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# Reductions in road sediment production and road-stream connectivity from two decommissioning treatments

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ABSTRACT

Unpaved forest roads can be an important source of sediment to streams. Road decommissioning is an increasingly common technique to eliminate these impacts, but few pre- and post-treatment studies have rigorously assessed its effectiveness. The objectives of this study in the northern Colorado Front Range were to: (1) quantify the effects of key variables on road sediment production before decommissioning; (2) quantify the changes over time in segment-scale sediment production from two decommissioning treatments (ripping only, and ripping plus mulching) versus untreated controls; and (3) quantify the factors affecting road-stream connectivity and the changes in connectivity due to decommissioning 12.3 km of roads. Median sediment production rate in the first year prior to decommissioning was 0.3 kg $m^{-2}$, but values varied from 0.0 kg $m^{-2}$ to 3.0 kg $m^{-2}$. Traffic, precipitation intensity, and road segment area had the greatest effects on road sediment production. In the first two years after decommissioning the median road sediment production was zero kg $m^{-2}$, as the furrows created by ripping trapped nearly all of the eroded sediment. Decommissioning also reduced road-stream connectivity from 12% of the total length to only 2%, with most of the connected segments being immediately adjacent to a stream. While both decommissioning treatments were effective, the ripping plus mulching treatment had visibly less surface erosion and no segment generated any measurable sediment. These results can help guide the design and quantify the benefits of future road decommissioning projects.



## 1. Introduction

Roads are essential for forest management and many recreational activities, but roads can be a significant hydrological disturbance and source of sediment in forested watersheds (Croke and Hairsine, 2006; Motha et al., 2003). Actively-used unpaved road surfaces are highly compacted and typically have infiltration rates of ≤5 mm $h^{-1}$ (Foltz et al., 2009; Luce, 1997; Ramos-Scharrón and LaFevor, 2016; Ziegler et al., 2007). The very low infiltration rate means that even low or moderate intensity rains generate infiltration-excess overland flow and road surface erosion. In comparison, infiltration rates for undisturbed forests are almost always lower than maximum rainfall intensities, resulting in little or no Horton overland flow (Robichaud, 2000; Ziegler and Giambelluca, 1997).

The amount of road surface runoff is a major control on road surface erosion, and the low infiltration rates mean that the amount of runoff is directly proportional to road surface area (MacDonald et al., 1997). The energy of the overland flow is primarily a function of flow depth and slope, so road segment area times slope is commonly used to predict road surface erosion (e.g., Luce and Black, 1999; MacDonald et al., 1997; Ramos-Scharrón and MacDonald, 2005). Snowmelt typically generates very little road surface erosion due to the much lower volumes of runoff compared to rainstorms and the greatly reduced detachment due to the absence of rainsplash (Fu et al., 2010; Sugden and Woods, 2007).

Road surface erosion also varies with road surface characteristics, including soil texture (Luce and Black, 1999), ground cover (Luce and Black, 1999; Ziegler et al., 2000), and time since construction or maintenance activities (i.e., grading) (Luce and Black, 2001; Ramos-Scharrón and MacDonald, 2005; Stafford, 2011). Traffic is another major control on road sediment production (Coker et al., 1993; Reid and Dunne, 1984; van Meerveld et al., 2014), as this increases the supply of fine material through abrasion and crushing of the road surface materials (Sheridan et al., 2006) as well as the pumping of fine sediment to the surface (Reid and Dunne, 1984). Reported increases in sediment production due to

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high traffic are 7.5 times for road segments subjected to logging traffic compared to the same roads on days with no logging traffic (Reid and Dunne, 1984), and 2 to 25 times for road sections heavily used by logging trucks compared to lightly used road sections (Foltz, 1996).

The variability in precipitation, site conditions, and traffic mean that reported road surface erosion rates vary from nearly zero to more than 100 kg $m^{-2}$ $yr^{-1}$ (MacDonald and Coe, 2008). Annual road erosion rates per unit rainfall for studies published since 2000 range from 0.2 g $m^{-2}$ $mm^{-1}$ $yr^{-1}$ to 10 g $m^{-2}$ $mm^{-1}$ $yr^{-1}$ (Fu et al., 2010). Road erosion is primarily a concern when it affects the driveability of a road by creating deep rills, or when the runoff and sediment are delivered to a stream, wetland, or lake where they can adversely affect water quality and aquatic habitat.

The delivery of road runoff and sediment depends on the hydrologic connectivity, where connectivity refers to the linkage or connection between a runoff source and the receiving water(s) (Croke and Mockler, 2001). Key factors that affect road-stream connectivity include: the amount of runoff from the road segment; frequency, location, and type of road drainage structures; distance from the drainage outlets to a stream; hillslope gradient; downslope infiltration capacity; and the trapping efficiency of obstructions (Croke and Hairsine, 2006; Megahan and Ketcheson, 1996).

An increasingly common way to reduce the adverse environmental impacts from roads is to remove or decommission roads that are no longer needed or desirable (Switalski et al., 2004; Weaver et al., 2015). Road decommissioning as a restoration tool was first done on a large scale in the U.S. in the late 1970s in Redwood National Park, California (Madej, 2001), and road decommissioning is an increasingly important component of watershed restoration efforts on both public and private lands. From 1998 to 2002 the USDA Forest Service decommissioned 3200 km of road per year at an average cost of $2500 per kilometer (Schaffer, 2003), and over 2000 km of roads per year from 2010 to 2014 (USDA Forest Service, 2010–2014).

Decommissioning techniques can be as cheap and simple as closing the road to traffic by installing a gate or other barrier. The other extreme is to completely remove the road by ripping it, removing the crossings, recontouring the road prism, and revegetating the disturbed area (Switalski et al., 2004; Weaver et al., 2015). An intermediate approach is to rip the roadbed with a bulldozer or other machines to eliminate the compaction (Luce, 1997; Weaver et al., 2015), and this can be followed by mulching to reduce surface erosion. Relatively few studies have measured sediment production and road-stream connectivity prior to and after decommissioning (Kolka and Smidt, 2004; Lloyd et al., 2013; Madej, 2001), making it difficult to rigorously quantify the benefits of these efforts on road sediment production and road-stream connectivity. No studies have quantified the benefits of road decommissioning at the segment or larger scale in the central or southern Rocky Mountains, although some studies have measured changes in bulk density, infiltration, and surface cover (Foltz et al., 2007; Luce, 1997).

The overall goal of this study was to evaluate the effectiveness of two road decommissioning treatments for reducing road sediment production and road-stream connectivity. The specific objectives were to: (1) quantify the effects of key variables on road sediment production before decommissioning; (2) quantify the changes over time in segment-scale sediment production from two decommissioning treatments (ripping only, and ripping plus mulching) versus untreated controls; and (3) quantify the factors affecting road-stream connectivity and the changes in connectivity due to decommissioning 12.3 km of roads. Data were collected for one field season prior to decommissioning and two years after decommissioning to assess erosion rates and changes in effectiveness over time. The results can help guide the design and quantify the benefits of future road decommissioning projects.

## 2. Methods

### 2.1. Study area

The study area is in the Arapaho-Roosevelt National Forest (ARNF) in northcentral Colorado, about six kilometers southwest of Red Feather Lakes (Fig. 1). The study roads are at an elevation of 2630 to 2850 m in a previously glaciated, gently rolling, and primarily granitic terrain. Average annual precipitation at the Red Feather Lakes weather station is 460 mm (WRCC, 2016) with about 36% of this falling as snow between October and April (NOAA, 2013). From May through September the precipitation falls primarily as rain, often in brief but occasionally intense thunderstorms (NOAA, 2013). Soils are predominantly Redfeather-Schofield-Rock outcrop association. The Redfeather and Schofield soils vary only in their depth to bedrock, and they are shallow to moderately deep (40–100 cm), well-drained sandy loams formed on granitic bedrock; the taxonomic description is loamy-skeletal, mixed, superactive Lithic Glossocryalfs (Moreland, 1980; USDA NRCS, 1998). The vegetation is predominantly lodgepole pine (*Pinus contorta*) with some ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), and quaking aspen (*Populus tremuloides*) according to aspect, soil wetness, and elevation. Some areas within the overall study area had been clearcut or more recently thinned, but no timber harvests had been conducted for at least a couple of decades. Some residual slash was still present as the decay rate is extremely slow in this dry, cold climate.

### 2.2. Road decommissioning

In early summer 2013 the ARNF designated 12.3 km of roads for decommissioning over an area of approximately 16 $km^2$. The designated roads consisted of about 30 distinct road sections ranging in length from about 30 to 1200 m. These roads were selected because they were no longer needed for access, and they either posed a disturbance to wildlife and/or a risk to water resources. Many of the designated road sections had been closed to traffic for about 25 years, but there are no records of exactly when each section had been closed. A few sections were still open to recreational traffic, particularly by all-terrain vehicles (ATVs).

The decommissioning was conducted in September–October 2013, and the primary treatment was ripping the road surface to a depth of approximately 0.4 m. The ripping was done with a tracked bulldozer pulling three unwinged ripping teeth that made three furrows in the roadbed. Some dead trees were placed on the ripped roads to inhibit vehicle traffic. Wood-strand mulch and an organic fertilizer (biosol®) were applied to about 40% of the total length, and the road sections selected for this additional treatment were either in close proximity to a stream or with evidence of high erosion. The wood-strand mulch was manufactured wood shards about 15 cm long and about 0.5 cm wide and thick, and the specified application rates of the wood-strand mulch and fertilizer were 6.2 Mg $ha^{-1}$ and 0.3 Mg $ha^{-1}$, respectively. A more concerted effort also was made to apply branches or residual logging slash to the mulched segments, and this material was generally much coarser than the wood-strand mulch.

### 2.3. Precipitation

On 11 July 2013 we installed five tipping bucket rain gauges with each tip representing 0.254 mm of rainfall. The mean distance