WATER RESOURCES RESEARCH, VOL. 20, NO. 8, PAGES 1159-1163, AUGUST 1984

Alteration of Streamflow Characteristics Following Road Construction in North Central Idaho

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Effects of logging access roads on seven streamflow variables were monitored on six forested headwater watersheds in north central Idaho. The streamflow variables were annual maximum streamflow, date of maximum streamflow, annual minimum streamflow, annual water yield, and streamflow equaled or exceeded 5% of the year, 25% of the year, and 75% of the year. The watersheds, ranging in area from 28.3 to 147.7 ha, had less than 5% of their area in roads. Two statistically significant ($\alpha = 0.05$) changes occurred following road construction: an increase in the 25% exceedance flows in one watershed and a decrease in the 5% exceedance flows in another watershed. No significant changes were detected in other flow parameters on any of the watersheds. The results indicate that the hydrologic behavior of small forested watersheds may be altered when only a small area is disturbed by roads.

INTRODUCTION

The potential impacts that land use activities can have on water and soil resources have produced the recent impetus toward more definitive evaluation of the effects of forest management activities on forested headwater streams. Silviculture acti[illegible] such as harvesting, site preparation, regeneration, an[illegible]ated road construction can produce changes in strea[illegible]w yield and regimen. Therefore predictability of the magnitude of these changes, as related to silviculture activities, is prerequisite to selection of management alternatives which maintain acceptable levels of streamflow integrity.

Roads are an integral part of silvicultural systems; however, the impacts of roads on stream hydrology need to be separated from other activities. Establishment of a road network in a watershed may affect stream hydrology in several ways. The oad surface has a low permeability, which is conducive to eneration of overland flow. Ditch systems and relief culverts oncentrate surface runoff and alter the natural surface flow aths. Road location and height of the cut slopes will partially nfluence the amount of subsurface water intercepted at the oad and routed through the ditch system. The combined effects of roads could significantly affect local streamflow quanity and regimen. Streams, following road construction, may espond faster and have larger peak flows during snowmelt or ain events. Modifications of the flow quantities and regimen lue to roads may subsequently be reflected in changes in tream channel characteristics and sediment transport capaciy.

A majority of the studies investigating the hydrologic imacts of roads on forested headwater streams in the western nited States have been on larger watersheds and, in most nstances, have evaluated the combined effects of road construction and timber harvesting. In the H. J. Andrews Experienta[illegible]st of western Oregon, streamflow was monitored on a 101-ha watershed for 4 years following construction of roads which occupied 8% of the watershed area. *Rothacher* [1970] did not detect any significant increases in annual yield due to the roads. Also, no significant increases in mean peak flows occurred following road construction on this watershed [*Rothacher*, 1973].

Harr et al. [1975] evaluated storm flow response to road construction in four watersheds in western Oregon ranging in size from 40 to 304 ha. Significant increases in mean peak flows were observed in both the fall and the winter periods on a watershed with 12% of its area in roads. The other three watersheds, with 3-5% of their area in roads, showed no statistical increase in mean peak flows. *Harr et al.* [1979] reported significant increases in the average peak flows after road building in a 60-ha Coyote Creek watershed in western Oregon. Approximately 15% of this watershed was occupied by roads and skid trails. In analyzing results from watershed studies in Oregon, *Harr* [1976] states that both harvesting and road construction may increase small peak flows; however, large peak flows appeared to be increased only when greater than 12% of the area was severely compacted (roads, skid trails, landings, etc.).

Ziemer [1981] reported that the presence of roads, occupying 5% of a 424-ha Casper Creek watershed in northern California, did not alter any of the seven storm flow parameters he evaluated, including peak discharge. These results were not unexpected because of the small area in roads.

Although the results from past studies are variable, no or very small increases in water yield occurred if less than 8% of the area was in roads. Average peak flows may be significantly increased, but large peak flows were not increased until about 12% of the area was either in roads or a combination of roads and other severely compacted sites. All these studies were located in areas where precipitation is dominated by rain. In snowfall-dominated areas the magnitudes and types of hydrologic alteration may be quite different.

In 1965 the Horse Creek Administrative Research Project was initiated by the U.S. Department of Agriculture Forest Service. Major objectives of the Horse Creek project are (1) to

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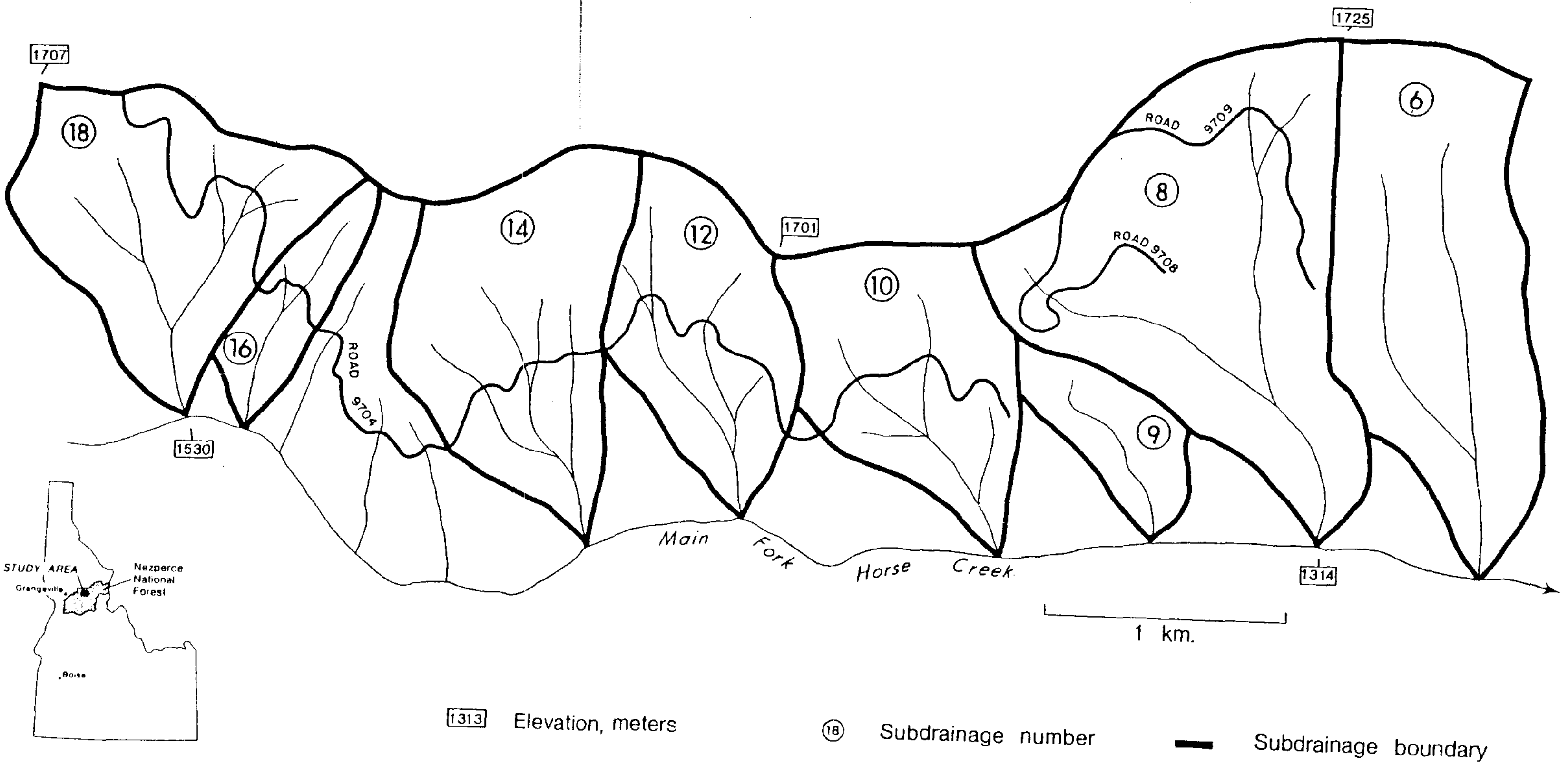

Fig. 1. Location of the Horse Creek Administrative Research Area and the seven monitored subwatersheds which were included in this study.

evaluate the effects of a specifically designed timber harvest on soil and water and (2) to evaluate alternative road construction, stabilization, and maintenance procedures on these same resources. This study was designed to investigate the impacts of preharvest road construction on the flow characteristics of selected streams within the Horse Creek drainage.

AREA DESCRIPTION

The Horse Creek Administrative Research Project is located in the Nezperce National Forest of north central Idaho, 57 km east of Grangeville, Idaho (Figure 1). The size of the watersheds ranges from 28 to 148 ha. Elevations range from 1292 to 1803 m, and the median side slope is 31%, although slopes frequently exceed 65%. Channel gradients average 17.5% in the headwaters and 7.5% in the lower portion of the watersheds. The watersheds are completely timber covered with a mixture of conifers, predominately grand fir (*Abies grandis* (Dougl.) Forbes).

The area is located on the border of the Idaho Batholith, a large igneous intrusion. Parent material is part of the Belt Super Group (E. H. Bennett, unpublished data, 1974), composed of sedimentary and metasedimentary rock of primarily gneissic material [*Greenwood and Morrison*, 1973]. The deeply weathered regolith is composed of well-drained sandy loam to loam soils. Loessal silt is present in the surface layers of the soil.

The climate is affected by modified marine air masses from the Pacific Ocean. The average annual precipitation is 107 cm, with about 70% occurring as snowfall. Summer rains are convective storms of high intensity and relatively short duration. About 40–50% of the precipitation appears as streamflow. Annual peak flows, which typically occur during spring snowmelt, range from 0.03 to 0.23 m^3/s for these small watersheds.

In the summer of 1978 a total of 6.5 km of logging access roads were constructed on watersheds 8, 16, and 18. A total of 3.9 km of roads were constructed on watersheds 10, 12, and 14 during the summer of 1979.

METHODS OF ANALYSIS

Daily discharge data were collected at the mouths of the watersheds using H-type flumes with 5-foot deep cutoff walls upstream. Comparison of measured annual streamflow and precipitation with regional maps of streamflow and evapotranspiration indicates that losses via underflow are negligible. Water years 1975–1980, which included pre- and post-road flow periods for watersheds 8, 10, 12, 14, 16, 18 and the control watershed 6 (no roads), were used to evaluate the influence of roads on streamflow. Harvesting began on the watersheds with roads 2 years after construction; therefore analyses of road effects on streamflow were limited to this time period.

Least squares regression models of the form $Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$ were used to develop pre-road calibration equations and associated statistics for certain flow parameters on watersheds 8, 10, 12, 14, 16, and 18 as related to the same flow parameter on control watershed 6. Regression equations were evaluated for significance at the $\alpha = 0.05$ level using the standard F-statistic test. Prediction intervals were calculated about the predicted values at the $\alpha = 0.05$ level [*Steel and Torrie*, 1960]. A post-road observation falling outside the prediction limits was considered a significant change in the flow regimen of a watershed as reflected in that particular variable.

Annual flow variables selected for analysis were peak flow (Q_{peak}), Julian date of peak flow (PEAKDAY), minimum flow ($Q_{\min}$), water yield (YIELD), and flows equaled or exceeded 5% of the time (Q_5), 25% of the time (Q_{25}), and 75% of the time (Q_{75}). The Q_5 flows represent the 18 days of highest flow, typically occurring during snowmelt runoff. The Q_{25} flows represent the snowmelt runoff season plus a few summer convective storms, and Q_{75} represents low flows which normally occur in the late summer and fall seasons.

Several watershed and road indicators were developed to assist in evaluating those watersheds that were significantly affected by the presence of roads. These indicators included road length, area of watershed in roads, contributing area of watershed above roads, number of stream crossings, and percentage of cut slopes with vertical height greater than 6 m.

RESULTS AND DISCUSSION

Regression equations were developed for the flow parameters of watersheds 8, 10, 12, 14, 16, and 18 with the control watershed 6 prior to road construction. The number of years of daily flow records was limited to 4 or 5, depending on the watershed. However, this period of record provided sufficient data for development of significant equations for the flow parameters selected in this study. Thirty-three of the 42 equations were significant at $\alpha = 0.05$ with $r^2 \geq 0.90$. These significant equations were used for post-road comparisons. The annual yields for control watershed 6 ranged from 234 to 721 mm, with an average of 517 mm during the calibration period. For water years 1979 and 1980, following road building on the other watersheds, the annual yields for this watershed were 334 and 342 mm, respectively. These flows are below the average yield and represent return periods of approximately 1.5 years based on 13 years of record from the Main Fork of Horse Creek. The magnitudes and significance of changes in the flow duration parameters are shown in Table 1.

The area of the Horse Creek watersheds disturbed by roads ranged from 1.8 to 4.3% (Table 2). Flow parameters in watersheds 8, 10, 14, and 16, which had road disturbances of 3.7%, 2.6%, 1.8%, and 3.0%, respectively, were not significantly changed during the study period. However, analysis of pre-road calibration plots, with associated prediction intervals and post-road observations, revealed significant changes in streamflow variables after road construction on watersheds 12 and 18, where road disturbances were 3.9% and 4.3%, respectively. The flow parameters Q_{peak}, PEAKDAY, $Q_{\min}$, YIELD, and Q_{75} were not significantly altered on any of the roaded drainages.

A significant increase in Q_{25} flows occurred in watershed 12 after road construction. Flow during the snowmelt period (Q_{25}) was 30.5% greater than that predicted, representing an increase in flow of 0.0029 m^3/s. The road in watershed 12 is located approximately midslope with a potential for intercepting subsurface flow from a comparatively large upslope contributing area, 54.2 ha (Table 2), which is 67% of the watershed area. Additionally, 61% of the length of the road has cut slopes greater than 6 m in vertical height. These two conditions favor the interception of subsurface flow. The most probable explanation for the significant increase of 30.5% in Q_{25} flows is that subsurface flow intercepted at the road cuts is now being diverted to the stream as surface flow with a comparatively shorter lag time. We observed that along one large cut slope, interception of subsurface flow is especially noticeable, as evidenced by long periods of flow in the ditches.

While subsurface flow magnitudes and flow paths may be highly variable between watersheds, the interception of sub-

TABLE 1. The Difference Between Predicted and Observed Streamflow Parameters for the Horse Creek Watersheds With Roads

	Streamflow Variables														
Watershed	YIELD, mm	YIELD, %	PEAK-DAY, Day	PEAK-DAY, %	Q_{peak}, m³/s	Q_{peak}, %	Q_5, m³/s	Q_5, %	Q_{25}, m³/s	Q_{25}, %	Q_{75}, m³/s	Q_{75}, %	Q_{min}, m³/s	Q_{min}, %
						Water Year 1980								
18	+22.8	+4.3			+0.007	+12.6	−0.009	−19.2*			+0.0006	+9.3		
16	−9.2	−3.0			+0.003	+22.7	−0.003	−25.0			+0.0000	+4.5		
14	+16.9	+4.7	0	0	+0.005	+13.7	−0.003	−8.6	+0.0015	+22.0	+0.0001	+7.5		
12	+56.5	+16.3	0	0	+0.024	+56.2	+0.003	+9.5	+0.0029	+30.5*	+0.0001	+3.3	−0.0020	−7.2
10	+7.9	+2.3	0	−1	+0.002	+5.3	−0.001	−5.8	+0.0005	+6.8	+0.0003	+14.7		
8	+20.0	+5.8	0	0	+0.010	+11.1	+0.002	+3.6	+0.0013	+7.0	+0.0007	+10.8	−0.0006	−1.4
						Water Year 1979								
18	−20.7	−4.0			−0.004	−4.6	−0.018	−29.4*	−0.0040	−24.4	+0.0008	+16.7		
16	−5.9	−1.9			−0.005	−19.5	−0.004	−20.7	−0.0009	−34.0	+0.0004	+82.4		
8	+29.8	+8.7	0	0	+0.010	+6.7	+0.006	+8.3	+0.0003	+2.2	+0.0011	+19.9	+0.0096	+6.7

*Significant at $\alpha = 0.05$.

surface flow at roads is an important hydrologic process. In the Intermountain West, most of the precipitation occurs as snowfall, and spring snowmelt generates the annual hydrograph peak. During this peak the soil mantle is saturated, and subsurface flow rates are high.

The interception of subsurface flow at road cuts during snowmelt, as reported in past studies, emphasizes the potential hydrologic alteration due to the presence of roads. *Burroughs et al.* [1971] measured subsurface flow interception along cut slopes on forest roads in northern Idaho. Cut slope heights averaged 0.9 m, and depths to bedrock ranged from 4.3 to 13.7 m. During a 5-day period in the middle of the snowmelt season, daily subsurface flow volumes averaged 11.7 m³/m of road. The peak discharge over that period was 0.008 m³/s from 30.5 m of road. In the Idaho Batholith, *Megahan* [1972] measured subsurface flow intercepted at roads below 1.3 ha of contributing area. Subsurface flow occurred only during snowmelt and large rain events. Volumes of intercepted flow were estimated to be 7.3 times greater than the estimated surface runoff from these roads. The maximum daily volume measured was 1.06 m³/m of road.

Watershed 18, with 4.3% of its area in roads, exhibited a significant decrease in the 5% exceedance flow, which represents the 18-day period of highest snowmelt flows. Decreases in Q_5 flows for water years 1979 and 1980 were 29.4% and 19.2% (Table 1), respectively.

Alteration of the hydrologic behavior of watershed 18 was not expected, because the roads are located on the upper slopes of the watershed with only 24% of the area (19.7 ha) above the road. Also, less than 1% of the cut slopes were higher than 6 m. However, this watershed had the largest percentage of its area in roads. Watershed 8 is similar to watershed 18 in many respects, but similar changes in the Q_5 flows were not detected. Watershed 8 has 3.7% of its area in roads and a 24.6-ha contributing area to the ditch system. The 5% exceedance flows following road building were not reduced in this watershed as in watershed 18. W. F. Megahan (personal communication, 1981) hypothesizes that the modifications in hydrologic responses caused by roads may be reflected as either increases or decreases in the flow duration parameters. Alteration of the natural synchronization of subsurface and surface water from the different units of the watershed could cause either increases or decreases in flow for selected time periods.

CONCLUSIONS

Hydrologic responses to road building in six small headwater watersheds were highly variable. Actual changes in flow parameters YIELD, PEAKDAY, Q_{peak}, Q_5, Q_{25}, Q_{75}, and Q_{min} could not be detected on watersheds 8, 10, 14, and 16 after road construction. Similar results occurred on watersheds 12 and 18 with the exception of Q_{25} flows and Q_5 flows, respectively, which were significantly altered after road construction.

The location of the road in the drainage and the design of the road will affect the magnitude of any hydrologic modification. In areas conducive to subsurface flow where the land is sloping, surface soil is permeable, a water-impeding layer is near the surface, and the soil is saturated [*Whipkey*, 1965], the amount of subsurface flow intercepted along road cuts will typically increase with increasing upslope contribution, depending on the degree to which the road cuts intersect the water-impeding layer. A significant increase in streamflow during the snowmelt hydrograph occurred in watershed 12, which has a large contributing area and a road with relatively high cut slopes.

Subsurface flow paths and the timing of subsurface contri-

TABLE 2. Watershed Characteristics and Associated Road Information for the Horse Creek Drainages

Subwatershed	Road Length, km	Total Area, ha	Area in Roads, %	Contributing Area Above Road, ha	Number of Stream Crossings
18	1.835	86.2	4.3	19.7	3
16	0.445	28.3	3.0	16.8	2
14	0.907	62.3	1.8	36.6	4
12	1.608	83.8	3.9	54.2	3
10	1.376	65.2	2.6	43.4	2
8	4.170	147.7	3.7	24.6	3
6	0.000	103.6	0.0	0.0	0

butions to streamflow are usually not well known for most watersheds. The location of the road and its effects on nchronizing the subsurface flow to streams result in highly ble effects between watersheds. Increases in the 25% ex-cedance flows and reductions in the 5% exceedance flows were found on watersheds 12 and 18, respectively. Previous studies have indicated that streamflow is not altered if less than 8% of the watershed area is in roads and skid trails. Results of this study indicate that the impacts on streamflow in small headwater watersheds with 1.8–4.3% of the area in roads are highly variable but in general agreement with past findings.

REFERENCES

Burroughs, E. R., Jr., M. A. Marsden, and H. F. Haupt, Volume of snowmelt intercepted by logging roads, paper presented at the National Engineering Meeting, Am. Soc. Civ. Eng., Phoenix, Ariz., Jan. 11–15, 1971.

Greenwood, W. R., and D. A. Morrison, Reconnaissance geology of the Selway-Bitterroot Wilderness Area, *Pam. 54*, Idaho Bur. of Mines and Geol., Moscow, 1973.

Harr, R. D., Forest practices and streamflow in western Oregon, *Gen. Tech. Rep. PNW-49*, U.S. Dep. of Agric. For. Serv., Portland, Oreg., 1976.

Harr, R. D., W. C. Harper, J. T. Krygier, and F. S. Hsieh, Changes in storm hydrographs after road building and clear-cutting in the Oregon coast range, *Water Resour. Res., 11*(3), 436–444, 1975.

Harr, R. D., R. L. Fredricksen, and J. Rothacher, Changes in streamflow following timber harvest in southwestern Oregon, *Res. Pap. PNW-249*, U.S. Dep. of Agric. For. Serv., Portland, Oreg., 1979.

Megahan, W. F., Subsurface flow interception by a logging road in mountains of central Idaho, in *National Symposium on Watersheds in Transition*, pp. 350–356, American Water Resources Association, Minneapolis, Minn., 1972.

Rothacher, J., Increases in water yield following clear-cut logging in the Pacific Northwest, *Water Resour. Res., 6*(2), 653–658, 1970.

Rothacher, J., Does harvest in west slope Douglas-fir increase peak flow in small forest streams?, *Res. Pap. PNW-163*, U.S. Dep. of Agric. For. Serv., Portland, Oreg., 1973.

Steel, R. G. D., and J. H. Torrie, *Principles and Procedures of Statistics, McGraw-Hill*, New York, 1960.

Whipkey, R. Z., Subsurface stormflow from forested slopes, *Bull. Int. Assoc. Sci. Hydrol., 10*, 74–85, 1965.

Ziemer, R. R., Storm flow response to road building and partial cutting in small streams of northern California, *Water Resour. Res., 17*(4), 907–917, 1981.

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(Received June 15, 1983;
revised March 28, 1984;
accepted April 2, 1984.)