall in northern Thailand (Ziegler et al., 2001; 2002). Our assumption in this assessment is that the close agreement between predicted and observed will hold true at the segment scale.

Surveyed trail segments cumulatively produced 100 yd^3 yr^{-1}. Sediment production rates for the surveyed trail segments ranged from 2.1 to 24 yd^3 yr^{-1}. The overall median dust depth was used to calculate sediment production for trail segment 7, and the sediment production rate for this segment is estimated at 13 yd^3 yr^{-1}.

3.3. Sediment Delivery

Sediment delivery for trail segments 1, 3, 5, 6, and 7 is assumed to be 100 percent annually, since these trail segments discharge directly into the channel network. These trail segments deliver approximately 75 yd^3 yr^{-1} into the waters of the state. Trail segments 2 and 4 produce approximately 23 yd^3 yr^{-1} and 2.1 yd^3 yr^{-1}, respectively, for a total of 25 yd^3 yr^{-1}. However, these segments deliver sediment to the channel network via sediment plumes. While these segments do not deliver 100 percent of their sediment on an annual basis, most sediment deposited within a filter strip can be delivered to the channel network during high magnitude, low frequency storm events (Dr. William Elliot, personal communication[2]). Therefore we still assume 100% delivery from segments 2 and 4 over longer time spans. Hence, the surveyed road segments deliver a total of 100 yd^3 yr^{-1} of fine sediment to the channel network.

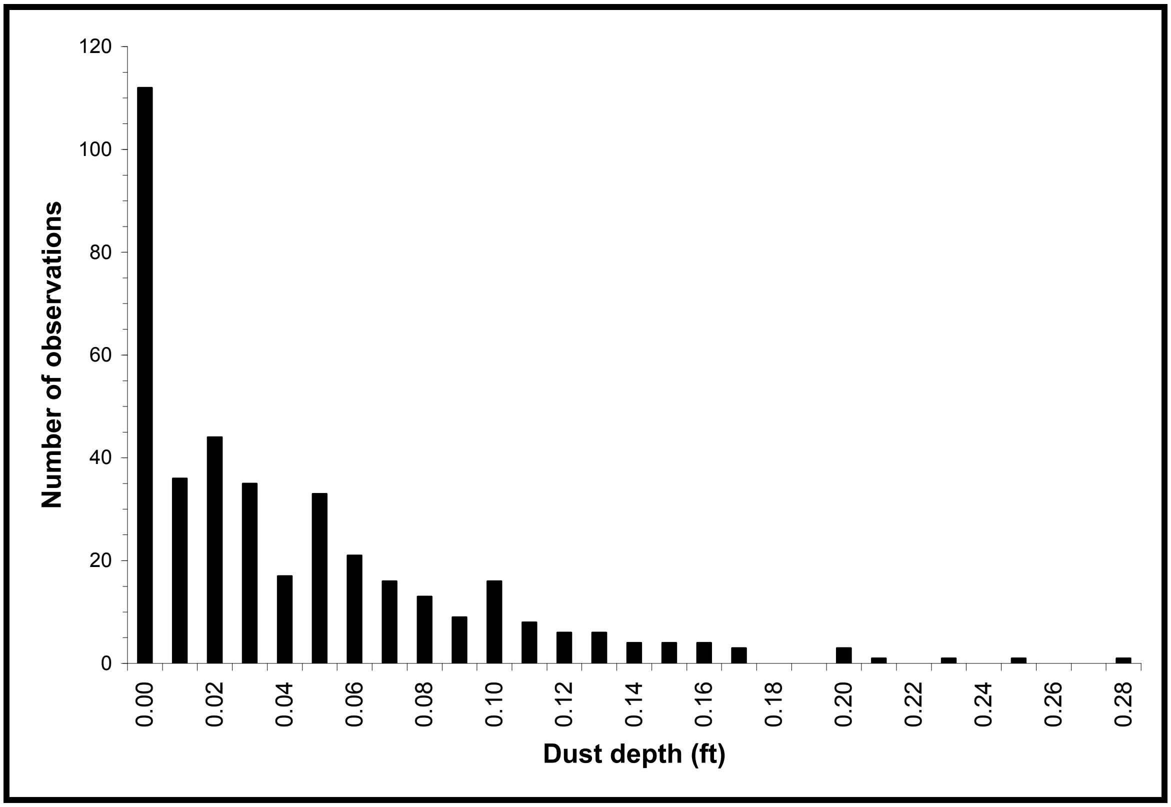

Figure 3. Histogram of measured dust depths for hydrologically connected road segments along the Rubicon Trail (n=448). A value of zero represents the absence of a dust layer or the presence of bedrock.

3.4. Beneficial Use Impairment

Beneficial use impairment was assessed using pebble counts above and below the Ellis Creek crossing. Measurements indicated that the median surface grain size (D_{50}) above the Ellis Creek crossing was approximately 28.0 mm, as compared to a D_{50} of less than 5.0 mm below the crossing. The more than 5-fold difference in median grain size indicates an increase in settleable solids to Ellis Creek. Furthermore, data indicate that the D_{50} above the Ellis Creek is suitable for rainbow trout, brook trout, and brown trout, whereas the D_{50} below the Ellis Creek crossing is below the published range of spawning gravel for these trout species (Kondolf and Wolman, 1993) (Figure 4).

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[2] Dr. William Elliot is the Project Leader for Soil and Water Engineering at the USDA Forest Service's Rocky Mountain Research Station lab in Moscow, Idaho.

Table 1. Measured trail segment characteristics used to calculate sediment production.

Segment	Length (ft)	Mean Width (ft)	Area (ft^2)	Dust depth (ft)		Sediment Production (yd^3 yr^{-1})	
				Mean	Median	Mean	Median
1-A1	135	12.2	1647	0.04	0.02	2.4	1.2
1-A2	25	22	550	0.06	0.07	1.2	1.4
1-A3	26	38	988	0.04	0.04	1.5	1.5
1-B	105	12.9	1354.5	0.04	0.02	2.0	1.0
∑	**291**		**4540**			**7.1**	**5.1**
2-A1	190	15.5	2945	0.08	0.07	8.7	7.6
2-A2	300	14.1	4230	0.03	0.02	4.7	3.1
2-A3	634	16.5	10461	0.04	0.03	15.5	11.6
2-B	88	16.5	1452	0.03	0.02	1.6	1.1
∑	**1212**		**19088**			**31**	**23**
3-A	98	16.6	1626.8	0.08	0.11	4.8	6.6
3-B1	62	29.9	1853.8	0.08	0.11	5.5	7.6
3-B2	326	13.8	4498.8	0.05	0.04	8.3	6.7
∑	**486**		**7979**			**19**	**21**
4-A	400	13.6	5440	0.02	0	4.0	0
4-B	92	12.4	1140.8	0.06	0.05	2.5	2.1
∑	**492**		**6581**			**6.6**	**2.1**
5-A	276	13.8	3808.8	0.04	0.03	5.6	4.2
5-B	1221	14.3	17460.3	0.04	0.03	25.9	19.4
∑	**1497**		**21269**			**32**	**24**
6-A1	120	17.3	2076	0.04	0.04	3.1	3.1
6-A2	330	17.6	5808	0.05	0.02	10.8	4.3
6-B	182	12.7	2311.4	0.05	0.05	4.3	4.3
∑	**632**		**10195**			**18**	**12**
7	875	13.0	11375	0.04	0.03	17	13
∑	**875**		**11375**			**17**	**13**
TOTAL:	**5485**		**81027**			**130**	**100**

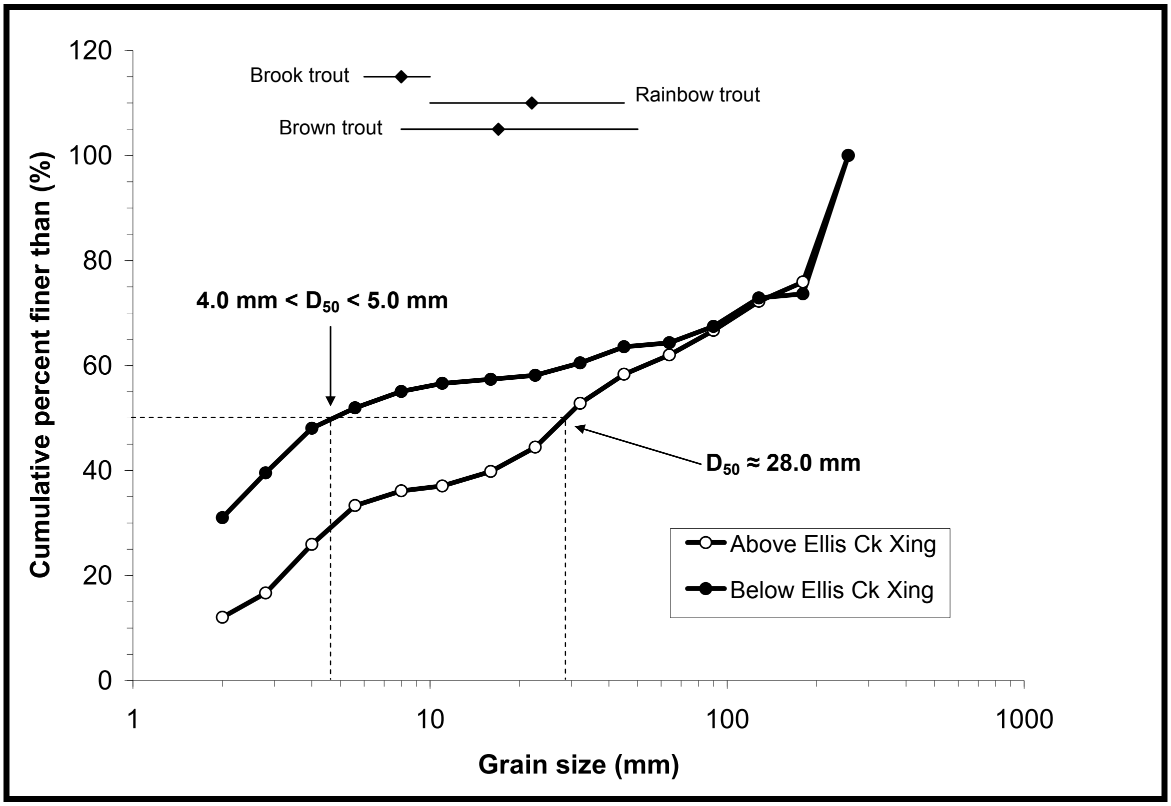

Figure 4. Surface grain size distributions above and below the Rubicon Trail - Ellis Creek crossing. The median grain size (D_{50}) below the crossing is approximately 1/6th the size of the D_{50} above the crossing. The horizontal lines represent the range of D_{50} preferred by trout species for spawning, and the diamonds represents the median D_{50} preferred by trout species (Kondolf and Wolman, 1993). Note that the D_{50} below the Ellis Creek crossing is below the published range of D_{50} preferred by brook, brown, and rainbow trout for spawning.

As noted previously, the estimated amount of sediment delivery from the RJT is expected to be low relative to the actual amount of delivered sediment. This is because the assessment assumes that the baseline erosion rate is zero and that the only erosion is due to transport of the traffic-induced dust layer. Also, the lack of robust statistical software precluded us from quantitatively determining whether the dust layer distribution was normally distributed. As a result, the median dust depth was used to calculate sediment volumes. By using the median dust depth to determine the volume of sediment delivery, our estimate of sediment delivery is 22% lower than the estimated volume utilizing the mean dust depth (Table 1).

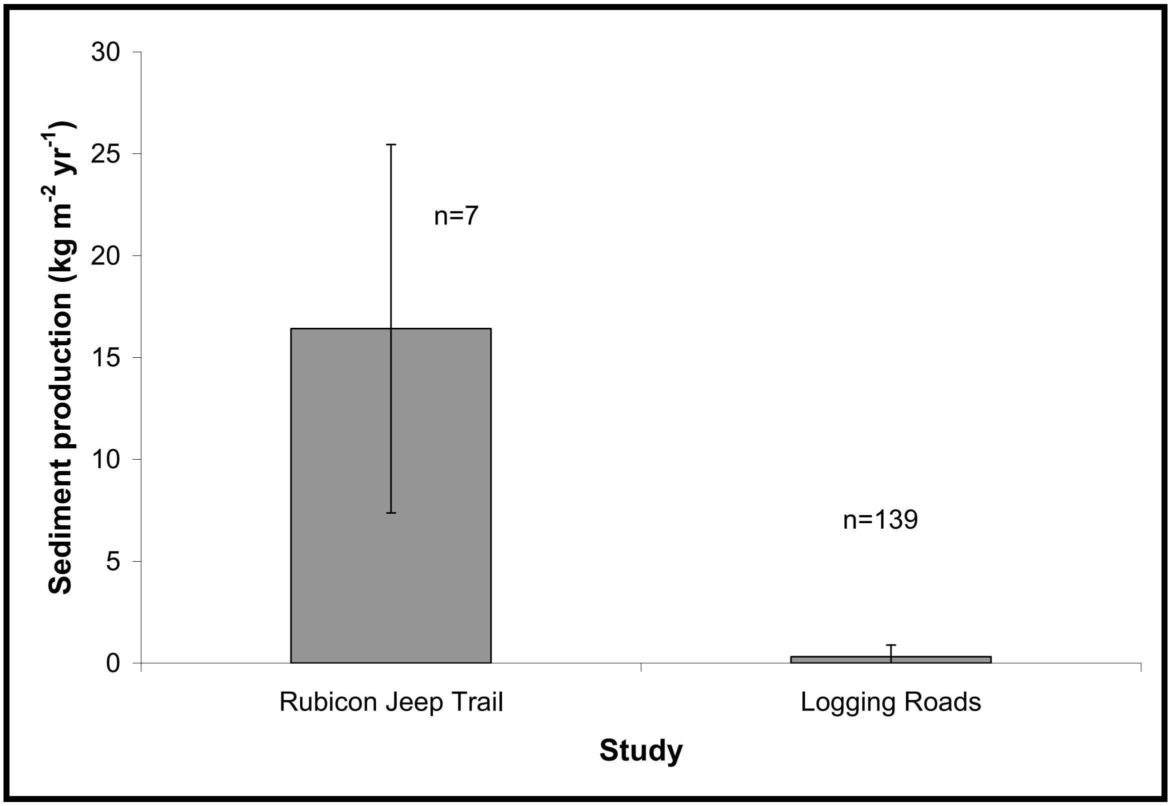

Figure 5. A comparison of the mean sediment production rate in kilograms per square meter per year from the Rubicon Jeep Trail versus the mean sediment production rate from native surface logging roads on adjacent managed forest lands (Coe, 2006). The error bars represent one standard deviation.

The estimated sediment production rates from the RJT are much higher than the sediment production rates from native surface roads on adjacent managed forest lands. Coe (2006) reported erosion rates from 139 native surface logging road segments over a three year period in the South Fork of the American River and Cosumnes River watersheds. Gravimetric sediment production rates from Coe's study (2006) ranged from 0.0002 – 4.0 kg m^{-2} yr^{-1}, with a mean value of 0.32 kg m^{-2}yr^{-1}. Assuming a bulk density of 1.6 Mg m^{-3}, we estimated the gravimetric sediment production rates from the RJT ranged from 4.2 – 35 kg m^{-2} yr^{-1}, with a mean value of 16 kg m^{-2} yr^{-1} (Figure 5). Median sediment production values differed by more than two orders of magnitude.

The 50-fold difference in mean erosion rates is attributed to the lack of drainage structures on the RJT, as longer trails segments generate more erosive runoff than shorter trail segments (Luce and Black, 1999, Coe, 2006). OHV trails are also subjected to more intensive traffic-induced sediment detachment processes than logging roads due to the steep gradients on the trail, the absence of dust abatement measures, and the use of the trail during the wet season. These factors can increase the erodibility of the trail surface by almost more than an order of magnitude relative to forest roads (Foltz, 2006).

5.0. Conclusions

The Rubicon Jeep Trail (RJT) was assessed to determine the relative magnitude of sediment production and sediment delivery to waters of the state. The Regional Board estimated that 7 surveyed trail segments were contributing approximately 100 yd^3 of sediment annually to waters of the state. Estimated sediment production rates from the RJT are 50 times greater than sediment production rates reported from native surface logging roads on adjacent forest lands (Coe, 2006). An above-and-below assessment of surface grain size distribution at the Ellis Creek trail crossing determined that settleable solids from the trail surface are causing a fining of the channel substrate, with potential impacts to cold freshwater trout species. Reductions in sediment delivery could be achieved through a combination of additional and well-placed drainage on the trail, by restricting traffic during the wet season, and/or by limiting the number of vehicles on the trail.

6.0. References

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