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Effects of closed roads, traffic, and road decommissioning on infiltration and sediment production: A comparative study using rainfall simulations

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ABSTRACT

Road closures and road decommissioning are increasingly being used to reduce runoff and sediment production from unpaved roads, but few studies have quantitatively assessed the effectiveness of these treatments. This study used rainfall simulations to: 1) quantify the differences in infiltration and sediment production among five treatments: undisturbed forest, closed roads, closed roads exposed to all-terrain vehicle (ATV) traffic, and two decommissioning treatments (ripping only, and ripping plus wood-strand mulch); and 2) quantify the effects of key site variables on infiltration and sediment production. Four replicate rainfall simulations were conducted for each treatment in northcentral Colorado, with 44 mm h^{-1} of rainfall being applied to 1 m^2 bounded plots for 45 min. The mean infiltration rate for the last 5 min ("infiltration capacity") for the forest was 28 mm h^{-1} and highly variable, while the closed roads with and without traffic had nearly identical mean values of only 5 and 4 mm h^{-1}, respectively. Ripping only increased the mean infiltration capacity to 9 mm h^{-1}, while adding mulch more than doubled this to 20 mm h^{-1}. Mean sediment production from the forested plots was only 3 g m^{-2} as compared to 43 g m^{-2} from the closed roads with no traffic. Eighty passes of an ATV tripled the mean sediment production compared to the closed roads with no traffic. The mean sediment production for the ripping treatment was 72 g m^{-2} or 67% higher than the mean value from the closed roads, while adding mulch decreased the mean sediment production to just 16 g m^{-2}. These results first show the importance of roads and even small amounts of traffic for increasing plot-scale runoff and sediment production, and second that ripping plus mulching is a more effective road decommissioning treatment than just ripping. The results provide important guidance for future road decommissioning efforts.

1. Introduction

Sediment production and delivery from unpaved forest roads is a key environmental concern due to the potential effects on water resources infrastructure and the physical characteristics of water, particularly turbidity and total suspended solids (Goode et al., 2012, MacDonald and Stednick, 2003; Motha et al., 2003). Changes in these parameters can adversely affect the beneficial uses of domestic water supply, recreation, and aquatic ecosystems, particularly coldwater fisheries (Wood and Armitage, 1997). The documented impacts of roads are a direct result of the very large changes in runoff and erosion due to the highly compacted road surface, even though roads typically represent a small proportion of most forested and rural landscapes (Ramos-Scharrón and LaFevor, 2016; Ziegler and Giambelluca, 1997).

A common way to reduce the adverse environmental impacts of roads is to remove or decommission a road that is no longer needed or desirable (Switalski et al., 2004; Weaver et al., 2015). Decommissioning treatments can vary from relatively cheap and simple methods, such as closing the road by installing a gate or other barrier, to more expensive treatments such as full recontouring (Madej, 2001; Switalski et al., 2004; Weaver et al., 2015). While closing a road is the least expensive treatment, closing a road—even for several decades—may not restore infiltration rates to the values observed in an undisturbed forest. In Idaho the saturated hydraulic conductivity of an abandoned road after thirty years with no traffic was still only 7–28 mm h^{-1} (Foltz et al., 2009), which is much lower than the value of 40–80 mm h^{-1} for an undisturbed forest (Robichaud, 2000). In Peninsular Malaysia an abandoned logging road had > 80% vegetation cover after 40 years, but the saturated hydraulic conductivity of 62 mm h^{-1} was still an order of magnitude lower than the value of 675 mm h^{-1} for the adjacent hillslopes (Ziegler et al., 2007).

Although closing a road may not restore infiltration rates, the partial recovery in infiltration—when combined with the lack of traffic and the increase in surface cover by vegetation and litter—can greatly

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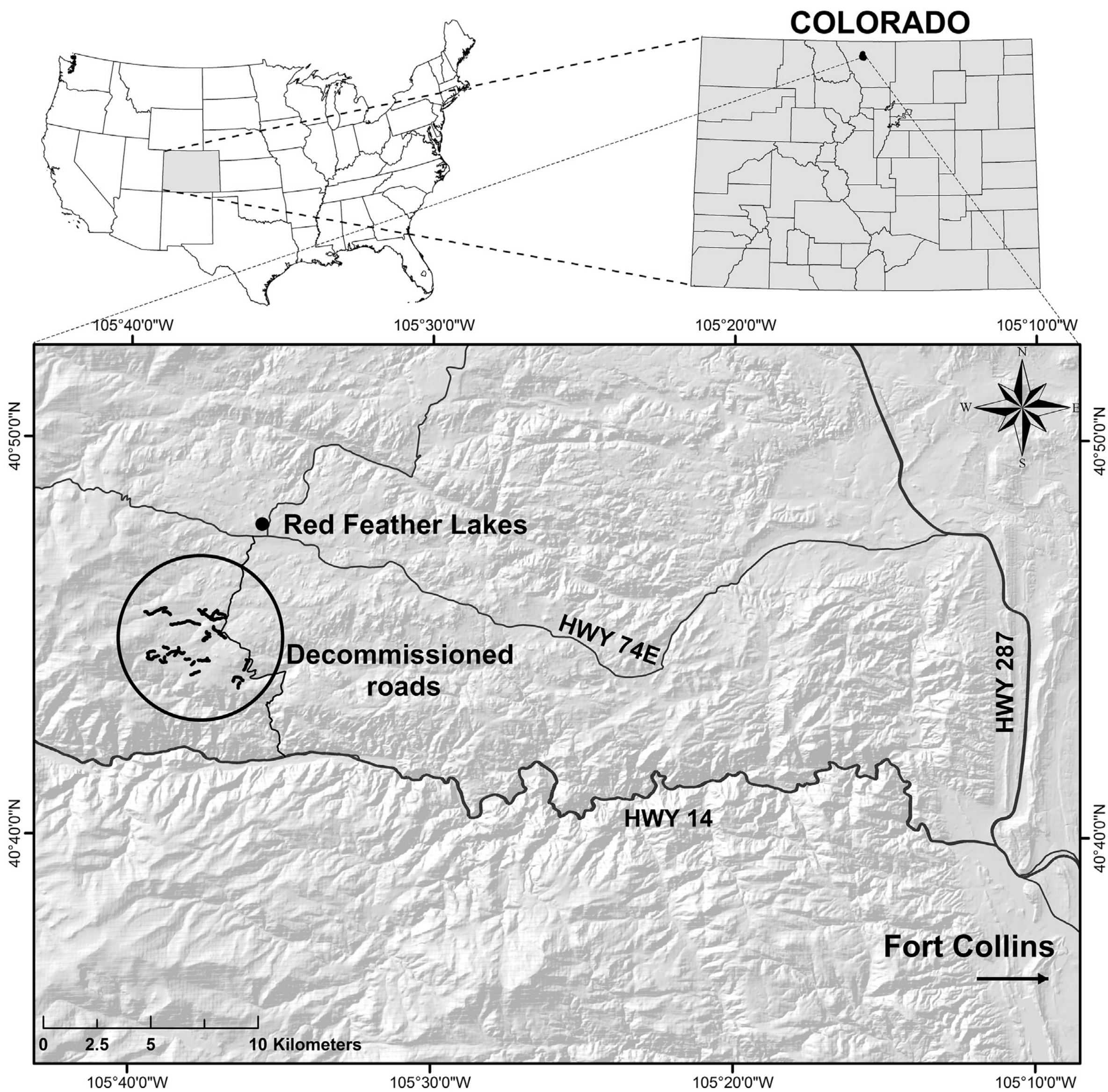

Fig. 1. Location of the road sections in the Arapaho-Roosevelt National Forest that were decommissioned in fall 2013 by ripping or ripping plus mulching. The closed roads and forested plots were immediately adjacent to the decommissioned roads.

reduce road sediment production. Rainfall simulations on an abandoned road in Idaho with 98% ground cover yielded a mean sediment concentration of $2.2\ g\ L^{-1}$, which was only 14% of the value from a similar road that had been subjected to logging traffic two years before the rainfall simulation (Foltz et al., 2009).

Numerous studies have shown that traffic greatly increases road sediment production by increasing the fine sediment supply through abrasion and crushing, as well as forcing fine sediment to the surface (Luce and Black, 1999; Reid and Dunne, 1984; Sheridan et al., 2006; Ziegler et al., 2001). High numbers of log trucks increased sediment production by 7.5 times compared to the same roads on days with no logging traffic (Reid and Dunne, 1984), and 2 to 25 times for roads heavily used by logging trucks as compared to roads with light traffic (Foltz, 1996). The type of traffic also may be important, as the erosion from unmanaged ATV and dirt bike trails can be similar to or greater than an active forest road with regular car and truck traffic (Meadows et al., 2008; Welsh, 2008).

A second common road decommissioning treatment is to rip the roadbed by metal tines being pulled behind a bulldozer to eliminate the compaction (Luce, 1997; Weaver et al., 2015). The ripping can be followed by the addition of mulch to reduce surface erosion, but the effectiveness of ripping, or ripping plus mulching, is still controversial. In Alberta, Canada ripping only decreased the bulk density from 1.60 to $1.40\ Mg\ m^{-3}$, or 13% (McNabb, 1994). In Idaho ripping initially decreased the bulk density to $1.50\ Mg\ m^{-3}$ and increased the hydraulic conductivity from 8 to $30\ mm\ h^{-1}$, but after 90 mm of simulated rainfall the bulk density increased back up to $1.70\ Mg\ m^{-3}$ and the hydraulic conductivity dropped by half to $15\ mm\ h^{-1}$ (Luce, 1997). Similarly, the hydraulic conductivity two years after ripping was only $9\ mm\ h^{-1}$ (Foltz et al., 2007). These results indicate that the initial increase in infiltration due to ripping is very transient, and the resultant infiltration rate is still substantially less than the typical infiltration rate of approximately $40–120\ mm\ h^{-1}$ for undisturbed coniferous forests (Robichaud, 2000; Moody and Martin, 2001).

The problem is that relatively few studies have experimentally quantified the effects of different decommissioning treatments on infiltration and sediment production, even though road decommissioning has become an important restoration treatment on both public and private lands (Madej, 2001; Weaver et al., 2015). For instance, from 1998 to 2002 the USDA Forest Service (USFS) decommissioned 3200 km of road per year at an average cost of $2500 per kilometer (Schaffer, 2003), and more recently the USFS has been