Infiltration, Erosion, and Vegetation Recovery Following Road Obliteration

R. B. Foltz, H. Rhee, K. A. Yanosek

Abstract. *Forest roads are obliterated to lower the risks of surface erosion and mass failures. One purpose of the road obliteration is to return the compacted forest roads to productive pre-road conditions, i.e., a forest floor with high infiltration capacity, low interrill erodibility, and high vegetation ground cover. It is important to know how these characteristics recover following road obliteration. Infiltration capacity, interrill erodibility, and vegetation ground cover are essential parameters for modeling erosion from obliterated roads for erosion prediction models such as the Water Erosion Prediction Project (WEPP). We chose three sites located on the Payette National Forest, Idaho. Rainfall simulations were conducted on 1 × 1 m plots with three replications in two consecutive years. Three 30 min storm events with an intensity of 89 mm h^{-1} were applied to each plot. Photos were taken to determine vegetation ground cover. Infiltration capacity and interrill erodibility in this study were determined as 9.0 mm h^{-1} for saturated hydraulic conductivity and 3.2 × 10^6 kg·s m^{-4} for interrill erodibility. This study postulated a history of saturated hydraulic conductivity on a forest road from prior to road building to years after obliteration. The low elevation (1400 m) site had vegetation ground cover of 27% after three years following road obliteration, while the other high elevation (1800 m and 2200 m) sites had 8% after four years. We conclude that four years was not sufficient time for obliterated roads to return to the pre-road (forest floor) conditions, especially for infiltration capacity.*

Keywords. *Erosion, Forest roads, Infiltration, Interrill erodibility, Obliteration, Rainfall simulation, Saturated hydraulic conductivity, Vegetation recovery, WEPP.*

Forest roads are essential for forest management, such as thinning and timber harvesting, as well as providing recreational access. The U.S. Forest Service has been building forest roads mainly in order to provide such services to forest managers and the public. As of 2004, the inventoried Forest Service road system reached 600,000 km (USDA Forest Service, 2007), of which many roads do not meet standards of safety and environmental protection today because of insufficient funding. One solution for these road problems can be decommissioning unneeded substandard roads (Bell, 2000). In fiscal year 2004, about 1,700 km of roads were decommissioned from the National Forest Service Road System (USDA Forest Service, 2007).

Road decommissioning is defined as "activities that result in the stabilization and restoration of unneeded roads to a more natural state"(USDA Forest Service, 2001). There are five levels of treatments for road decommissioning: (1) block entrance, (2) revegetation and waterbarring, (3) remove fill and culverts, (4) establish drainage ways and remove unstable road shoulders, and (5) full obliteration recontouring and restoring natural slopes (USDA Forest Service, 2003). Road removal and obliteration are commonly used terms similar to decommissioning. Road removal is defined as "the physical treatment of a roadbed to restore the form and integrity of associated hillslopes, channels, and floor plains and their related hydrologic, geomorphic, and ecological processes and properties" (Switalski et al., 2004). Obliteration is defined as "unbuilding, decommissioning, deactivating, or dismantling a road; the denial of use, elimination of travelway functionality, and removal of the road from forest development road system; return of the road corridor to resource production by natural or designed means" (Moll, 1996). Road obliteration usually involves the use of heavy equipment to decompact road surfaces, to remove drainage structures and fill material from streams and draws, and to recontour through unstable areas (Connor et al., 2000). The term "obliteration" is used in this study since it best fits the forest management objectives of our sites.

The purposes of road obliteration (removal) are various such as: "to restrict access, increase hillslope stability, minimize erosion, restore natural drainage patterns, protect endangered plants and wildlife, and restore aquatic and wildlife habitat" (Switalski et al., 2004), which can be accomplished using one or more of the following three treatments: restoring stream crossings, ripping (subsoiling) the road bed, and recontouring hillslopes. Restoring stream crossings involves culvert removal, fill material excavation and restoration of the original land surface, recontouring streambanks, channel stabilization, and revegetation (Switalski et al., 2004). Ripping involves decompacting (loosening) compacted and impermeable road and fill material to a depth of 0.5 to 1 m.

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Recontouring involves restoring the original slope by placing fill material onto the excavated area during road construction (Bagley, 1998). These obliteration treatments require some level of excavation and earthwork depending on the road management objectives, which range from landslide mitigation and restricting vehicular access to water quality improvement and habitat restoration (Moll, 1996; Connor et al., 2000).

Road management objectives can be achieved by decompacting the road surface, thus removing traffic-induced compaction to accelerate the natural recovery of soil properties, which is usually slow and relies on wetting and drying, frost activity, animal activity, and root growth (Kolka and Smidt, 2004). This natural recovery takes place in other compacted soil conditions such as skid roads and snig tracks (skid trails). Subsoil bulk densities in skid roads, which are usually much less compacted than forest roads, had not recovered to undisturbed levels after 23 years in central Idaho (Froehlich et al, 1985) and 32 years in Oregon (Wert and Thomas, 1981). Pennington et al. (2004) reported a significant difference in bulk density between snig tracks and control areas 17 to 23 years after harvesting. Since infiltration capacity increases with decreasing soil bulk density, infiltration capacity is similarly expected to recover slowly.

Infiltration, soil erodibility, and vegetation ground cover are essential soil parameters from an erosion point of view. Since minimizing erosion is one of the purposes of road obliteration, it is worth envisioning how road obliteration changes these soil erosion parameters.

Forest roads have a compacted running surface whose infiltration capacity is much lower than that of the forest floor. Undisturbed forest soils have relatively high infiltration rates, typically 40 to 80 mm h^{-1} (Robichaud, 2000), compared to forest road surfaces of 5×10^{-5} to 8.8 mm h^{-1} with a geometric mean of 0.11 mm h^{-1} (Luce and Cundy, 1994) and 0.2 to 5.1 mm h^{-1} (Ziegler and Giambelluca, 1997). This low infiltration allows forest roads to produce excessive runoff quickly, which can detach and deliver fine soil particles from forest roads to streams. Forest roads are considered a significant source of sediment delivery in forested watersheds (Best et al., 1995; Hoover, 1952; Megahan and Kidd, 1972; Motha et al., 2003; Weitzman and Trimble, 1955).

Luce (1997) examined infiltration capacity of obliterated forest roads on two coarse-grained soils after ripping 1 m deep. Three consecutive rainfall simulations were used to determine an infiltration parameter, i.e., saturated hydraulic conductivity immediately after ripping on the gravelly sand soil. A saturated hydraulic conductivity of 30 mm h^{-1} was observed immediately following ripping on a granite soil. This hydraulic conductivity decreased to 15 mm h^{-1} after three consecutive simulated rainfall events with a total precipitation of 135 mm.

A measure of the susceptibility of a forest road to erosion is soil erodibility, consisting of interrill and rill erodibility. Interrill erosion occurs in shallow overland or sheet flow between rills where raindrops are the primary soil detaching agent. Rill erosion occurs under conditions of concentrated flow; therefore, rill erosion detaches more soil particles than interrill erosion. Both erosion processes depend on soil infiltration rates. However, interrill erosion also depends on soil surface conditions, such as vegetation cover (Elliot and Ward, 1995), whereas rill erosion strongly depends on the length and steepness of the slope (Haan et al., 1994). On a forest road surface, interrill erosion dominates erosion process; on the other hand, in roadside ditches or wheel ruts, rill erosion dominates. Obliterated roads do not have roadside ditches or wheel ruts; therefore, interrill erosion is the dominant form of erosion. Typical forest road interrill erodibility is 3×10^6 kg·s m^{-4} (Elliot and Hall, 1997).

Vegetation ameliorates compacted forest road surfaces and increases the infiltration capacity by their root system. Both ground vegetation and tree canopy cover decrease erosion by intercepting raindrops, increasing infiltration rates, or holding soil particles with their root system. There are typically two goals of vegetation cover establishment from the road obliteration: (1) erosion control for short term, and (2) converting temporary vegetation, often non-native species, to native species for the long term (Clearwater National Forest, 2000). Grass seed is used primarily to accomplish the short-term goal because their extensive, fibrous root systems increase infiltration capacity and hold the soil in place (Robichaud et al., 2000). Dyrness (1975) reported that a grass-legume seed mix on a forest road cutslope in Oregon reached 70% to 90% cover in two years, while non-seeded, natural revegetation control plots reached 10% cover in five years.

Current knowledge of road obliteration envisions changes in infiltration, interrill erosion, and vegetation cover immediately after road obliteration. One of the goals of road obliteration is the reduction of chronic sediment input into streams. Road obliteration is believed to accelerate the natural recovery of soil properties, and thus reduce sediment from roads. However, without scientific knowledge of the long-term effects of road obliteration, we can not be certain about the benefits of obliterating roads. This study contributes to understanding the long-term effects of road obliteration and envisioning changes in the soil erosion parameters. Once these soil erosion parameters are known for pre- and post-obliteration conditions, we can predict and compare runoff and sediment production of pre- and post-obliteration using an existing erosion model, such as WEPP.

The purposes of this study were to measure and determine (1) infiltration capacity, (2) interrill erodibility, and (3) vegetation cover in consecutive years following road obliteration.

METHODS

The study sites were located on the Payette National Forest, Idaho, and referred to as Brush Creek, Long Walk, and Summit. All three sites were forest roads that had been obliterated prior to this study. The Brush Creek road was obliterated two years prior to the start of the study. The Long Walk and Summit roads were obliterated three years prior to the study. Similar obliteration methods were employed at each site, where stream crossings were restored by excavating all fill material down to the original land surface, removing drainage structures, recontouring stream banks, stabilizing stream channel, and revegetation. Rainfall simulation plots were located on restored stream banks 1 m above the high water mark (bank full flow), as shown in figure 1. The obliterated area, including restored stream banks, were treated with a perennial seed mix at an application rate of 800 live seeds m^{-2}, an organic fertilizer

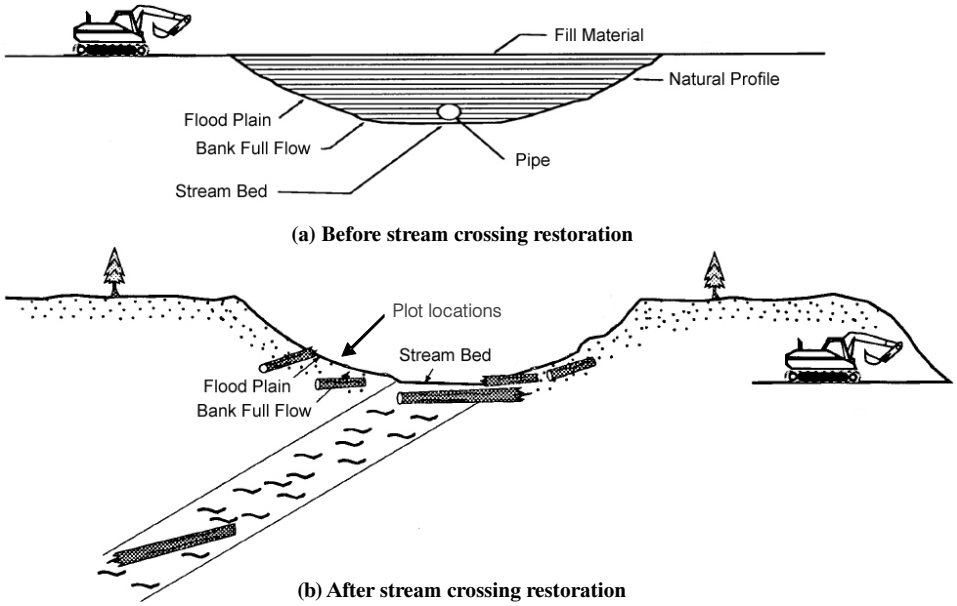

Figure 1. Rainfall simulation plot locations (Moll, 1996). Plots were located on a restored stream bank above bank full flow.

Table 1. Seed mix composition.

Species		Seeds
Scientific Name	Common Name	(%)
Achillea millefolium	Western yarrow	9
Agropyron riparium 'Sodar'	'Sodar' streambank wheatgrass	13
Agropyron trachycaulum 'Pryor'[a]	'Pryor' slender wheatgrass	14
Bromus marginatus 'Bromar'	'Bromar' mountain brome	9
Festuca trachyphylla 'Durar'	'Durar' hard fescue	20
Poa compressa 'Reubens'	'Reubens' Canada bluegrass	20
Sanguisorba minor	Small burnet	12
Vicia villosa	Hairy vetch	3
Total		100

[a] Syn = *Elymus trachycaulus* 'Pryor'.

Table 2. Soil characteristics for each site.

Study Site	Parent Material	USCS[a] Soil Classification	d_{84}[b] (mm)	d_{50}[b] (mm)	d_{16}[b] (mm)
Brush Creek	Basalt	Gravelly loamy sand	1.32	0.20	0.04
Long Walk	Glacial till	Gravelly sand	5.57	0.59	0.15
Summit	Glacial till	Gravelly sand	2.53	0.46	0.11

[a] The Unified Soil Classification System.
[b] The d_{84}, d_{50}, and d_{16} are soil particle diameters of 84, 50, and 16 percentile by weight, respectively.

(Biosol, 2006) at a rate of 1350 kg ha^{-1}, and certified weed-free wheat straw immediately following restoring stream crossings. Detailed seed mix composition is listed in table 1.

Brush Creek has a sub-alpine fir/paxistima habitat and gravelly loamy sand (Typic Cryosammet) soil derived from basalt parent material. The elevation of the Brush Creek site is 1400 m (4800 ft). The Long Walk and Summit sites are located in sub-alpine fir/huckleberry habitat and have gravelly sand (Typic Cryoumbrepts) soils derived from glacial till. The elevations of Long Walk and Summit are 1800 m (6000 ft) and 2200 m (7200 ft), respectively. Soil characteristics of each site are as listed in table 2.

Rainfall simulations and vegetation ground cover evaluations were conducted in August of two consecutive years at each site to determine the soil erosion parameters following road obliteration. Rainfall simulations were conducted on three 1 × 1 m plots at each site. Each plot was constructed with sheet metal borders and a runoff apron on the downhill border. The sheet metal borders prevented outside water from flowing into the plot. The apron was constructed to direct runoff to a 25 mm pipe opening from which 500 mL grab samples were taken once every minute. The downhill border and runoff apron were sealed with bentonite to prevent water from flowing under the plot border. This installation prevented rill formation, thus enabling the isolation of raindrop splash erosion from rill erosion. Plots were located within the side slopes of the restored stream crossing, to best represent the dominant slope feature and vegetation ground cover. Plot slopes ranged between 9% and 26% among the three sites.

The rainfall simulator used in this study consisted of a frame and fiberglass housing that suspended a Veejet 80100 nozzle 3 m above the ground. Adjustable telescoping legs enabled leveling on uneven ground and steep slopes. A nylon windscreen was used to ensure even rainfall distribution on the plot.

Three 30 min storm events with an intensity of 89 mm h^{-1} were applied to each plot. The initial rainfall (called the "dry run") was applied to the plots with existing soil moisture conditions. The second rainfall (called the "wet run") was applied the following day, while the final rainfall (called the "very wet run") was applied within 30 min following the completion of the wet run.

The 89 mm h^{-1}, 30 min duration storm had a return period greater than 100 years at these Idaho sites. This rainfall intensity and duration were chosen not to represent a specific design storm but to exceed the expected infiltration rate at each site, thus allowing the entire plot area to contribute to runoff. Entire plot contribution to runoff is a requirement

when determining infiltration and interrill erosion parameters from simulated rainfall.

Timed grab samples were dried overnight at 105°C to determine runoff rate and sediment concentration. Soil samples were taken before the dry run and after the very wet run at a depth of 0 to 40 mm, and dried overnight at 105°C to determine soil water content (ASTM standards, 2000). We did not determine other water contents before the wet run and very wet run, or after the dry run and wet run, since this would have required taking soil samples within the plots, i.e., disturbing the plots before finishing the experiments.

Photos were taken from above each plot to determine vegetation ground cover. Vegetation cover was measured manually by placing a ten-by-ten grid over each photo and counting point intercepts in a manner similar to the digital grid overlay method (Booth et al., 2005). The spacing between the points represented 10 cm with respect to the true plot size. This process was repeated three times to determine an average vegetation ground cover. Significance of changes in vegetation ground cover between consecutive years was determined with a mixed model, repeated measures analysis using SAS (SAS, 2003).

Infiltration and interrill erosion parameters were determined by comparing predicted values from the WEPP model and measured values from the rainfall simulations. The saturated hydraulic conductivity was determined from the very wet run, while the interrill erodibility was determined from the dry run. Both parameters were estimated by fitting model-predicted values to measured values. The optimized fit for saturated hydraulic conductivity was found by changing the assumed saturated hydraulic conductivity value until the differences between the corresponding predicted and observed runoff volumes, and between the predicted and observed peak runoff rates, were minimized; i.e., minimizing the objective function value (eq. 1):

$$Obj_{Ksat} = (RO_{obs} - RO_{WEPP})^2 + (Peak_{obs} - Peak_{WEPP})^2 \quad (1)$$

where Obj_{Ksat} is the objective function for the saturated hydraulic conductivity, RO_{obs} is the observed total runoff, RO_{WEPP} is the WEPP-predicted total runoff, $Peak_{obs}$ is the observed peak runoff, and $Peak_{WEPP}$ is the WEPP-predicted peak runoff.

After determining a value for saturated hydraulic conductivity, various interrill erodibility values were assumed and determined by matching predicted sediment loss to observed sediment loss. The parameter values were tested for significant differences among sites and years using a mixed model, repeated measures analysis in SAS (SAS, 2003).

The WEPP model was used to generate runoff predictions from 1 × 1 m road surface of both the pre- and post-obliteration road for the three sites. The pre-obliteration road was assumed to be closed to traffic and, therefore, received no traffic. For the pre-obliteration road, a hydraulic conductivity of 1 mm h^{-1} was used. This value is ten times the typical 0.1 mm h^{-1} for high traffic, native surface roads (Luce and Cundy, 1994) and appears reasonable for a road closed to traffic. For the post-obliteration road, the average hydraulic conductivity determined in this study was used for each site. Weather data for the model predictions were generated by CLIGEN (Climate Generator) in WEPP, as modified by the PRISM (Precipitation-elevation Regressions on Independent Slopes Model) database (Daly et al., 1994). The PRISM database allowed generation of stochastically valid climate sequences at 4 km grid spacing. The closest grid point to each site was used in the runoff simulations. The runoff from the 1 × 1 m area was simulated for 30 years to estimate the number of runoff events from rainfall and snowmelt and to estimate the average annual runoff depth.

Results and Discussion

Rainfall Simulation Results

Soil water content before rainfall simulations ranged from 8.0% to 24.7%, depending on antecedent soil moisture and plot locations. After rainfall simulations, as listed in table 3, the water content increased to 23.7% to 37.3%, which was considered saturated soil water content at each site.

Table 4 presents the saturated hydraulic conductivity calculated from the very wet run. Compound symmetry and an autoregressive covariance structure had equal Akaike Information Criteria (AIC; Akaike, 1974), which was less than the unstructured value. There were no significant differences among sites ($F_{2,6}$ = 0.79, p-value of 0.49) or between years ($F_{1,6}$ = 1.92, p-value of 0.22) and no significant interactions between sites and years ($F_{2,6}$ = 0.25, p-value of 0.79). Thus, we conclude that the saturated hydraulic conductivity did not vary among sites or between years and that the best estimate of the saturated hydraulic conductivity was the average of 9.0 mm h^{-1}.

Rainfall simulation on three sites varied from two years to four years after obliteration. Because there were no significant differences between runoff in the current study, we conclude that four years was not sufficient time for these

Table 3. Soil water content (%) before and after rainfall simulations.

	Water Content (%)					
	2 Years After[a]		3 Years After		4 Years After	
Site	Before RS[b]	After RS[c]	Before RS	After RS	Before RS	After RS
Brush Creek	24.7	37.3	nd[d]	37.7	nd	nd
Long Walk	nd	nd	8.0	23.7	19.3	27.3
Summit	nd	nd	10.7	27.0	15.2	24.8

[a] Number of years after road obliteration.
[b] Before rainfall simulations were applied to the plots.
[c] After rainfall simulations were applied to the plots.
[d] No data taken.

Table 4. Parameter values determined from measured and WEPP rainfall simulations.

	Saturated Hydraulic Conductivity[a] (mm h^{-1})			Interrill Erodibility[b] (10^6 kg·s m^{-4})		
Site	2 Years After[c]	3 Years After	4 Years After	2 Years After	3 Years After	4 Years After
Brush Creek	5.2	6.9	nd[d]	1.2	1.8	nd
Long Walk	nd	8.9	10.2	nd	5.1	6.6
Summit	nd	11.0	11.9	nd	2.4	1.9
Average		9.0			3.2	

[a] Based on very wet soil rainfall simulation results.
[b] Based on dry soil rainfall simulation results.
[c] Number of years after road obliteration.
[d] No data taken.

Table 5. Selected published studies of the effects of road obliteration on saturated hydraulic conductivity.

Reference	Region	Soil Parent Material	Land Use/Timeline	Saturated Hydraulic Conductivity (mm h^{-1})
Robichaud (2000)	Western Montana, central Idaho	Weathered rhyolite, granite	Undisturbed forest	36 to 81
Luce and Cundy (1994)	Northern Colorado, western Montana, multiple locations in Idaho	Eolian sandstone, metamorphic schist, metamorphic gneiss, metamorphic shale, loess	Forest road surface	5×10^{-5} to 8.8 (geometric mean of 0.11)
Luce (1997)	Central Idaho	Metasedimentary belt series, granite	Immediately after obliteration	30
Foltz et al. (current)	Central Idaho	Basalt, glacial tilt	3 to 4 years after obliteration	9

obliterated road crossings to return to the infiltration rates of the undisturbed forest floor. Additionally, this study found that the lower infiltration rates (9.0 mm h^{-1}) on recontoured roads after four years following road obliteration were close to the value of 15 mm h^{-1} reported by Luce (1997) after 45 mm rainfall on a ripped road.

Combining the current study with others (Kolka and Smidt, 2004; Luce, 1997; Luce and Cundy, 1994; Robichaud, 2000), we envision a history of hydraulic conductivity on a road from prior to road-building to years after obliteration, as listed in table 5 and shown in figure 2. Before road construction, the forest floor has a hydraulic conductivity of 40 to 80 mm h^{-1} (Robichaud, 2000). After construction and road use during moderate amounts of traffic, the value is 5×10^{-5} to 8.8 mm h^{-1} (Luce and Cundy, 1994). Immediately following road obliteration, the hydraulic conductivity spikes to as much as 30 mm h^{-1}, which lasts perhaps as short as a cumulative rainfall of 45 mm (Luce, 1997). Up to four years after the obliteration, the hydraulic conductivity remains near 10 mm h^{-1}. Ultimately, the infiltration capacity is expected to approach that of the forest floor (40 to 80 mm h^{-1}), since wetting and drying, frost activity, animal activity, and root growth will recover soil properties (Kolka and Smidt, 2004); however, the time period required to reach this rate, or whether it is ever reached, remains unknown.

Table 4 presents the interrill erodibility calculated from the dry run. The covariance structure with the lowest AIC was unstructured. There were no significant differences between years ($F_{1,6}$ = 0.16, p-value of 0.70) and no significant interactions between sites and years ($F_{2,6}$ = 0.29, p-value of 0.76). However, there were significant differences among sites ($F_{2,6}$ = 7.10, p-value of 0.03). Therefore, we conclude that the sites had statistically significant differences in interrill erodibility and that these differences persisted between years. The Brush Creek site had lower interrill erodibility (1.5×10^6 kg·s m^{-4}) than the other sites. Brush Creek had the lowest elevation and highest vegetation ground cover among the sites (table 6).

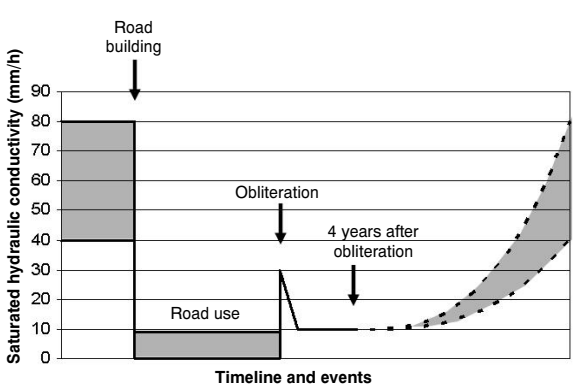

Figure 2. Postulated changes in hydraulic conductivity for a forest road. During road use, a moderate level of traffic is assumed. Shaded areas indicate range of possible values. Dashed lines represent unknown trend after road-obliteration.

Vegetation Ground Cover

Vegetation ground cover is shown in table 6. Despite seeding, fertilizing, and mulching application, overall site regeneration was slow within the first two to four years following the obliteration on all three sites. There was a statistically significant difference among the sites ($F_{2,6}$ = 13.7, p-value of 0.006). The two higher elevation sites, Long Walk and Summit, were not pairwise significantly different, while the lower elevation site, Brush Creek, was significantly different from both Long Walk and Summit. There were no significant differences in vegetation cover between subsequent years ($F_{1,6}$ = 0.68, p-value of 0.44) and no significant interactions between sites and years ($F_{2,6}$ = 0.78, p-value of 0.50).

All three sites were seeded with annuals in an effort to quickly stabilize soils without establishing non-native vegetation. Rocky soil, low organic matter, and high solar exposure likely slowed vegetation regeneration, particularly at the Long Walk and Summit sites where there were few adjacent trees to provide shade. In addition, the short growing season contributed to slow vegetation recovery at each site. The Long Walk and Summit sites have only 60 growing days a year, while Brush Creek has a slightly longer growing season (100 days). The greater vegetation cover measured at Brush Creek was likely due to the longer growing season and more productive soil.

The low vegetation recovery at the two higher elevation sites illustrates the need for post-obliteration monitoring. All three sites were obliterated in late-July or August, when soil

Table 6. Vegetation ground cover in consecutive years following road obliteration.

Site	Vegetation Ground Cover (%)		
	2 Years After[a]	3 Years After	4 Years After
Brush Creek	13	27	nd[b]
Long Walk	nd	4	6
Summit	nd	12	9

[a] Number of years after road obliteration.
[b] No data taken.

moisture was low and toward the end of the growing season. These conditions are not favorable for vegetation establishment in the same year of obliteration. These high elevation revegetation rates are consistent with those reported by Dyrness (1975) for natural vegetation recovery in Oregon, which took five years to reach 10% cover.

Model Predictions for Pre- and Post-Obliteration Conditions

Before a management decision for road obliteration, it might be useful to estimate the benefits of road obliteration, e.g., the reduction of chronic sediment input into streams. Forest Service specialists responsible for preparation of environmental impact statements are required to make such estimates. Rigorous sediment prediction would require many detailed geometric conditions, such as presence or absence of wheel ruts, spacing of drainage structures on the road, ditch condition, traffic amount, road gradient, and the length and steepness of the forest floor from the road to the stream (i.e., slope position of the road), which are beyond the scope of this article. However, the number and depth of runoff events is not dependent on geometric conditions but on the hydraulic conductivity of the road and forest floor. A comparison of model-predicted runoff can illustrate changes in the number of runoff events and runoff depth due to road obliteration without other detailed geometric conditions.

Table 7 summarizes the pre-obliteration and post-obliteration WEPP model predictions for each obliterated road stream crossing using the saturated hydraulic conductivity determined from this study (9.0 mm h^{-1}). Noteworthy are the reduced number of runoff events following obliteration. Since the WEPP model does not allow multiple storms in a single day, the number of runoff events is equivalent to the number of days with runoff. The decrease in the number of days with runoff from rain was highest at Brush Creek, where 15 days per year were expected prior to obliteration to 4 days per year after obliteration. Smaller reductions were predicted at the higher elevation Long Walk and Summit locations. Days with snowmelt runoff were reduced from nearly two months (66.6 events) to 9 days at Summit and from 21 days to 1 day at the lower elevation Brush Creek.

Runoff depths from both rain and snowmelt were similarly reduced on the obliteration sections compared to the pre-obliteration conditions. Runoff from rain was predicted to be reduced by a factor of 3 to 6, while snowmelt runoff was predicted to be reduced by a factor of 5 to 20 depending on elevation; higher elevations benefit more from snowmelt reductions, and lower elevations benefit more from rain runoff reduction.

Table 7. Predicted number of runoff events and runoff depth per year for pre- and post-obliteration conditions of the road surface.

	Number of Runoff Events ($year^{-1}$)				Runoff Depth (mm $year^{-1}$)			
	Rain		Snow		Rain		Snow	
Site	Pre[a]	Post[b]	Pre	Post	Pre	Post	Pre	Post
Brush Creek	15.4	4.2	21.3	1.3	61.2	10.3	144.0	28.0
Long Walk	13.8	7.5	48.3	5.1	72.2	23.3	354.4	19.4
Summit	8.2	6.2	66.6	9.4	61.7	20.9	729.8	34.3

[a] Based on the pre-obliteration condition of 1 m^2 road running surface.
[b] Based on the post-obliteration condition of 1 m^2 obliterated road surface.

Conclusions

This study determined infiltration and interrill erosion parameters on obliterated roads from two to four years after obliteration. Values of 9.0 mm h^{-1} for saturated hydraulic conductivity and 3.2×10^6 kg·s m^{-4} for interrill erodibility were determined. There was no statistically significant difference between the three sites and years, and no significant interactions were found between sites and years for saturated hydraulic conductivity. There were differences among the sites for interrill erodibility, but no differences between years and no significant interactions between sites and years. While the infiltration capacity of 9.0 mm h^{-1} was greater than that for a heavy-volume traffic road (<8.8 mm h^{-1} with a geometric mean of 0.11 mm h^{-1}), it was not as high as that of an undisturbed forest (40 to 80 mm h^{-1}). We conclude that four years was not sufficient time for the infiltration capacity of obliterated roads to return to the pre-road (forest floor) level.

The current study and previous studies have enabled us to envision a history of saturated hydraulic conductivity for a forest road: 40 to 80 mm h^{-1} before road construction, 5×10^{-5} to 8.8 mm h^{-1} during road use, 30 mm h^{-1} immediately after road obliteration, and around 10 mm h^{-1} up to four years after obliteration. Following mulching, seeding, and fertilizing, the lower elevation site displayed vegetation ground cover of 27% after three years, while high elevation sites treated in the same manner had significantly lower vegetation ground cover of 8% after four years.

Using the saturated hydraulic conductivity determined from this study, the WEPP model predicted the decrease in the number of runoff events and in runoff depth from rain and snowmelt. The low elevation site had the greatest decrease in the number of runoff events and runoff depth from rainfall, while the high elevation site had the greatest decrease from snowmelt.

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