EFFECTS OF FOREST ROADS ON STREAM SEDIMENT

John King[1/] and Michael Gonsior[2/]

ABSTRACT

This paper discusses some on-site erosion and stream sedimentation consequences of forest road construction in small watersheds in northern Idaho. Pioneering and culvert installation increase sediment fluxes in the streams, just below the road, 100 to 10,000 times the normal daily flux for short periods of time. Subsequent to construction, rain and snowmelt events acting on the road prism features appreciably increase sediment fluxes in the streams just below the roads. Sediment measurements at the mouths of these small watersheds indicate that very little of the road derived sediment is being transported out of the watersheds. Thus, sediment is being stored in the channel systems. Channel transect data supports the conclusion that the channels are aggrading as a result of storage of road derived sediment.

Erosion and sediment transport are very dependent on climatic events and the resulting streamflow. Thus, the results could have been substantially different under a different set of climatic events. Current and future research is attempting to calibrate existing physical process models which would enable prediction of the erosion rate and sediment fluxes for different climatic events.

INTRODUCTION

The Horse Creek Administrative-Research Study area was established in 1965 as a field laboratory for determining the effects of alternative forest management practices on streamflow and water quality. The Horse Creek watersheds are located in the north central portion of Idaho within the Nezperce National Forest, approximately 35 air miles east of Grangeville, Idaho (Figure 1). Horse Creek flows easterly into Meadow Creek, 4 miles above its confluence with the Selway River.

The watershed lies on the border of the Idaho Batholith, a large igneous intrusion in central Idaho and western Montana. The parent material is part of the Belt Super Group (Bennett 1974) composed of sedimentary and metasedimentary rock of primarily gneissic material (Greenwood and Morrison 1967). The deeply weathered soil is a well drained sandy loam to loam. Median side slopes are 31 percent, but slopes in excess of 65 percent are common. In an undisturbed condition there is little evidence of any surface erosion and stream sediment is predominately derived from channel sources. However, there is a high potential for surface erosion following disturbance of the forest floor. Thunderstorm activity during the summers and rapid spring snowmelt provide conditions conducive to accelerated erosion especially on disturbed sites.

[1/] Research Hydrologist, Intermountain Forest and Range Experiment Station, Moscow, Idaho.
[2/] Research Engineer, Intermountain Forest and Range Experiment Station, Missoula, Montana.

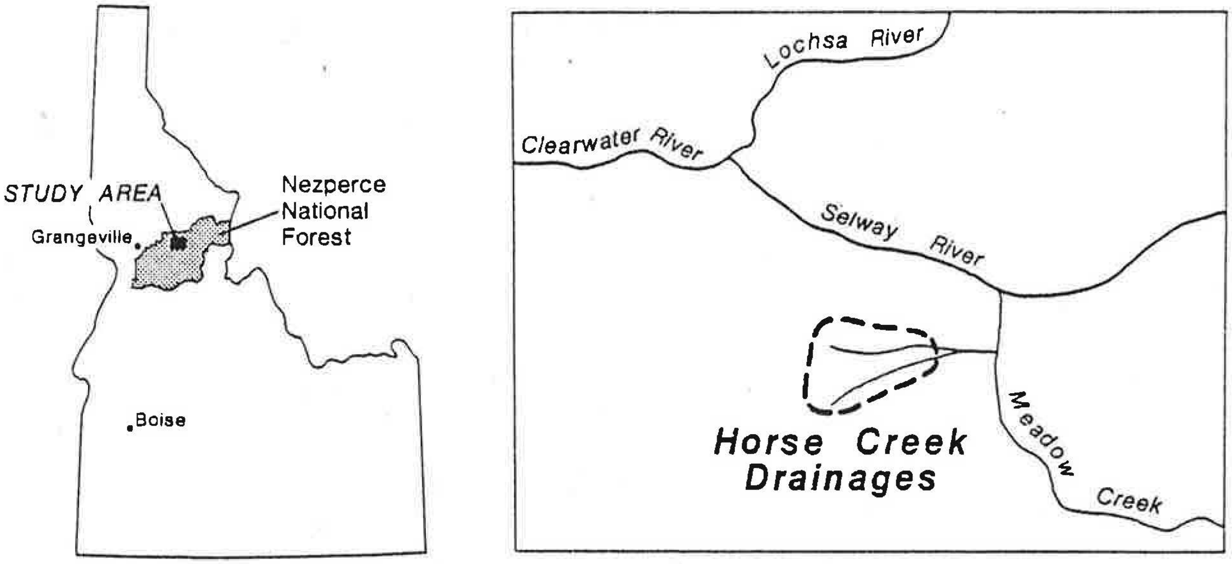

Figure 1. Location map for the Horse Creek Administrative Research Study Area.

One of the studies in this area focuses on determining rates of erosion from various parts of forest road prisms, and subsequent downslope and in-stream disposition of the resulting sediments. The monitoring scheme is designed to provide data on erosion and sediment transport rates at various locations in the watersheds, from the sites of disturbance to the watershed outlets. Ultimately, these monitoring systems will be used to test predictions of various water and sediment routing models. However, currently we can only describe some of our observations and draw some inferences on the occurrence and magnitude of various processes.

THE SITUATION

Forest roads are necessary or desirable for many reasons; notably for the removal of forest products. In the past, much of the logging and road building occurred on relatively gentle terrain and at a time when public concern about impacts on water quality was relatively mild. Now, steeper and more rugged terrain is being entered and public concern about water quality and other environmental impacts is relatively strong.

Many studies in the western United States have shown that forest roads are the major source of sediment and a major cause of water quality degradation. Megahan (1972) stated that "roads create a disproportionate share of the problem, probably greater than 90 percent in most instances." Timber harvesting, reforestation, site preparation and other silvicultural practices generally contribute less sediment to streams.

The impacts of forest roads on streamflow and sediment concentrations are most apparent during road construction and during subsequent rainstorms and snowmelt events. The amount of sediment introduced into a stream channel during construction depends on the methods and care employed during pioneering and culvert installation operations, the nature of the climatic events and the magnitude of streamflow. During subsequent rainstorms and snowmelt events, the amount of sediment contributed to a stream channel largely depends on the physical characteristics of the road and the rate of restabilization of the disturbed areas.

Once sediment enters a stream, its subsequent disposition depends on the organic debris loading in the channel, the hydraulic properties of the stream channel and the magnitude of streamflow. The significance of naturally derived and extraneous sediment depends on downstream water uses and in-stream values such as fisheries habitat.

PURPOSE

Our purpose is to describe some of our observations relative to the amounts and disposition of sediment contributed by forest roads, during construction and throughout the following two years and to assess the relative contribution of various road features to stream sedimentation. We will also describe some preliminary indications related to the effects of road-derived sediments on channel bottom composition, channel storage and aquatic habitat.

METHODS

Figure 2 is a map of Horse Creek delineating the six roaded subdrainages, road locations, stream crossings, and other pertinent features. These subdrainages range in size from 70 to 364 acres. A sediment dam, H-flume and stage recorder are located at the mouth of each subdrainage. The flumes and stage recorders provide continuous streamflow records.

Also located at the mouths of the roaded watersheds and control watershed 6 (figure 4) are automatic water samplers. These devices take discrete time based samples and have been set up to sample twice a day during most of the study period. Analysis of the suspended sediment concentrations of these samples allows for determination of sediment quantities passing through the sediment dams.

The sediment deposited in the dams at the watershed mouths is measured annually using a sag-tape surveying technique. Thus, the total sediment leaving a subdrainage during any year can be estimated by combining the amounts in the dams with the amounts passing through the dams as suspended sediment.

Along the logging roads, monitoring stations have been installed at all live water crossings (Figure 2). At each stream crossing there are three monitoring locations (Figure 3). The A stations are located just upstream from the culvert inlets. Natural sediment transport is measured at these stations. The B stations, at the culvert outlets, measure the combination of natural sediment plus sediment derived from some identifiable lengths of cut slope and ditch and road surface area. The C stations are located approximately 100 yards downstream from the B stations. The measurements at the C station enable detection of sediment that may enter the stream between the B and C stations as a result of overland transport from definable segments of the fill slopes. In the absence of overland transport, the data from the B and C stations provide evidence of channel aggradation or degradation between these stations.

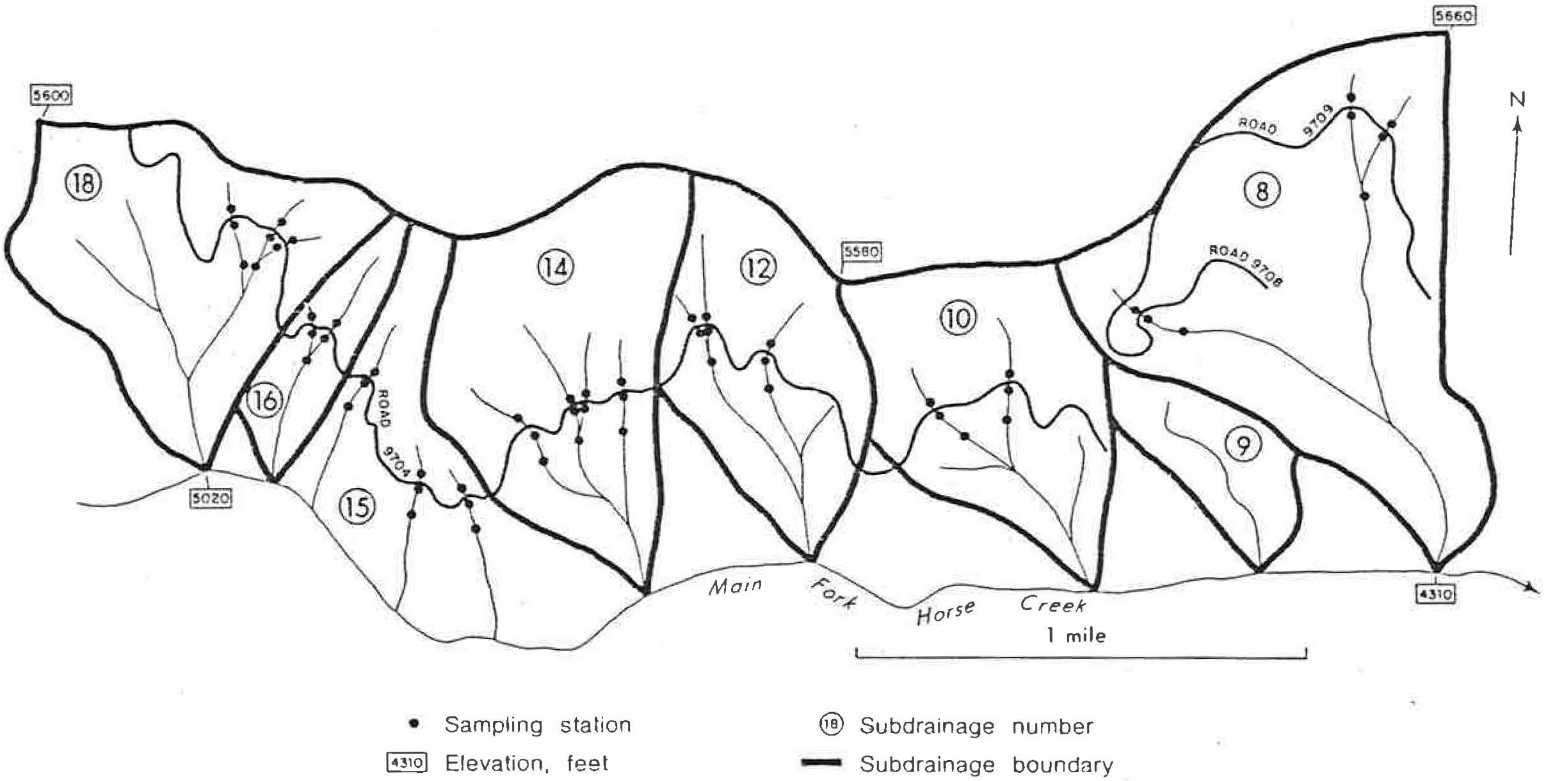

Figure 2. A map of the roaded Horse Creek subdrainages showing the location of the roads and sampling stations.

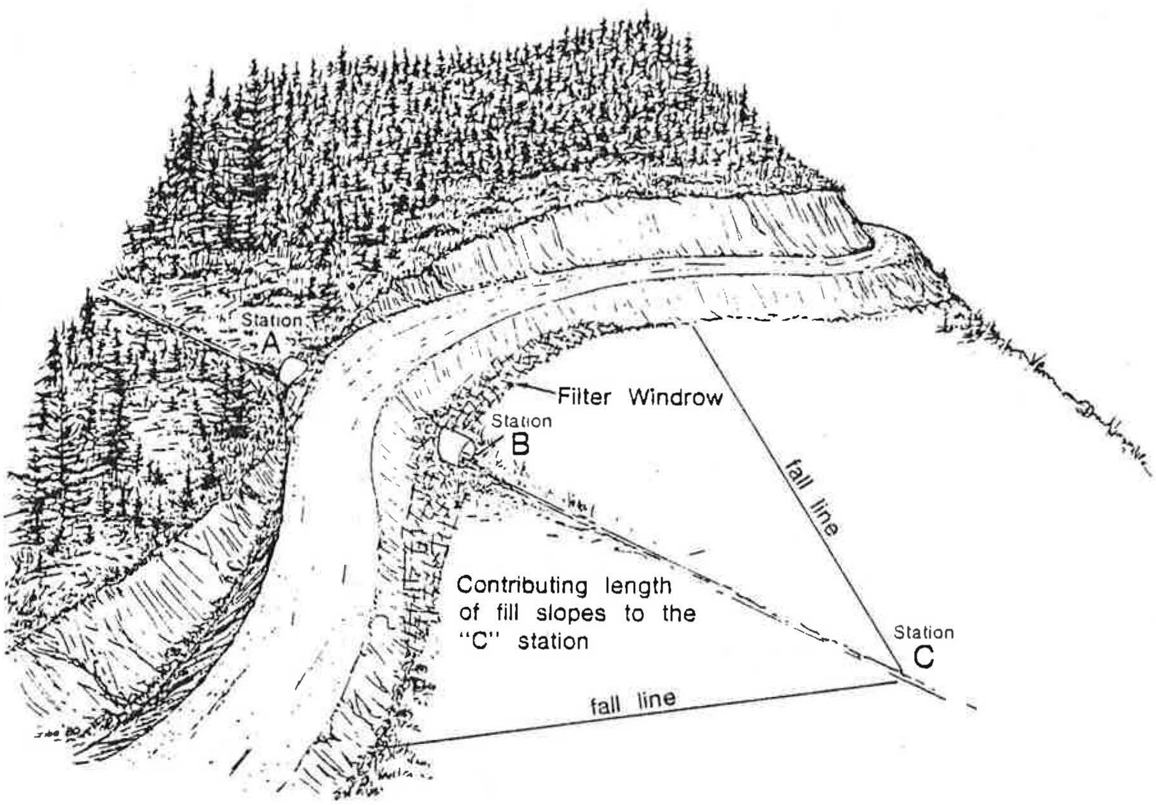

Figure 3. The sampling station locations at each live water crossing.

At each of the A, B, and C stations a small wooden flume was installed to concentrate flow and elevate the streams. Water samples are collected at the outlets of these flumes and analyzed for total sediment concentrations. Discharge measurements are determined using a bucket and stopwatch method. Sediment samples and discharge measurements at these stations are taken twice a week throughout periods of snowmelt and monthly during late summer and fall low flow periods. Selected stream crossing stations are intensively sampled during rainstorm events.

Continuous monitoring stations were installed at the A, B, and C stations at four selected stream crossings (Figure 4). Stage recorders and H-flumes provide continuous streamflow records. Automatic water samplers take samples for analysis of total sediment concentrations based on intervals of discharge or time. The data from the continuous monitoring stations should enable simulation of complete records at other crossings where only periodic manual samples are taken.

In those streams which have continuous monitoring stations associated with the roads and in one control stream, measurements are made of channel aggradation and/or degradation and the particle size distribution of channel bottom material (Figure 4). Six representative channel reaches, approximately 30 feet in length, are surveyed twice a year, once following snowmelt and again in the fall. One sample channel reach is located above the road, two are located between the B and C stations and three are located between the C station and the mouth. The spatial distribution of these channel reaches allows us to trace the road effects downstream.

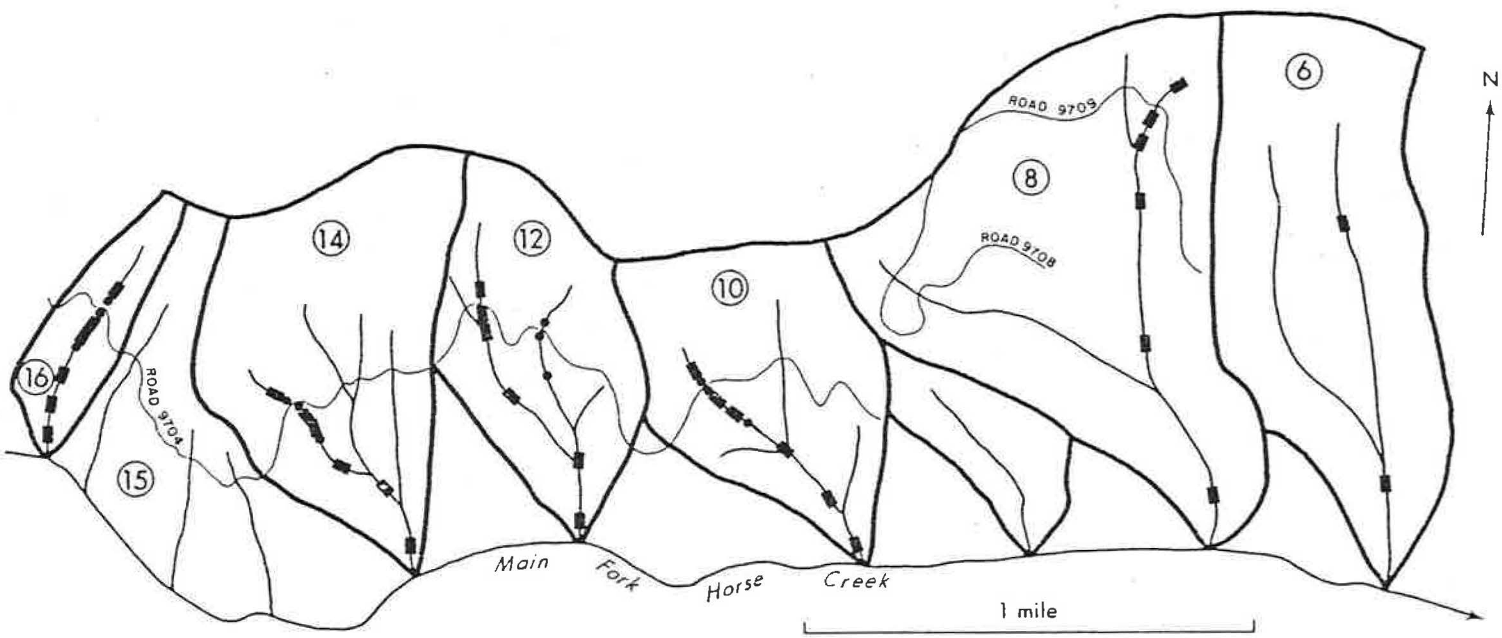

Figure 4. The location of the automatic sampling stations (•) and the channel transects (▬) in the roaded Horse Creek subdrainages.

Finally, to enable estimation of erosion on cut and fill slopes, a variety of techniques have been used. Four-foot long traps are used to collect eroded material at the base of cut and fill slopes. Volumes of eroded material in the traps are measured following snowmelt, after major thunderstorms and in the late fall. Also, a complete survey of rills and gullies in the fill slopes is conducted after snowmelt and in the late fall. Measurements are made to determine the volume of material leaving the fill slope and the downslope transport distance of the material on the forest floor. In addition, we are experimenting with the use of close range stereophotography to estimate cut slope erosion. Stereo pairs are taken twice annually to determine erosion during snowmelt and erosion during the summer and fall rain season.

RESULTS

Road construction was completed in subdrainages 18, 16, and 8 during the summer and autumn of 1978, and in subdrainages 14, 12 and 10 during the 1979 construction season. Presently, we have data for the first year following construction for subdrainages 18, 16 and 8. We will present and discuss a limited range of measurements and observations; primarily focusing on subdrainage 16.

We preface this discussion by pointing out numerous difficulties and deficiencies in our methods during the first year of this study. At the continuous monitoring stations we utilized commercially available water samplers that provided us the choice of either sampling at fixed intervals of time or of flow proportional sampling. Unfortunately neither technique is adequate for monitoring construction events or short duration rainstorms. Thus, we relied heavily on manual sampling during construction and storm events following construction. Storm events which occurred at night or on weekends were not sampled. Moreover, the effort required to conduct an extensive monitoring program with limited personnel often meant that only a single sediment sample and discharge measurement was acquired at each of several locations during a rainstorm event.

Due to these deficiencies, we are presently only able to relate order of magnitude changes in sediment concentrations during road construction activities and the subsequent year. The amounts and disposition of road contributed sediment are at best rough estimates. As will be discussed later, we have been and will continue to make improvements in our methods, which will result in considerably greater resolution and comprehensiveness in our future efforts.

Preconstruction Watershed Behavior

Stream discharge at the mouths of these watersheds are in the range of 10^{-2} to 10^{-1} cfs during summer low flow periods, and as low as 10^{-3} cfs at some road crossings. Low flow sediment concentrations range from 1 to 10 mg/1.

During high intensity rainstorm events, stream discharge and sediment concentrations increase by one to two orders of magnitude. Thus, a stream ordinarily flowing at 0.05 cfs during the summer with sediment concentrations of 1 mg/1 might, during a storm event, increase

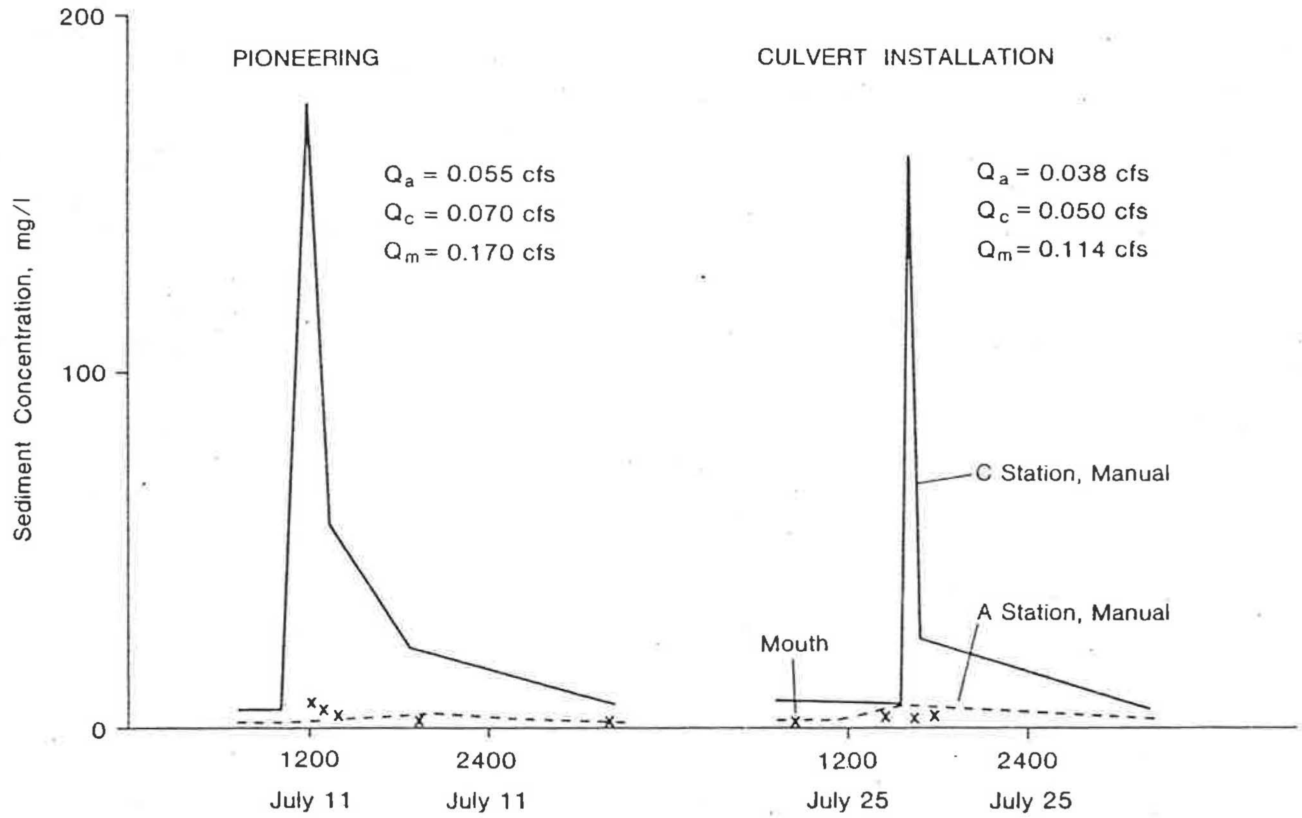

Figure 5. Sediment concentrations resulting from pioneering and culvert installation activities in subdrainage 16.

to 0.5 cfs with a sediment concentration of 100 mg/l. Correspondingly, the sediment flux would increase from the low flow level of 0.01 lbs/hr to approximately 10 lb/hr.

During spring snowmelt, streamflows increase to levels about two orders of magnitude greater than during low flows. Likewise, sediment concentrations increase by one to two orders of magnitude during the period of rising discharge, but during falling discharge the concentrations are usually less than one order of magnitude greater than those during low flow. Typically, the amount of sediment passing through the sediment dams at the mouths of the watersheds during the entire snowmelt hydrograph period of 40 to 50 days are in the range of 10^3 to 10^5 lbs; with peak fluxes in the range of 10^2 to 10^4 lb/day.

<u>During Construction</u>

The road construction season began shortly after spring runoff, when discharges were still as much as 10 times higher than their lowest summer discharges, and extended until late autumn. There were two periods of major disturbance at any given stream crossing: (1) during the pioneering phase, when right-of-way timber and debris was cleared from the stream channel and a temporary culvert was installed, and (2) during replacement of the temporary culvert with a permanent culvert. Figure 5 illustrates the sediment concentrations at various locations during these activities in a stream in subdrainage 16. The estimated total contributions to the stream during pioneering and permanent culvert installations were 12.3 and 0.2 lbs., respectively, or the equivalent of about 45 days of summer low flow sediment delivery past the C station. Virtually none of the sediment passing the C station during these activities reached the watershed mouth indicating that this added material was stored in the channel. Similarly, the amount of sediment passing the C station during these construction activities was less than the total amount added to the stream. This implies that the difference was stored in the stream channel between the B and C stations.

Installation of the permanent culvert at the crossing in subdrainage 16 was preceded by diverting of the stream around the construction site. Thus, construction was "in the dry" (termed a dewatered culvert installation) and the impact to the stream was confined to the brief period during which the stream was returned to its natural channel. This caused a washing of the loosened material that resulted from construction disturbance above the culvert inlet and just below the culvert outlet. At other crossings, culvert installations took place "in the wet", with the stream running continuously through the construction site. Figure 6 shows the effects of one such installation compared with a dewatered installation. In this example of an "in the wet" culvert installation the total amount of sediment passing the C station was about 46 lbs, or the equivalent of about 113 days of summer low flow sediment delivery. This is substantially greater than the 0.2 lbs contributed to the stream during an "in the dry" culvert installation. Again, the fraction of sediment reaching the watershed mouth was negligible which implies storage of the sediment in the channel.

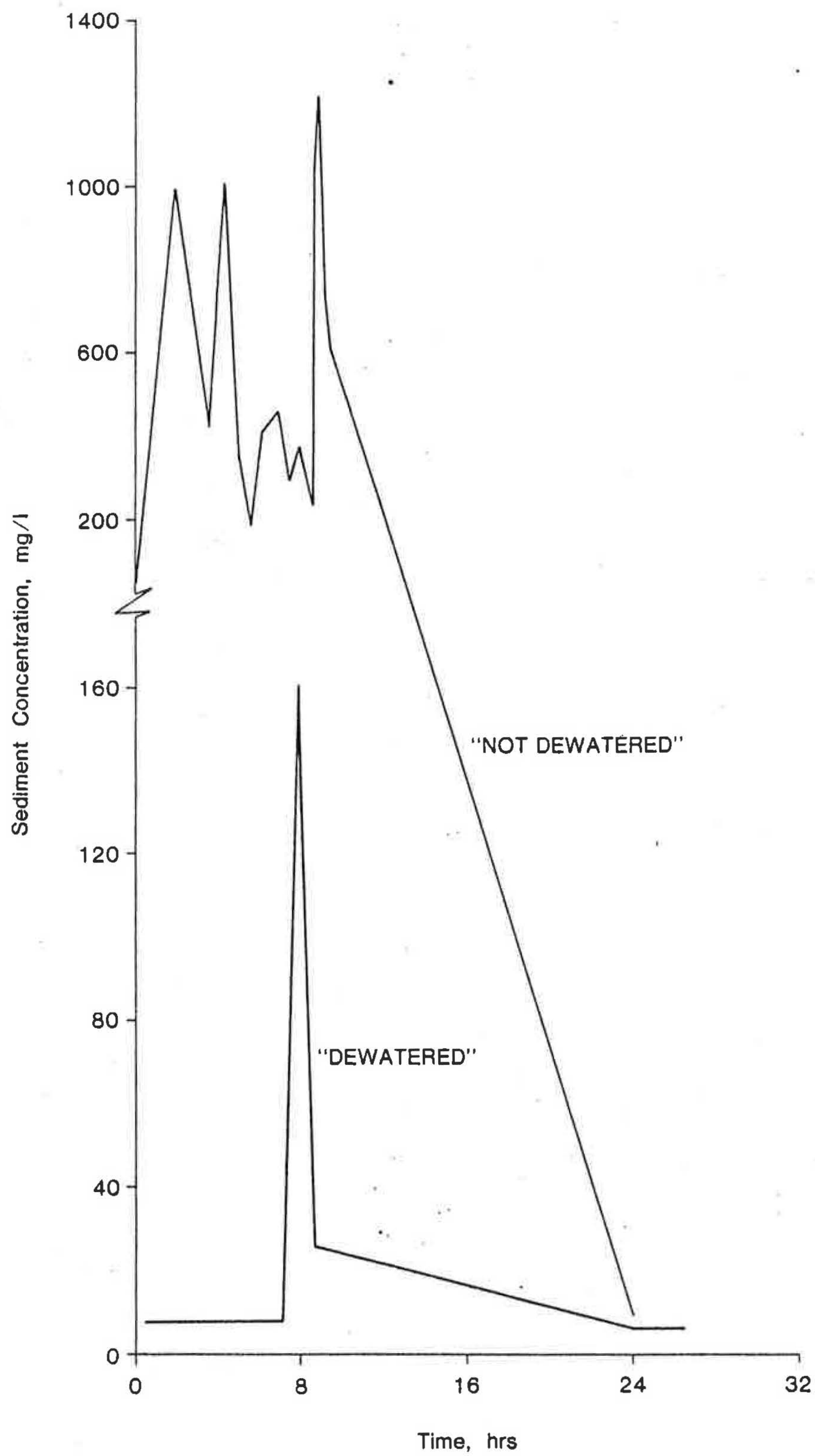

Figure 6. The sediment concentrations due to culvert installation at a "dewatered" site and a "not dewatered" site.

In summary, the amounts of material added to these small streams during construction activities is comparable to 100 to 10,000 times the normal daily sediment flux at these locations. Virtually none of this material was transported out of the subdrainage.

After Construction

During low flow periods, the sediment concentrations and streamflows measured below the newly constructed roads rapidly return to their preconstruction levels. However, during rainstorm events, especially those of sufficient intensity and duration to generate flows in the ditch systems, sediment concentrations at the B and C stations increase as much as 10^2 times those at the A stations. In many instances, the ditch flows were comparable to the flow rates at the A stations, resulting in an approximate doubling of flow rates at the B stations. Thus, the sediment flux at the A stations might increase from the low flow level of 0.005 lb/hr (2 mg/l at 0.01 cfs) to 0.2 lb/hr (40 mg/l at 0.02 cfs) and the flux at the B station might increase from 0.005 lb/hr to 35 lb/hr (4000 mg/l at 0.04 cfs). The ditch, during such an event, could contribute a flow equivalent to the A station, but with a sediment concentration of nearly 8000 mg/l.

In summary, during the first few rainstorms after construction, we estimate that sediment loadings due to the movement of newly exposed materials on the cut slopes, road beds and in the ditches, were in the order of 10^2 to 10^4 times the normal sediment fluxes at the B stations. The total additions of sediment from all of these storms were probably in the range of 10^2 to 10^3 lbs at each stream crossing. Once again, sediment concentrations at the mouths of the watersheds indicate that only a very small fraction of these quantities was transported out of the watershed during storm events, and that most of the material was stored in the channels.

As will be discussed later, significant fill slope erosion occurred during these initial storm events, but little or none of the eroded fill material was transported to the streams.

First Snowmelt Period After Construction

Figure 7 illustrates the streamflow hydrograph and sediment concentration relationships at the A, B, and C stations in subdrainage 16 for the 1979 snowmelt period. Approximately 500 lbs of sediment were transported past the A station and 900 lbs past the B and C stations. The ditch system, which contributes to the culvert inlet, approximately doubled the amount of sediment in the stream when compared to undisturbed or preroad levels.

During this same snowmelt season approximately 1400 lbs of sediment passed through the sediment dam and out of subwatershed 16. Based on pretreatment records, the expected yield would have been about 1200 lbs, virtually the same as after treatment.

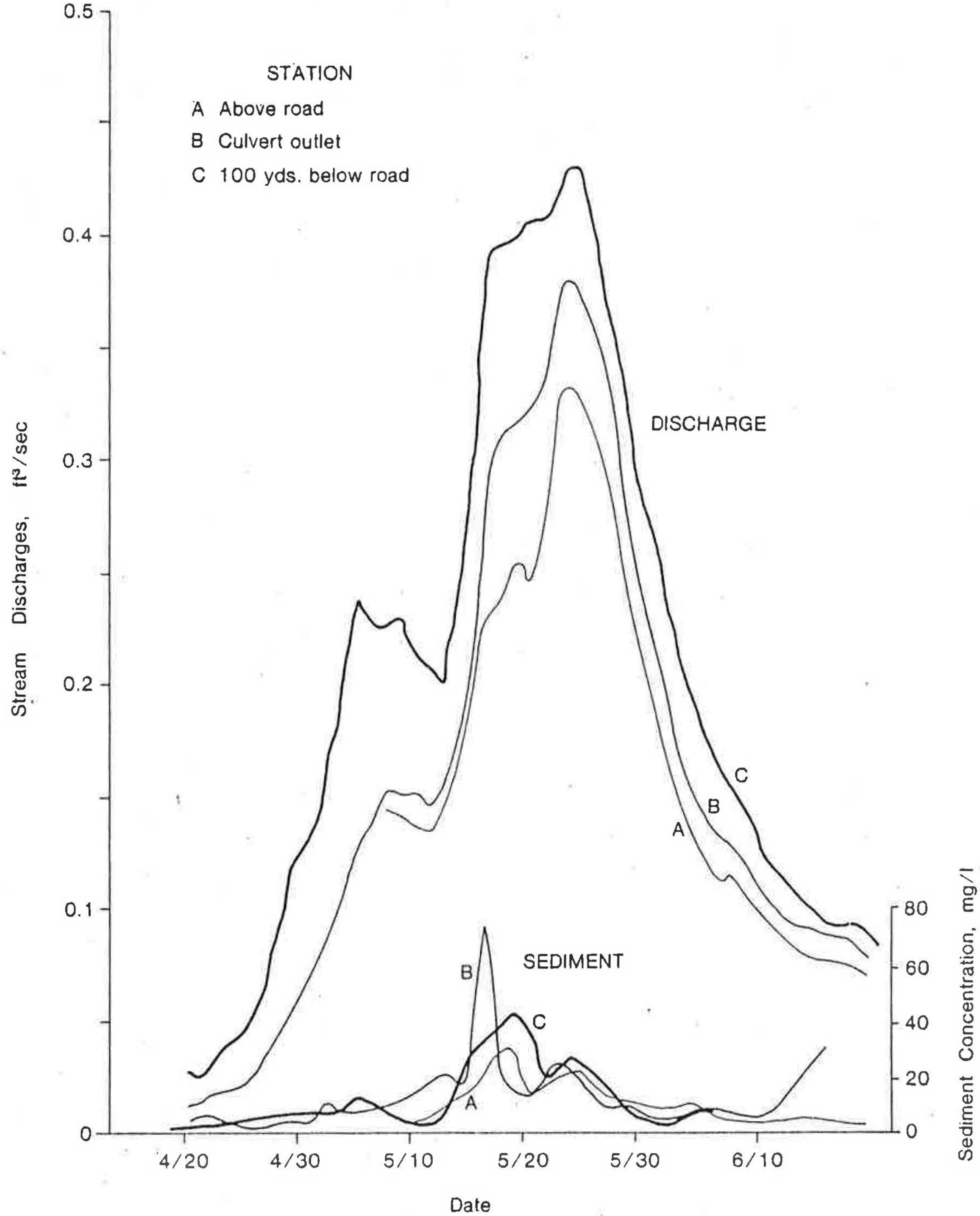

Figure 7. Stream discharge and sediment concentrations measured at the road sampling stations in subdrainage 16 during the snowmelt period of 1979.

Total Annual Sediment Production for the Watersheds

Figure 8 shows the relationship between annual sediment deposited in the sediment dams at the mouths of the subwatersheds and annual water yield. There is no apparent effect of road construction on the sediment yields for subdrainages 18, 16, or 8 during the first year following construction. This also implies that the road derived sediments are being stored in the stream channels.

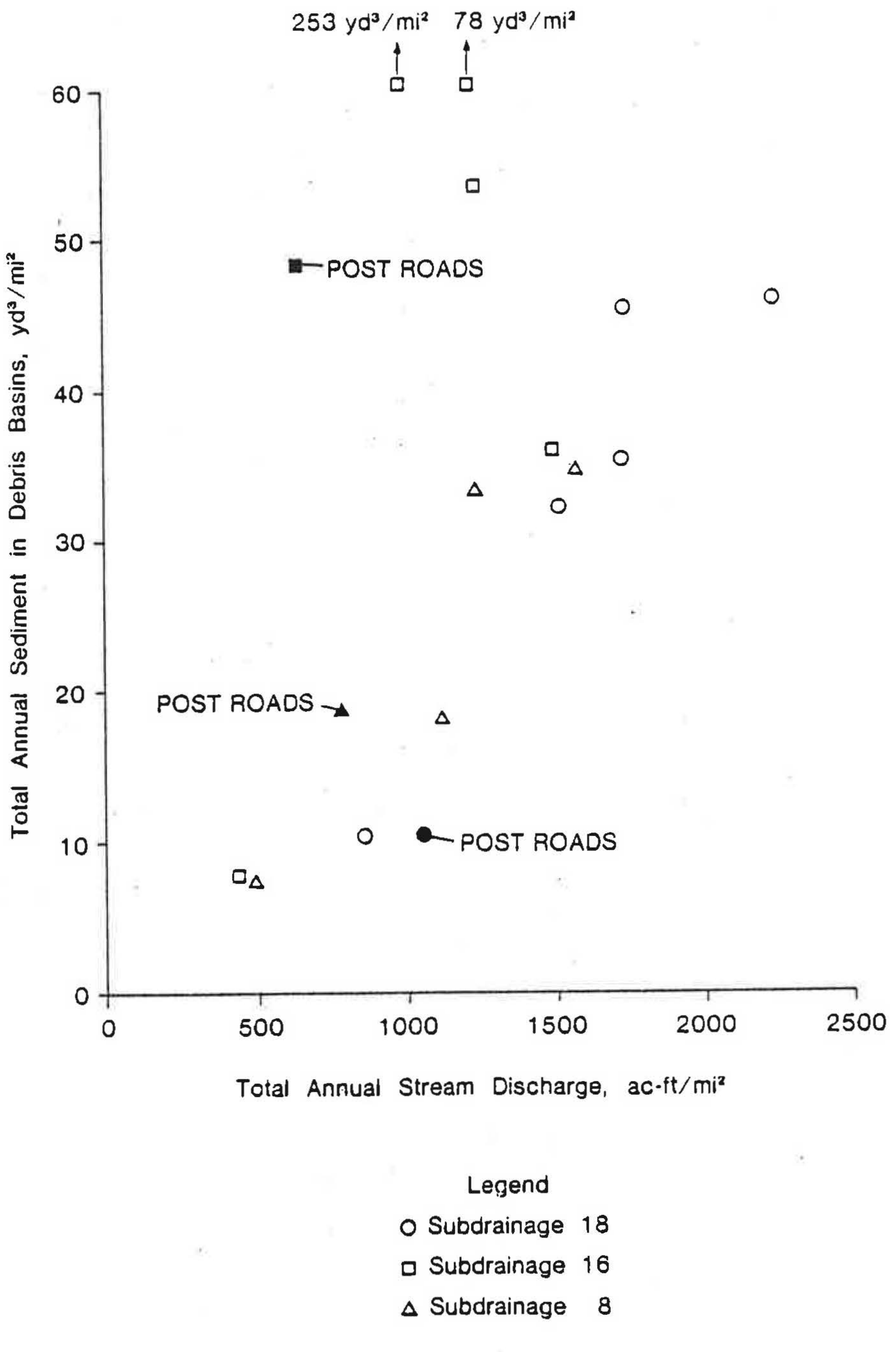

Figure 8. The relationship between total annual stream discharge and total annual sediment in the debris basins for the three subdrainages roaded in 1978.

Stream Transects

Figure 9 illustrates the aggradation and degradation of the stream channel transects subsequent to road construction. During the summer of road construction all of the transects show aggradation of the stream channel. During the first snowmelt period those transects located a short distance below the roads (transects 2, 3, and 4) degraded while those transects in the lower portion of the subdrainage (transects 5 and 6) aggraded. The average net elevational change of the stream channel transects in subdrainages 8 and 16 for the 18 months following road construction was + 0.27 inches. Although the absolute accuracy of the transect measurements is unknown, the data does indicate that road derived sediment is stored in the channel system, with the largest accumulations in the lower reaches of the channel.

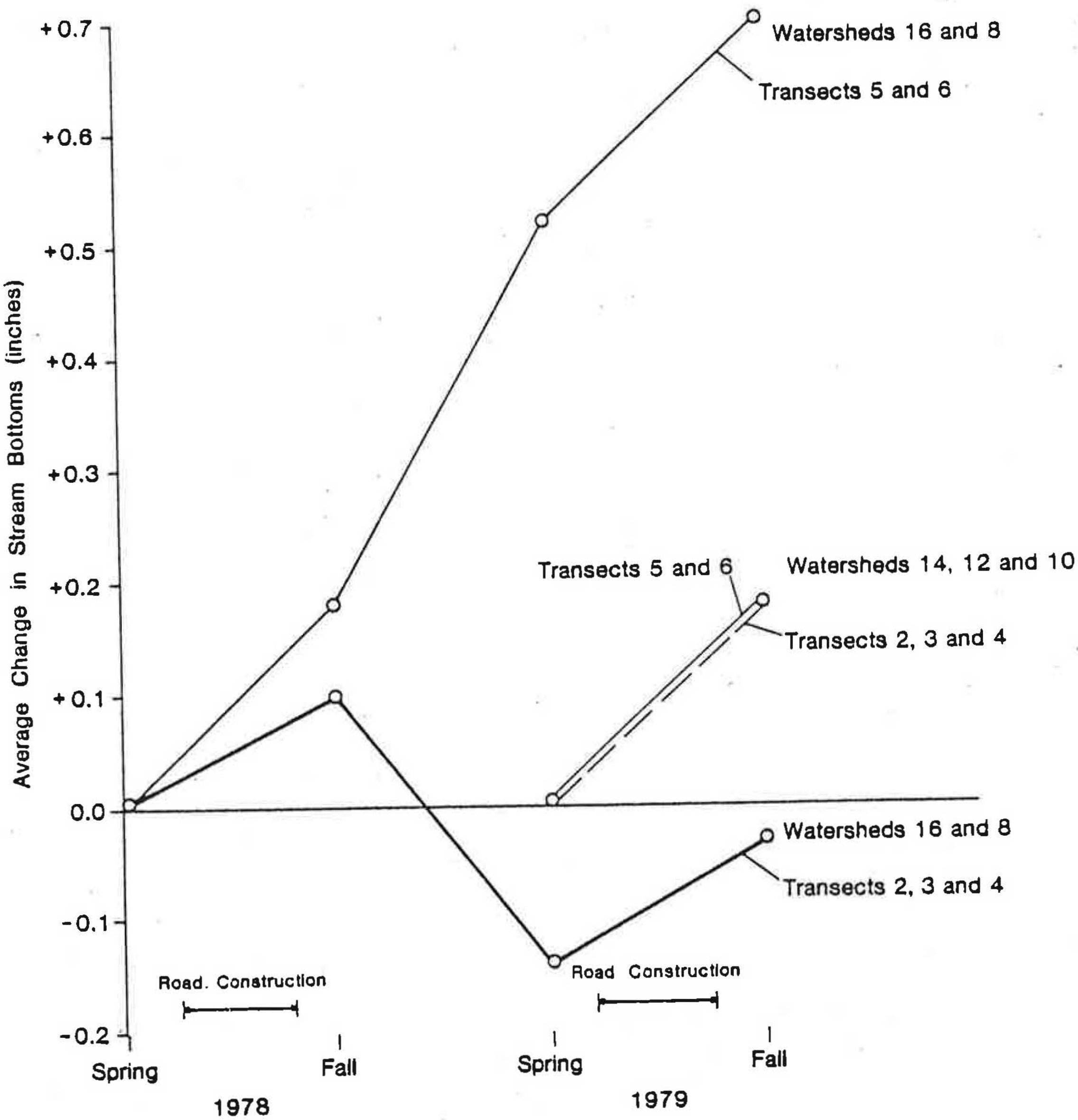

Figure 9. Channel transect aggradation/degradation following road construction in the Horse Creek subdrainages.

Summary of First-Year In-Stream Monitoring Results

We estimate that the amount of sediment contributed to the stream system in subdrainage 16 during road construction and the first year following construction, was a sizeable fraction of the average annual sediment production from this watershed. Most of this sediment remains in the channel system of the subdrainage between the road crossing and the subdrainage mouth.

Second Year After Construction

Figure 10 illustrates the effects of a major thunderstorm on August 23, 1979 that generated 0.7 inches of rainfall in approximately one hour. Sediment fluxes past the B and C stations were one order of magnitude greater than the flux past the A station. The total contribution of sediment at the B station was relatively small, only 8 lbs. This is considerably less than what was measured during thunderstorms the previous summer. It is hypothesized that there is now a lack of fine particulates on the road surface and in the ditches that can be transported to the stream. Sloughed cut slope material that enters the ditch system does not contain large quantities of fine particulates. Very little of this sloughed material is being transported to the stream. The contribution of sediment from this road crossing is diminishing as time progresses, and barring any extreme events, this trend should continue.

On-site Erosion

Erosion occurring on the cut and fill slopes was monitored with four-foot long unbordered traps at the base of the slopes. Sample intensity was less than one percent of the entire length of road; thus, this information does not accurately reflect total erosion volumes but does provide information on the relative magnitude of the cut and fill slope erosion and time trends in erosion rates following road construction.

Fill slope erosion was also measured by a complete survey of rills and gullies. Sediment movement downslope was described as a distance of transport and fate of the sediment. While this technique does not include quantities of interrill erosion, it does allow estimation of fill slope erosion along any specific length of the road.

The road through subdrainage 16 has 731 feet of fill slopes and 755 feet of cut slopes that could contribute sediment to the C monitoring station. However, 550 feet of the fill slopes, adjacent to the live water crossings, are protected with filter windrows. These filter windrows consist of logging slash and debris remaining from the clearing operation. Cull logs are "keyed" into the toe of the slope and slash is placed above the log on the lower one-half to two-thirds of the slope and tamped into the surface. This provides a filter of slash to trap eroded fill material and prevent downslope transport.

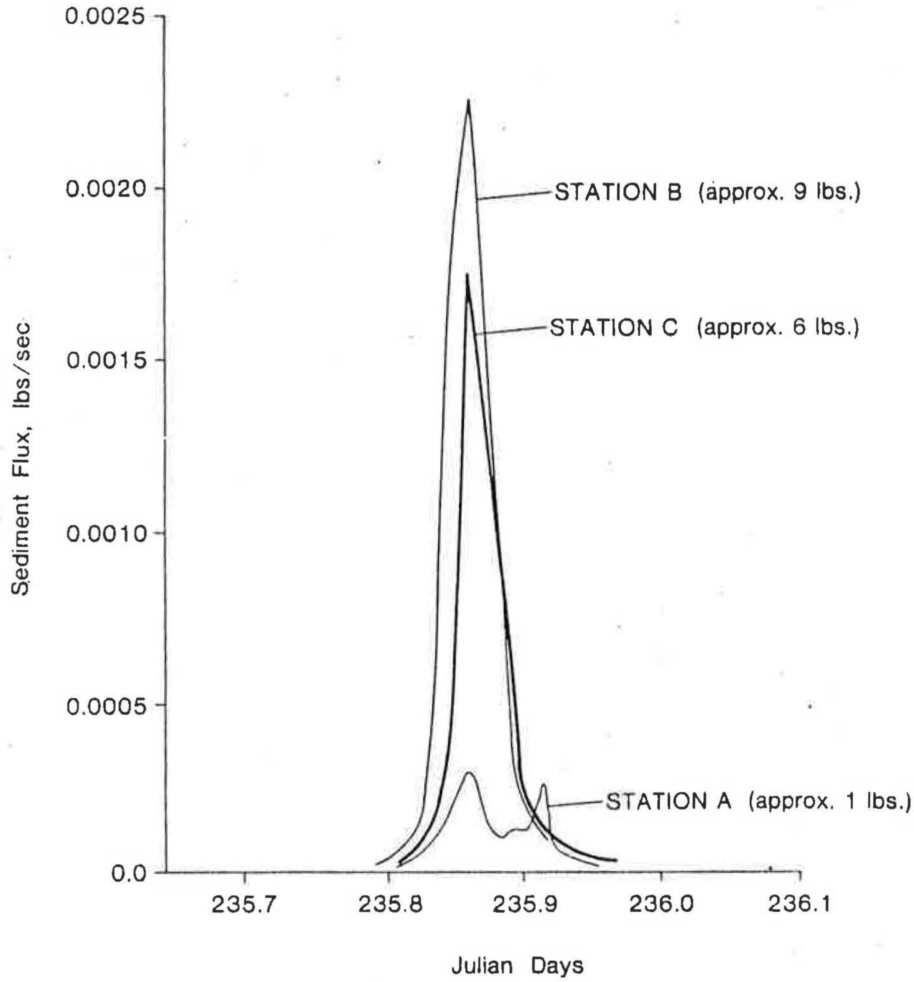

Figure 10. The sediment flux measured at the automatic sampling stations in subdrainage 16 during a thunderstorm on July 23, 1979.

During the first summer and fall after construction approximately 1,000-1,500 lbs of material eroded from cut slopes in subdrainage 16 compared to 25,000-40,000 lbs from the fill slopes. The filter windrows captured all of the eroded fill material. On those fill slopes not protected with filter windrows, none of the eroded material reached live water. Thus, any road derived sediment reaching the C station during rain events was contributed from the cut slopes, ditches, and/or some portion of the road surface. Near the end of the construction season the cuts and fills were hydroseeded and mulched.

In the spring of 1979, cut slope erosion increased dramatically to 26,000 lbs in subdrainage 16. This is attributed to sloughing of loose material during saturated or near saturated conditions during snowmelt. Fill slope erosion was relatively small in comparison, only 1,600 lbs. For this snowmelt period, all of the eroded fill material was deposited in the filter windrows. Thus, road derived sediments were all routed to the stream via the ditch system.

The second summer and fall following construction cut slope erosion amounted to 10,000 lbs, a substantial increase from the previous summer. However, fill slopes were less than the previous summer by a factor of 5, totalling 7,000 lbs. There was one breach in the filter windrows but none of the material was transported to the stream.

It becomes obvious that (1) the magnitudes of on-site erosion are much greater (in the order of 10^2) than the amount of stream sedimentation that can be attributed to the roads, (2) fill erosion is very high during the first few intense storms following construction and becomes less susceptible to erosion during subsequent rain events, (3) cut slope erosion is much greater during the spring snowmelt event than during rainstorm events and (4) filter windrows provide an effective means of controlling sediment movement from fill slopes at least during the first 1 1/2 years following construction.

Roads constructed in 1978 had filter windrows on 1,220 feet of road fill. Both the volumes of material moving through the windrows and transport distance below the windrows was held to a minimum (Figure 11). The downslope transport distance of material from unprotected fills was one to two orders of magnitude greater than from windrowed fills. In watershed 16 there probably would have been a substantial increase in the sediment flux at the C station during intense rain storms or periods of rapid snowmelt, if a filter windrow was not present. The long term effectiveness of the windrows will be evaluated. Their performance will depend in part on their storage capacity, the rate of stabilization of the fills, the occurrence of extreme events, and the long term stability of the filter windrows.

SUMMARY AND CONCLUSIONS

The results indicate that the roads have had a minimal impact on the Main Fork of Horse Creek to date. Only small amounts of road derived sediment, predominately suspended sediment, were evident at the mouths of the subdrainages. However, under different climatic conditions, the results could have been substantially different.

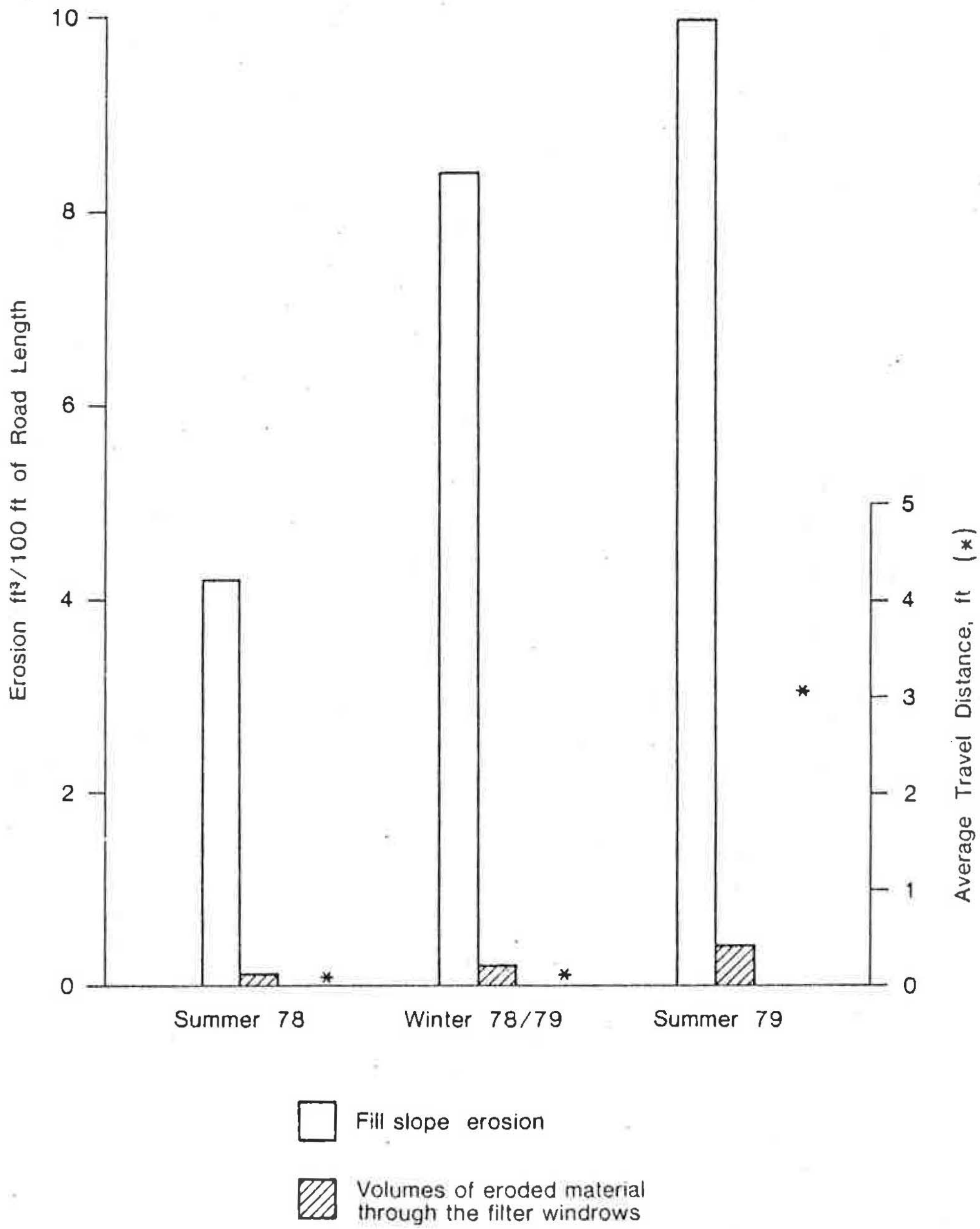

Figure 11. Volumes of fill slope erosion and material transported through the filter windrows and the distance of material transported downslope.

During pioneering and culvert installation and during thunderstorm activity the first summer following construction considerable fluxes of road derived sediment reached the stream channel. Although measured sediment concentrations are high, total amounts added to the channel are relatively small when compared to the natural annual sediment production.

During the first snowmelt period the flux of sediment past the B and C stations was appreciably higher than the flux measured at the A station. The filter windrows prevented fill material from being transported downslope; therefore, the primary source of the sediment was from the road surface, ditch system and cut slopes.

Sediment transported from the road prism is being stored in the channels. The flux of sediment past the B station was considerably higher than the flux measured at the C station. Similarly, the flux past the C station was considerably higher than at the subdrainage mouth. Channel transect measurements substantiate channel aggradation due to the storage of road derived sediments. These measurements indicate that material is predominately being stored in the lower reaches of the channel system in the subdrainages.

During the second summer, following construction, the inputs of road derived sediment were considerably reduced. This is partially attributed to the revegetation of the fill slopes and the armouring of the ditches. Again, this sediment is being stored in the channel system.

Inputs of sediment to the streams can be significantly reduced by the construction of filter windrows on the fill slopes. Virtually no sediment was contributed to the C station from windrowed fills. Another technique to reduce sediment contributions to streams is the dewatering of the site during culvert installation. Both the duration of the effect and the total amount of sediment produced were significantly less than the sediment contributed during installation of culverts "in the wet."

We are continuing to monitor the erosion and sedimentation processes in Horse Creek. Intuitively we feel that these streams are becoming loaded with sediment and a single extreme event could flush the channels and perhaps affect the physical and biological character of the Main Fork of Horse Creek. Continued refinement of our sampling and measuring techniques will hopefully allow us to use the data to adapt existing models or to develop new models for extrapolating erosion and sediment information.

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