Construction phase sediment budget for forest roads on granitic slopes in Idaho*

WALTER F. MEGAHAN
KATHLEEN A. SEYEDBAGHERI
TIMOTHY L. MOSKO
USDA-FS, Intermountain Forest and Range Experiment Station, Boise, ID 83702
and
GARY L. KETCHESON
USDA-FS, Sawtooth National Forest, Twin Falls, ID 83301

ABSTRACT
Total erosion for the construction period was determined for forest roads built in three steep, granitic basins in Idaho, using sediment budgeting techniques that accounted for total sediment leaving the basin plus that stored on the slopes and in stream channels. Sediment storage on slopes was documented with respect to both travel distance and volume for 387 sediment deposits below fill slopes and 31 sediment deposits associated with culverts. Sediment yields from the study basins increased an average of 5.0 times as a result of erosion during the construction period. Total road erosion during construction amounted to 303 m^3, distributed as follows: 259 m^3 on slopes, 24 m^3 in channels, and 21 m^3 delivered to watershed outlets, providing a delivery ratio averaging 7% for the construction period. Much of the erosion during construction depended on the stage of construction at the time of a storm rather than road design features.

INTRODUCTION
Accelerated surface and mass erosion and resulting sedimentation often occur following road construction on mountainous lands (Megahan, 1985). For a given road location, much surface and mass erosion can be reduced or eliminated by careful road design and construction practices. Most erosion control features (embankment protection, drainage control, etc.), however, are not yet operable during construction. Thus, storms during construction cause excessively high erosion rates and help contribute to maximum erosion rates reported for the first year after road construction and followed by declining erosion rates over time (King, 1984).

Logging road construction is particularly damaging in highly erodible areas, such as the 41 400 km^2 Idaho Batholith (Fig. 1), which is characterized by steep topography and shallow, coarse-textured soils overlying granitic bedrock. Road construction on steep slopes in the Idaho Batholith may accelerate sediment production by hundreds of times compared to undisturbed drainage basins in response to accelerated mass and surface erosion (Megahan, 1985).

The objective of the present study was to document the disposition of eroded material from the road prism to the drainage basin outlet during the construction period when erosion rates are high. Such a sediment budgeting approach allows us to not only define the changes in sediment yields caused

* Contribution of the U.S. Dept. Agric. Forest Service, Intermountain Forest and Range Expt. Sta., Ogden, Utah 84401.

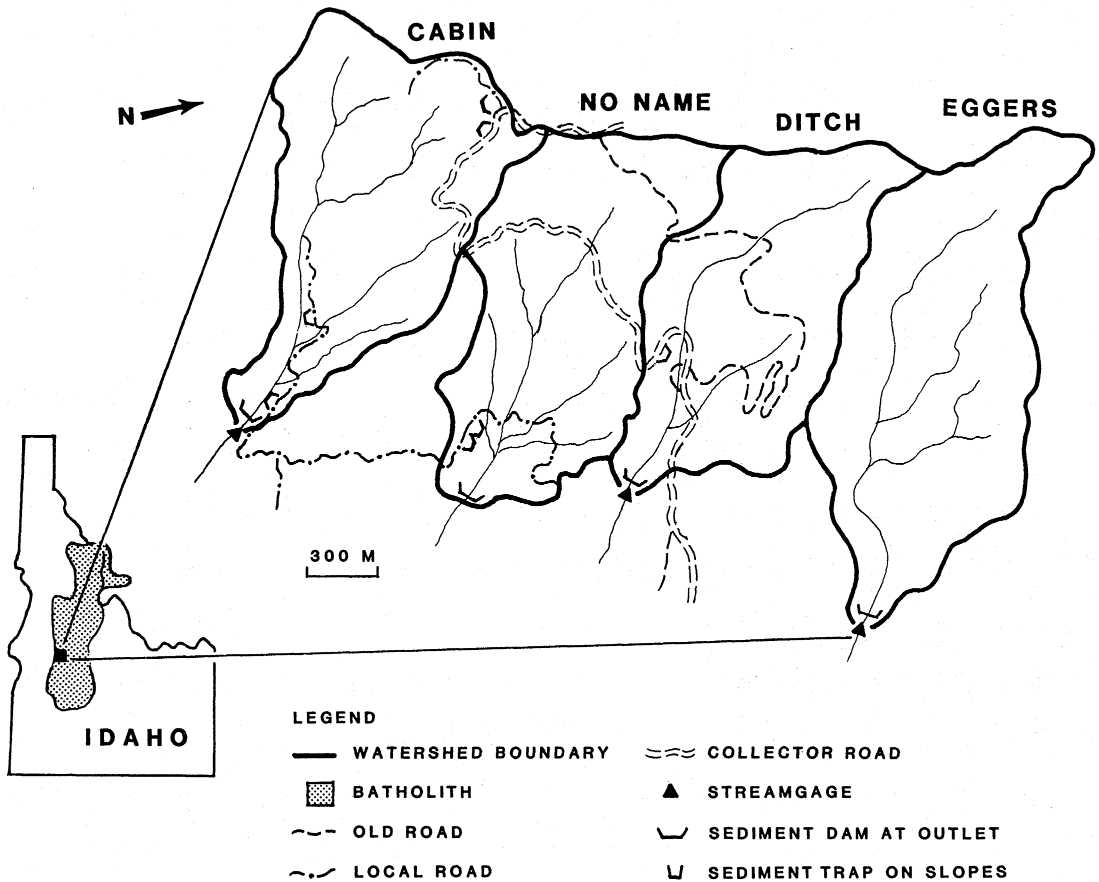

FIG. 1 Location map and road construction in the study watersheds.

by road construction but to define sediment movement and storage within the basin as well.

DESCRIPTION OF THE STUDY AREA

The study area is located in the Silver Creek drainage basin, a tributary of the Middle Fork of the Payette River in south central Idaho. Four study basins ranging from 104 to 130 ha in size were involved in the development of the road construction sediment budget. Roads were constructed in the Ditch, Cabin, and No Name Creek basins. The Eggers Creek drainage serves as a long-term control (Fig. 1). Quartz monzonite is the dominant rock in the study area and is moderately to well weathered according to the classification by Clayton et al. (1979). Soils are described as gravelly, loamy, coarse sands, and range in depth from 150 cm in topographical lows to 10 cm or less on ridges. Soils are noncohesive and thus are highly erodible because of low clay and silt contents (less than 5 and 10% respectively). Hill slopes in the vicinity are generally steep, with gradients ranging from 22 to 36 degrees.

Based on suspended and bed load sediment data, bed load accounts for about 70% of the total annual sediment yield on the study basins (Unpublished data, Intermountain Forest and Range Experiment Station, Boise, Idaho). Streamflows and sediment production exhibit marked seasonal variation with most of the annual streamflow and sediment yield occurring during spring snowmelt. Two of the study basins were undisturbed prior to road construction. A low-standard road constructed in 1933 passes through the lower and middle portions of the Ditch Creek drainage and the head of the No Name Creek drainage (Fig. 1).

Annual precipitation ranges from 90 to 130 cm in response to an elevation difference ranging from 1400 to 2070 m. About 65% of the precipitation falls as snow during the winter; most of the remainder falls as rain in the spring and fall. However, high-intensity, convective storms during the summer and fall cause about 80% of the annual erosion from unvegetated granitic road fill slopes in the vicinity of the study area (Megahan, 1978). Tree cover on the study drainage basin is predominantly ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and interior Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *glauca* [Beissn.] Franco).

ROAD CONSTRUCTION

Road construction took place in the Ditch, No Name, and Cabin Creek basins. Construction began on 22 June 1980, and was entirely completed by 13 November 1980. Two types of roads were constructed: (a) a connector road designed to provide permanent access across the divide between Silver Creek and the Middle Fork of the Payette River; and (b) local roads designed to support timber harvest activities on study basins. The connector road carries through traffic and thus has higher design speeds (32 km h-1) compared to the local roads (8 km h-1). This is accomplished by the use of a wider road surface and gentler horizontal and vertical curvature on the connector road. Local roads are closed to general use except for timber harvest activities. Portions of the old road built in 1933 required minor reconstruction to improve alignment and replace culverts to bring it up to present local road standards.

The connector road starts at the bottom of the Ditch Creek drainage basin and runs through the center of the No Name basin and the head of the Cabin Creek basin where it crosses the main ridge dividing Silver Creek and the Middle Fork of the Payette River. Local roads were constructed in the lower portions of the Cabin and No Name basins and in the upper end of the Cabin Creek basin. Reconstruction took place on portions of the old road in the upper ends of the No Name Creek and Ditch Creek drainages (Fig. 1).

A maximum erosion control effort was used on all roads constructed in the Cabin Creek drainage. This utilized all practical means to reduce erosion, including: asphalt surfacing on the connector road and crushed rock

TABLE 1 Details of road design features

Basin	Type of road	Road length (km)	Road area (ha)	Maximum total width* (m)	Mean cut-slope length (m)	Mean fill-slope length (m)	Mean road gradient (%)	Type of erosion control
Cabin	connector	0.93	1.52	8.6	12.2†	14.0†	10.7	maximum
	upper local	0.54	0.53	6.1	6.0†	10.0†	6.7	maximum
	lower local	1.48	1.78	5.5	11.2	12.2	6.6	maximum
No Name	connector	1.32	2.68	8.6	14.5	21.6	7.5	variable
	local	1.41	1.87	8.6	9.4	11.5	2.0	routine
Ditch	connector	0.96	1.38	8.6	13.5	11.0	8.1	routine

*Includes 4.3 m of driving surface (3.7 m for lower local road in Cabin basin) plus additional widening up to the amount shown to provide for any combination of the following: road shoulders, turnouts, ditches, curves, and settling of the outside edge of fills.

†Approximate figures

surfacing on the local roads; controlled compaction of all fill embankments; mulching and revegetation of fill slopes; culvert downspouts; energy dissipators, etc. Routine present day erosion control practices for the Boise National Forest (such as no road surfacing, uncompacted fill embankments, no culvert downspouts or energy dissipators, and dry seeding of fill slopes) were used on all road construction in the Ditch Creek basin. Routine erosion control practices were also used on the connector road in the No Name basin except at selected locations where plot studies were used to evaluate the effectiveness of various erosion control practices. Additional data summarizing details of design features for the new road construction are presented in Table 1.

METHODS

Budgets for sediments produced by accelerated erosion during the road construction period were developed for each study basin on the basis of sediment leaving a basin plus that stored at various locations downslope from the roads as follows:

$$E_r = \pm \Delta S_s \pm \Delta S_c + S_y \quad (1)$$

where:

E_r = total road erosion (defined as all material moving downslope below the road)

ΔS_s = change in sediment storage on slopes

ΔS_c = change in sediment storage in channels

S_y = sediment yield at the mouth of the basin attributed to construction.

Sediment Yields

Sediment yields were measured in sediment detention reservoirs at the outlet of each study basin using a network of closely spaced cross sections. The reservoirs are routinely surveyed in the spring and fall and at other times as needed. The dams have removable spillways to allow for periodic flushing to maintain storage capacity. Core samples of the sediment deposits in the dams are collected using a grid pattern sampling scheme at the time of flushing in order to determine sediment particle size distribution and volume weight. Supplemental suspended sediment data are collected with automatic sediment samplers. Samples are taken in 2.4-m-long, open-top, box-culvert control sections located about 30 m above the upstream end of the sediment detention reservoirs. The bottom of the box culverts is designed to create a hydraulic jump. Intakes for the automatic sediment samplers are located in the hydraulic jump in order to take advantage of sediment mixing at that point and thus provide a more reliable sample of total sediment load.

Channel Sediment Storage

Changes in channel sediment storage were evaluated with series of five channel cross sections spaced 3 m apart located at 150-m intervals along the main channel in each drainage, beginning at a point 30 m above each sediment dam and extending upstream for the entire length of perennial channel. Cross sections are referenced to permanent stakes and are measured using a sag tape procedure. Data are collected each year during the period 1 July to 15 September. A comparison of successive channel bottom surveys at each cross section provides a measure of the change in channel sediment storage.

Sediment Storage on Slopes

Sediment storage on slopes was determined by a detailed survey of all sediment deposited on slopes below the road prisms in all study basins. Surveys of sediment deposits caused by road erosion are possible because of the light color and coarse texture of the eroded granitic materials. Average length, width, and thickness of the sediment deposits were used to determine the volume of deposition on the slopes. The thickness of the deposits was obtained by excavating or coring the deposits.

At a few sites, slope storage was determined using small sediment traps constructed on the slopes adjacent to the road. Four, two, and one traps were located in the Cabin, No Name, and Ditch Creek basins, respectively. The traps were located from 8 to 55 m below the toe of the road fill. There was no sediment deposition in any of the traps during the preconstruction period. Sediment accumulations were measured using sag tape cross sectioning and coring techniques similar to those used at the downstream end of each study basin.

RESULTS AND DISCUSSION

Sediment Storage on Slopes

The total sediment storage on slopes in the study basins was: Ditch, 68 m^3; Cabin, 106 m^3; and No Name, 85 m^3. The surveys were made in October 1980 at a time when the roads were nearly completed. The total volume of sediment stored on the slopes had accumulated over about a 4-month period since the beginning of construction.

The distance that sediment travels down a slope defines the value of forest sites as a buffer for downstream sediment production. In order to evaluate this, we documented the total travel distance for individual sediment deposits. Sediment deposits that extended to perennial streams were included in the survey for total volume of slope storage but not in the analysis of sediment travel distance. Sediment deposits originating from the road fills were separated from those associated with berm drains and cross drains because road runoff captured by the culverts introduces greater energy for sediment transport than does fill surface runoff. Moreover, the culverts introduce up to three additional sediment source areas including the road surface, ditch, and cut slopes, depending on culvert type and location.

A total of 387 individual sediment deposits occurred from fill slopes and an additional 31 deposits were associated with drainage culverts. The average travel distance for sediment deposits from fills was 6 m, with 94% of the deposits travelling less than 15 m. The maximum deposit distance was 64 m. In contrast, the average travel distance for sediment from culverts was greater, averaging 32 m, with 39% of the deposits less than 15 m in length. The maximum distance for sediment deposits associated with culverts was 118 m. As might be expected, the data show that adequate buffer strip protection during construction is much more critical in the vicinity of fills with drainage culverts than it is for fill slopes without culverts.

The need for adequate protection for fills with culverts is further emphasized when we consider the volume of sediment movement. The average volume of deposits from fill slopes is 0.3 m^3 compared with 4.7 m^3 for deposits below culverts. This difference amounts to 15 times greater deposition per deposit for culverts or a total of 143.7 m^3 for the 31 deposits below culverts compared with 130.7 m^3 for the 387 deposits from fills.

Channel Sediment Storage

Cross section data are available for evaluating changes in channel sediment storage below the roads on the study drainages relative to the undisturbed control drainage (Eggers Creek). Three channels with a total of 55 cross sections were compared for 1979-1980 and four channels with a total of 106 cross sections were compared for 1980-1981. The total volume change in channel sediment storage was estimated by multiplying the measured change in channel cross section area by the length of channels below the roads for the three basins with roads, and by the total channel length for the unroaded Eggers Creek basin.

An analysis of variance test showed no statistical difference (95% level) in the change in channel sediment storage from 1979 to 1980 on the Ditch and Cabin Creek basins relative to the control basin. This was expected because the 1980 channel data were collected before road-related sediment began accumulating in the channels (except in Ditch Creek, where pioneer road construction and a culvert failure in July caused some apparent deposition in portions of the channel). Road effects were apparent for the period 1980 to 1981 when significant (95% confidence level) channel deposition occurred in Ditch Creek amounting to 9 m^3 and in No Name Creek amounting to 42 m^3 but not in Cabin Creek.

The summer 1981 channel survey data include both construction phase and postconstruction erosion. Based on observations of road erosion rates both during and after construction, we estimate that of the road-related channel aggradation occurring from 1980 to 1981, 75% in Ditch Creek eroded during construction, and 40% in No-Name Creek eroded during construction. On this basis, the total change in channel storage caused by construction alone is estimated to be +7 m^3 for Ditch Creek and +17 m^3 for No Name Creek.

Sediment Delivery to Basin Outlets

Each measurement of the sediment detention reservoirs integrates sediment production for the entire period back to the previous measurement. Thus, the early fall data represent sediment yields for the summer streamflow period. Measurements made in early October 1980 can be used to evaluate possible effects of construction up to that time. Trap efficiencies of the detention reservoirs were found to be about 95% for the low flow summer-fall period. This value is based on suspended sediment samples taken with the automatic sediment samplers projected over the measurement period using sediment-discharge curves.

Sediment data for the undisturbed control basin (Eggers Creek) and the three roaded basins are summarized in Table 2 for the preconstruction and construction periods. The average summer-fall sediment yields for the 1968-1979 preconstruction period are shown for the Eggers, Cabin and Ditch Creek basins. All mean values are relatively close as are the 95% confidence levels. There are no statistically significant differences between the sediment yields for the streams measured during the preconstruction period. During construction in 1980, the sediment yield for the undisturbed watershed was actually lower than average whereas the sediment yields on Cabin and Ditch Creek were far above the long-term average. The 1980 values for these two drainages fall outside the 95% confidence level, indicating statistically significant increases in sediment yield caused by road construction.

TABLE 2 Summer-fall sediment yields at the drainage basin outlets before and during construction*.

Stream	Before: 1968–1979† Mean	Before: 1968–1979† 95% Confidence interval	Before: 1979	During: 1980	Type of erosion control
	(m³)		Individual values		
Ditch	1.0	0.2–1.8	1.5	5.6	routine
Cabin	0.8	0.2–1.5	0.5	1.8	maximum
No Name	-	-	0.8	4.0	variable
Eggers	0.9	0.4–1.4	1.2	0.5	no roads

*Data corrected for 95% trap efficiency.
†1978 data missing for all watersheds.

Although long-term data are not available for the No Name drainage, this basin is contiguous and similar to the Cabin and Ditch Creek basins. Thus, sediment yields from No Name Creek would be expected to be very similar to Cabin and Ditch Creeks for undisturbed conditions. Data for 1979 suggest this assumption is valid; the sediment yield for No Name Creek fell between that recorded for Cabin and Ditch Creeks. Road construction in the No Name Creek basin caused a large increase in sediment yield similar to the responses for the other roaded basins.

A subsequent sediment yield measurement was required during January to avoid overtopping the sediment dam in Ditch Creek. This was the first time in the study's history when any sediment reservoir had to be surveyed and flushed in midwinter. The sediment reservoirs in the other three drainage basins did not require cleaning in January; however, there were obvious sediment accumulations. Detailed surveys of the other reservoirs were not made at that time because of minimal sediment accumulations and severe weather conditions. Instead, sediment volumes in the dams were estimated using measurements of average length, width, and depth of the sediment deposits.

The winter sediment accumulation resulted from some postconstruction as well as some construction period erosion. Based on timing of construction and observations of pre- and post-construction road erosion through January 1981, we estimate that 50, 60, and 100% of the January sediment yield was caused by erosion during construction in Ditch, No Name, and Cabin Creek basins, respectively. With these adjustments, the sediment yield attributed to construction was greatest in Ditch Creek ($13\ m^3$), intermediate in No Name Creek ($6\ m^3$), and least in Cabin Creek ($2\ m^3$), for a total of $21\ m^3$. The predicted total sediment yield for all three study basins assuming no roads was $4\ m^3$. The roads added an additional $21\ m^3$ of sediment, which resulted in about 5 times more sediment production for the construction period than would have occurred without the influence of the roads.

Sediment Budgets

Sediment budgets to derive total road erosion for the construction period were developed using Equation 1. Components of the sediment budget for each basin are summarized in Table 3.

One of the most striking features in the sediment budget is the importance of the slope storage component. Within the Ditch Creek drainage, 77% of the construction period erosion was stored on the slopes. For Cabin

TABLE 3 Sediment budgets for the roaded basins for the construction period

Drainage basin	ΔSs Storage on hill-slopes	ΔSc Channel storage	Sy Delivered to outlet	Total road area	Er Total road erosion		Type of erosion control
	(m^3)			(ha)	(m^3)	(m^3 ha^{-1})	
Ditch Creek	68	7	13	1.38	88	63	routine
Cabin Creek	106	0	2	3.82	108	28	maximum
No Name Creek	85	17	6	4.55	108	24	variable
Totals	259	24	21	9.75	304		
Average						31	

Creek, the slope storage component was 98% of total construction erosion; for No Name, 79%. Primarily because of the large amount of slope storage (averaging 85%), the total sediment yield at the basin mouths averaged only 7%, with a high of 15% in Ditch Creek, 2% in Cabin Creek, and 6% in No Name Creek. The higher delivery to the mouth of Ditch Creek is because of the short distance from the collector road to the stream channel (Fig. 1), the introduction of sediment directly into the channel from culvert installation and culvert failure, the shorter channel length in Ditch Creek (975 m compared with 1800 m for Cabin Creek and 3320 m for No Name Creek) and the fact that construction started first in the Ditch Creek drainage basin. The low delivery in Cabin Creek was caused by the location of the collector road in the upper reaches of the drainage basin and the associated lack of live water crossings. In addition, the local roads in Cabin Creek were carefully fitted to the terrain to minimize cut and fill heights. Thus, little ground was disturbed compared to the collector road and the local road in No Name Creek. Also, the local road in lower Cabin Creek was pioneered after a severe thunderstorm on 2 July and most of the embankments were completed before another intense storm on 10 September. The opportunity for erosion was therefore limited as compared to the other roads that took longer to complete. In the No Name drainage, the roads have several live water crossings; however, the channel length is much longer than in Ditch and Cabin Creeks, resulting in an intermediate delivery value.

Based on the total road erosion data expressed per unit area of road disturbance, one might conclude that higher erosion rates on the Ditch Creek drainage were caused by the minimal erosion control features included in the road design compared to the extensive erosion control measures and lower erosion rates in Cabin Creek. Such a comparison is not valid because of variations in road standards and in the timing of construction on the two drainage basins. A better approach is to compare erosion rates for the collector road alone on the two drainage basins. Such a comparison is possible because only 2% of the eroded material moved into the stream system in Cabin Creek; all of the rest is stored on the slopes. The total slope storage below the collector road in Cabin Creek translates to a road erosion rate of 50 m^3 ha^{-1}. This figure provides a good estimate of the total construction period erosion on the collector road in Cabin Creek. Field observations during construction suggested that none of the eroded material resulting from reconstruction of the old road in Ditch Creek reached the channel system. Thus, slope storage below the collector road plus the total of channel storage and sediment yield provide a measure of the total construction period erosion on the collector road in Ditch Creek. This value is 62 m^3 ha^{-1} as compared with 50 m^3 ha^{-1} for Cabin Creek. The two figures suggest that erosion during construction was reduced by about 20% because of the additional road erosion control measures included in the Cabin Creek basin road design. However, the benefits of the additional erosion control in the Cabin Creek basin undoubtedly exceed 20% because much of the erosion that occurs during construction is unrelated to the final erosion control measures included in the road design. Rather, the stage of construction at the time a storm hits governs the location and amount of erosion that takes place. This was obvious on the ground when, for example, runoff from the road surface was directed down newly constructed fills because the berms required for prevention had not yet been constructed. This was a common problem on the project and caused considerable erosion. It could easily be prevented by construction of temporary berms when storm threats are high. Such emergency erosion control measures would go a long way toward reducing the overall erosional impacts of forest roads during the construction phase.

REFERENCES

Clayton, J.L., Megahan, W.F. & Hampton, D. (1979) Soil and bedrock properties - weathering and alteration products and processes in the Idaho Batholith. Research Paper INT-237, USDA Forest Service, Intermountain Research Station, Ogden, Utah, USA.

King, J.G. (1984) Ongoing studies in Horse Creek on water quality and water yield. National Council of the Paper Industry for Air and Stream Improvement, Technical Bulletin No. 435, 28-35.

Megahan, W.F. (1978) Erosion processes on steep granitic road fills in central Idaho. Soil Sci. Soc. Am. J. 42(2), 350-357.

Megahan, W.F. (1985) Road effects and impacts -- watershed. In: Proc. Forest Transportation Symp., Denver, Colorado, 11-13 December 1984, 57-97. USDA Forest Service, Rocky Mountain Region, Engineering Staff Unit, Denver, Colorado.