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SUSPENDED SEDIMENT TRANSPORT AND FOREST ROAD CONSTRUCTION WILDHORSE CREEK, KALAMA RIVER BASIN

by

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INTRODUCTION

Public Law No. 92-500, Section 208, established requirements for area-wide waste treatment management planning requiring states to assess the effectiveness of current regulations and impacts on non-point source pollution. The Department of Ecology established a two-year forest practices demonstration project for the purposes of monitoring forest water quality and assessing the effectiveness of the forest practices rules and regulations as embodied in the Washington Forest Practice Rules and Regulations (July 16, 1976), in protecting or enhancing forest water quality.

This report summarizes the non-point source sediment loads from forest roads construction in Wildhorse Creek, a tributary of the Kalama River in Cowlitz County, Washington. Cooperatively with the Weyerhaeuser Company and Department of Ecology, the College of Forest Resources, University of Washington, studied sources and quantities of suspended sediment produced by phases of road construction. The specific objectives of the study were:

I. Establish sources and quantities of suspended sediment from:
   A. Culvert installations during construction,
   B. Exposed mineral soil during early fall rains following construction,
   C. Road induced minor slope failures.

II. Monitor downstream sediment mixing in tributaries.

III. Establish the relationships between suspended sediment concentrations and optical properties of turbid water by NTU measurements.

RESEARCH METHODS

The study portion of Wildhorse Creek has a total area of 5.96 square miles (sq.mi.) of which the west fork of Wildhorse Creek was most intensively studied (3.48 sq.mi.). Sampling stations were established as identified in Figure 1, starting with Wildhorse 0 (WH 0) below the confluence of the west fork of Wildhorse Creek and the main Wildhorse Creek. Wildhorse 1 (WH 1) was the station immediately upstream in the west fork of Wildhorse Creek. Wildhorse 2 (WH 2) is a station midway upstream in the west fork located so that the major upstream area is currently undisturbed. Road construction is planned for the area above Wildhorse 2. Wildhorse 3 (WH 3) was a major upstream tributary proposed for culvert installation. Watershed areas as sq. mi., acres and percentage are summarized in Table 1.

A gauging station was established where the existing road (6240) crossed the west fork of Wildhorse Creek. A Fischer-Porter gauge for continuous recording of water level was installed in January 1977. Measurements of both suspended sediment and streamflow were initiated in January 1977.

The method used for estimating streamflow requires development of a stage-discharge equation, whereby the record of water level can be related to stream discharge. Discharge is measured as cubic feet per second in the stream channel at times of known stage (the elevation of the stream water surface). An equation is developed based on measurements through a range of stages which predicts discharge for any stage as recorded. By comparing stage-discharge measurements for Wildhorse 0, 1, 2 and 3 with the gauging station, discharge for each of the watershed areas is predicted.

Concentrations of suspended sediment in streams were sampled with Manning automatic water samplers (S-4040). Manning samplers can be

Table 1. Summary of area of portion of the Wildhorse watershed.

Area of Wildhorse Study Basins

	Acres	Sq.M.	Percent Total	Percent of WH 1
WH 0	3812	5.96	100	-
WH 1	2227	3.48	58	100
WH GS	1811	2.83	47	81
WH 2	1222	1.91	32	55
WH 3	416	0.65	11	19

FIG 1

AREAS	MI^2
VH 3.	0.65
NH 2	1.91
NH 1	3.48
AGE	2.83
JO	— ?

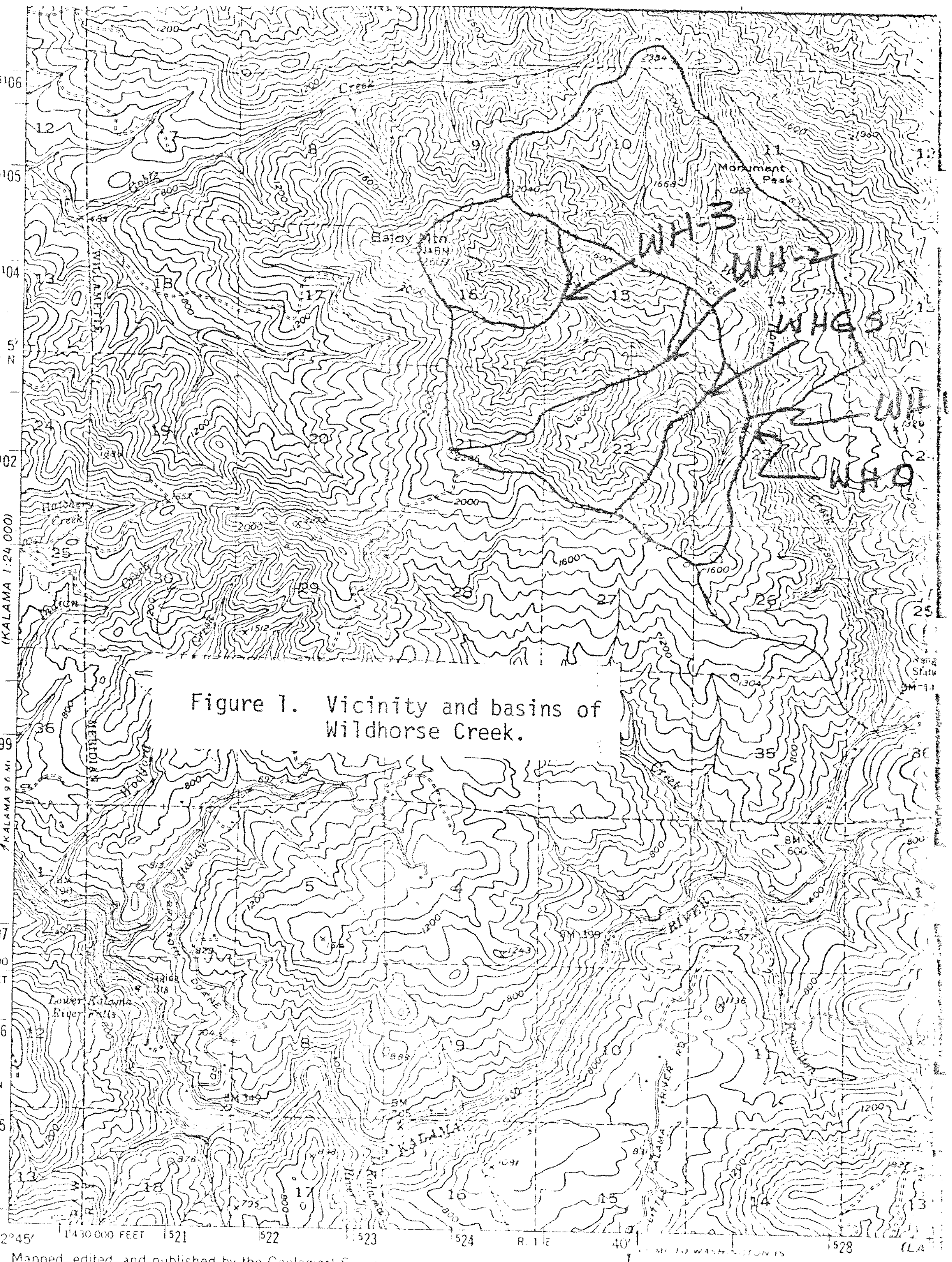

Figure 1. Vicinity and basins of Wildhorse Creek.

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1951 Field check 1953

Polyconic projection 1927 North American datum
10,000-foot grid based on Washington coordinate system, south zone

Dashed land lines indicate approximate locations

Unchecked elevations are shown in brown

1000-meter Universal Transverse Mercator grid ticks,
zone 10, shown in blue

UTM GRID AND 1953 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1

CONTOUR INTE

DATUM IS MEA

FOR SALE BY U. S. GEOLOGICAL SURVEY, DEN programmed to sample at discrete time intervals accumulating a programmed sample volume up to a total volume of 500 mls in a single sample bottle. Usually the samplers were programmed to sample either once an hour, every two hours or once every four hours, accumulating four 125 ml samples per bottle. Manning samplers were moved upstream progressively as road construction work progressed upstream in the watershed.

Manual grab samples were also taken in conjunction with automatic sampling during particular phases of the road construction process.

Rainfall was monitored using a tipping bucket rain gauge located near the confluence of the west fork of Wildhorse Creek and main Wildhorse Creek. One-hundredth of an inch of rain is required to tip the bucket marking an event on the continuous event recorder. Both rainfall intensity and duration were monitored. Precipitation measurements were initiated in March 1977.

LABORATORY PROCEDURES

All laboratory and analytical procedures used in this study are accepted hydrologic research methods. Determinations of suspended sediment followed procedures of Guy (1969) and Guy and Norman (1970). This method establishes quantities of suspended sediment in water samples through physical filtration of samples and oven drying (at 105° C) sediment caught on filter papers to a constant weight. Volumes of sample are measured and results reported in milligrams per liter (mg/l). Turbidity in NTUs[1] is determined on a Hach model 2100A turbidometer by Standard Procedures prescribed by the manufacturer.

Discharge is estimated from the field measured stage-discharge data of actual measurements of discharge. The Fischer-Porter recorder punches a digital number every 15 minutes. A computer program was developed which

[1]Turbidity is determined by passage of a light up through the bottom of the tube containing a sample. Reflected light intensity is measured by a photomultiplier tube. Calibration of the instrument is based on a formazin material which can be synthetically reproduced to a 1% accuracy. The unit of measure used by the Hach 2100A instrument is the Nephelometric Turbidity Unit (NTU). NTUs may be used interchangeably with the Jackson Turbidity Unit (JTU).

provides the average of four 15-minute discharge recordings giving average hourly discharge in cubic feet per second (cfs) and inches (in.) of runoff. The 24-hour data are averaged giving a printout of daily peak flows, daily minimum flows, mean daily flow based on the average of 24 one-hour averages, converting this value to inches of runoff also. The instantaneous minimum and maximum flows are selected from the array of 15-minute readings so the peak or minimum flow may be lesser or greater than any of the average hourly flows.

A data management system was set up within the computer for maintaining the sequence of sediment concentration, NTUs and discharge over time. Sampling intensity by the automatic water samplers also must be known to calculate total sediment represented by each sample. These data are then used to calculate the tons of suspended sediment transported by the stream over time.

Interpretation of impacts of prescribed road construction activities or forest practices on water quality requires establishment of the time and duration of the particular activity. When time and date are known, then records of suspended sediment can be checked for concentration and duration of impact. Records of construction activities in the Wildhorse basin are a compilation of Weyerhaeuser Company, Department of Ecology, and College of Forest Resources records.

Interpretation of impacts of road construction activities on water quality in the Wildhorse basin was accomplished by installation and movement of automatic water samplers as road construction progressed. Basic to the analyses and interpretation of water quality data was the continuous record of streamflow. The stream discharge record provides the basis for estimation of discharge from ungauged portions of the basin, as well as calculations of total quantities of sediment transport as a result of a given construction activity.

The Manning automatic water samplers as used at a series of sites established quantities of sediment transported from various locations in the watershed in relation to construction activities. Figure 2 shows the locations of monitoring equipment during portions of the study. Table 2 summarizes the locations, movement and sampling by the automatic samplers.

Sampling was more or less continuous for the major portion of the study from mid-January 1977 through May 1978. The December 1977 flood washed out three samplers; thus, suspended sediment records are not available for sediment transport during the major flood. Study of Wildhorse 0 below the confluence of the west fork was initiated in November 1977, discontinuous due to the flood in December 1977, with a new sampler installed in late January 1978 and maintained for the balance of the study. Wildhorse 1, 2 and 3 were sampled continuously for the major portion of the study, although not always in exactly the same locations.

ROAD CONSTRUCTION ACTIVITIES AND OBSERVATIONS

Road construction on 6241 (Weyerhaeuser Company road identification number) was initiated prior to establishment of the monitoring stations. The following record is a compilation of information from the Weyerhaeuser Company, records of the Department of Ecology, and the diary maintained by the College of Forest Resources during conduct of the study.

December 6, 1976	Road construction had started with felling of the right-of-way timber and pioneering grade of the road past station 1+90, the site of the main culvert installation across Wildhorse Creek and the location identified as Wildhorse 2 in this report.
December 8 ~~or 9~~, 1976	A pipe arch culvert was installed at station 1+90, and prior to this time the channel of Wildhorse Creek had been rechannelized away from a steep eroding bank in the natural channel. Felling of timber was continuing. (Date of riprap required by Game Dept.?)

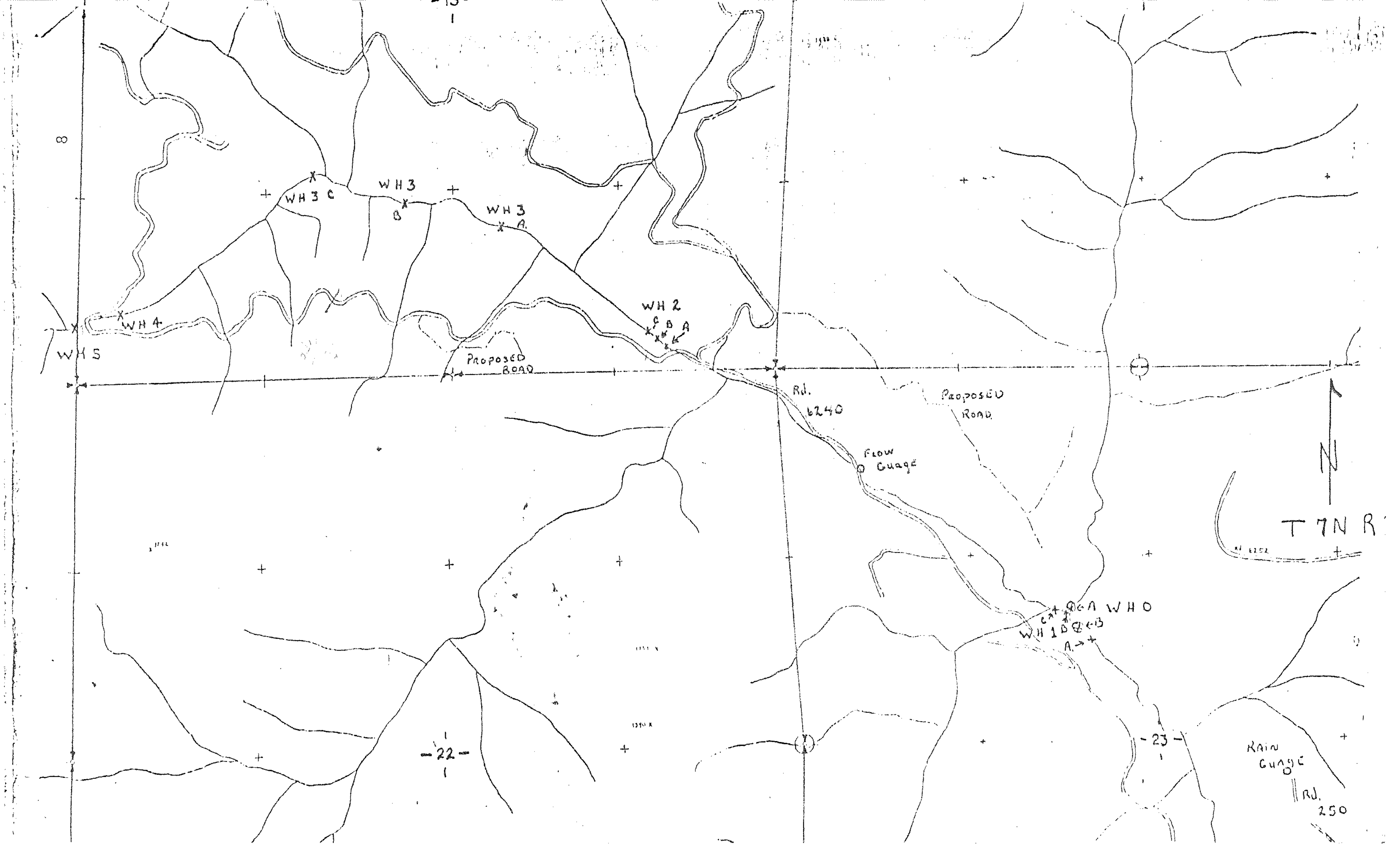
8
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Table 2. Dates and duration of Wildhorse Creek monitoring stations.

WH 0	A.	Sampler installed November 29, 1977. This sampler was lost during December 1977 flood.
	B.	New sampler installed downstream January 26, 1978. Sampler removed from site June 1, 1978.
WH 1	A.	Sampler installed January 21, 1977.
	B.	Sampler moved upstream February 11, 1977.
	C.	Sampler moved upstream February 14, 1977. Removed from this site June 1, 1978.
WH 2	A.	Sampler installed January 6, 1977.
	B.	Sampler moved upstream January 21, 1977. This sampler was lost during December 1977 flood.
	C.	New sampler installed upstream December 12, 1977. Sampler removed from this site June 1, 1978.
WH 3	A.	Sampler installed January 21, 1977.
	B.	Sampler moved upstream March 7, 1977.
	C.	Sampler moved upstream July 22, 1977. Sampler removed from this site June 1, 1978.

Sampler was installed below the upper stream crossing to monitor culvert installation. That sampler was put in place August 25, 1977 and removed August 29, 1977 after culvert installation was completed and after the water had cleared up.

WH gauge installed January 6, 1977.

Tipping rain bucket and long-term event recorder installed March 7, 1977.

December 14, 1976 to January 21, 1977	Station 0+00 to station 33+00. Stumps were shot, right-of-way logs decked; right-of-way cleared and graded to preliminary grade.
January and February, 1977	Existing road (6240) received an additional lift of rock. New road (6241) rocked for approximately 5 stations.
January 21, 1977	Roads (6240 & 6241) were observed to be very muddy. The rock base was still solid; freezing and thawing was taking place, and truck traffic was very heavy. Sediment was observed to be collected in the stream bottom. Road builders reported little or no rain all week. Road construction was halted as of January 21.
January 27, 1977	Weather cold and clear. Rainfall not reported. Stream (WH 1) is low and clear.
February 11, 1977	Road (6240) very muddy. No runoff from the road apparent even though raining.
February 22, 1977	Had rained hard most of the weekend with signs of overland flow from the road, ditches and cuts in sections.
March 7, 1977	Cold, wet and windy. Rock of road surfacing appears eroded or worked into mud. Berms are obvious and channel surface flow.
April and May	No observations were made. Assume no activities.
June 22, 1977	Hydromulched cuts and fill were observed to be very green and grass 6 to 8 inches tall. Alder along the mainline had been sprayed.
July 22, 1977	Five stations of new road (6241) had been graded and existing road (6240) had been graded.

August 16, 1977	Two tractors and four or five gravel trucks operating. Built an additional one and a half stations of road and rocked past 5+00.
August 19, 1977	Road rocking continues; right-of-way timber is removed, and pioneering to initial grade continuing.
August 24 to September 15, 1977	Station 33+00 to 88+40, right-of-way logs decked, grade cleared to preliminary grade.
August 24, 1977	Road pioneering approaching location of upper crossing on Wildhorse Creek. No machinery had entered the stream, and no logs had been yarded across the stream. Approaching the culvert crossing, two springs were uncovered within 100 ft. of the crossing. These springs required drainage and the second had to be diverted from the road surface with a berm. Sidecasting was observed to have occurred in Wildhorse Creek.
August 25, 1977	Culverts installed in the small type V streams at 1100. Rocking had continued throughout the day at 5 trucks per hour. Rain fell from 1130 to 1400. Considerable road runoff was observed from below Wildhorse 2. Road rutted.
August 26, 1977	Fill placed on near side of Wildhorse Creek. Tractor crossed the creek with pioneering work continuing. Channel disturbance was observed.
August 29, 1977	The culvert installation across upper Wildhorse Creek started about 800 and was completed by 10 o'clock. A travel time for sediment movement of 4 hrs. was approximated for the 3/8 mi. of stream length. Rain occurred through the day causing road runoff to also increase stream turbidity.

September 16, 1977	Rocking of road completed. Five trucks per hour were travelling the road with an estimated 383 cubic yards of rock per station. With a 10-yd. truck, this would require 38 loads per station for a total of 3000 loads for the 88 stations of road.
August 29 to October 3, 1977	Decked right-of-way logs were hauled from the entire road length.
September 1 through October 4, 1977	The entire length of road was graded and ditched.
October 4, 1977	Hydromulching was completed for the entire road length.
November 29, 1977	Flow at Wildhorse 3 observed to be very high but clean. A slide from a cut 3 stations uproad blocked the 6241 road.
December 1-2, 1977	Flood of 10+ in. rain in 2 days; 8.4 in. in 24 hrs. Intense rain started at noon on 12/1 and continued for 24 hrs.
December 9, 1977	6240 road blocked by a slide at the barrow pit. At Wildhorse 2 the channel rerouted to its original channel eroding all of the riprap. A cottonwood was toppled almost blocking the culvert. Flow over-topped the road with significant depositions upstream from the culvert. On the upper culvert surface run-off was diverted down the road surface eroding 10 to 15 yards of culvert fill. An impoundment 6 to 7 ft. deep formed above the culvert at the gauging station.
January 12, 1978	The road was cleared.
January 26, 1978	Ditches were being cleaned by the drott.
March 23, 1978	Heavy sediment load observed at Wildhorse 0 from main tributary.

RESULTS

The following sections provide the results of the field monitoring of sediment samples and discharge, relating discharge to quantities and concentrations of suspended sediment transported from sub-basins of Wildhorse Creek and where possible will relate the quantities of sediment transport to forest road construction or the dynamics of natural events. The first sections contain a discussion of the discharge calculations and the relationship of suspended sediment transport concentrations to optical properties (NTU values) of water as estimated by turbidity determinations.

Results of the study were influenced by two significant unavoidable events--first, the initiation of road construction and first culvert installation on the 6241 road (station 1+90) prior to establishment of monitoring facilities, and the major flood of December 1 and 2, 1977. The installation of the culvert at station 1+90 and diversion of the channel of Wildhorse upstream from the culvert caused very significant sediment transport throughout the downstream reach (the stream section between WH 1 and WH 2). The early initiation of construction work also prevented establishment of a natural sediment transport-discharge relationship for the basin.

The December 1 and 2, 1977 flood was of significant magnitude in that numerous shifts of the natural channel occurred as well as the channel reverting to its original location just below above the Wildhorse 2 station. Major floods events induce significant channel instabilities which have persisting effects on the future sediment transport-discharge relationship. Frequently, several years are required before the relationships return to the preflood condition. These two factors make the interpretation of sustained low level turbidities which occurred difficult. The results section which follows will discuss only those aspects of the road construction process that can clearly and positively be identified and the resulting suspended sediment transport.

DISCHARGE CALCULATIONS

The continuous discharge record from the gauging station on Wildhorse Creek (WH-GS) was the basis for calculating discharge of ungauged areas and prorating these discharges to other portions of the basin. The stage-discharge relationship developed from actual discharge measurements used a power function curve where:

$$\text{Discharge (Q)} = A\ (\text{stage})^{B} = 29.74\ (\text{stage})^{3.894}$$

Discharge is predicted in cubic feet per second (cfs) when stage is measured in feet to hundreds. This equation was used for discharge measurements until the December 1-2, 1977 flood. The flood transported a large amount of bed load which changed the downstream cross-section of the stream channel at the gauging station, requiring calculation of a new stage-discharge equation. The new equation was:

$$\text{Discharge (Q)} = 0.206\ (\text{stage})^{10.455}$$

Initial phases (Jan. to Dec. 1977) of the study also used staff-discharge relationships to predict the flow of the various sub-watersheds based on the staff-discharge relationship of the gauge. Later phases (after Dec. 2, 1977) of the study found it more reliable, particularly after the flood, to predict the discharge of ungauged portions of the watershed on a proportionate basis. The unit area contribution to flow at the gauge is prorated into the separate watersheds based purely on their size.

This method provides accurate estimation of streamflow for large scale orographic storms which deliver reasonably uniform rainfall over a large area. It is less accurate for cyclonic storms where intense cells of rainfall occur and deliver a short-term intense rain to a relatively small area.

DECEMBER 1 AND 2, 1977 FLOOD

A storm initiated at around 8:00 a.m. on December 1 and continued with intense rainfall through noon December 2; 4.93 inches fell on December 1 and 5.18 on December 2. Most intense rain occurred for 24 hrs.

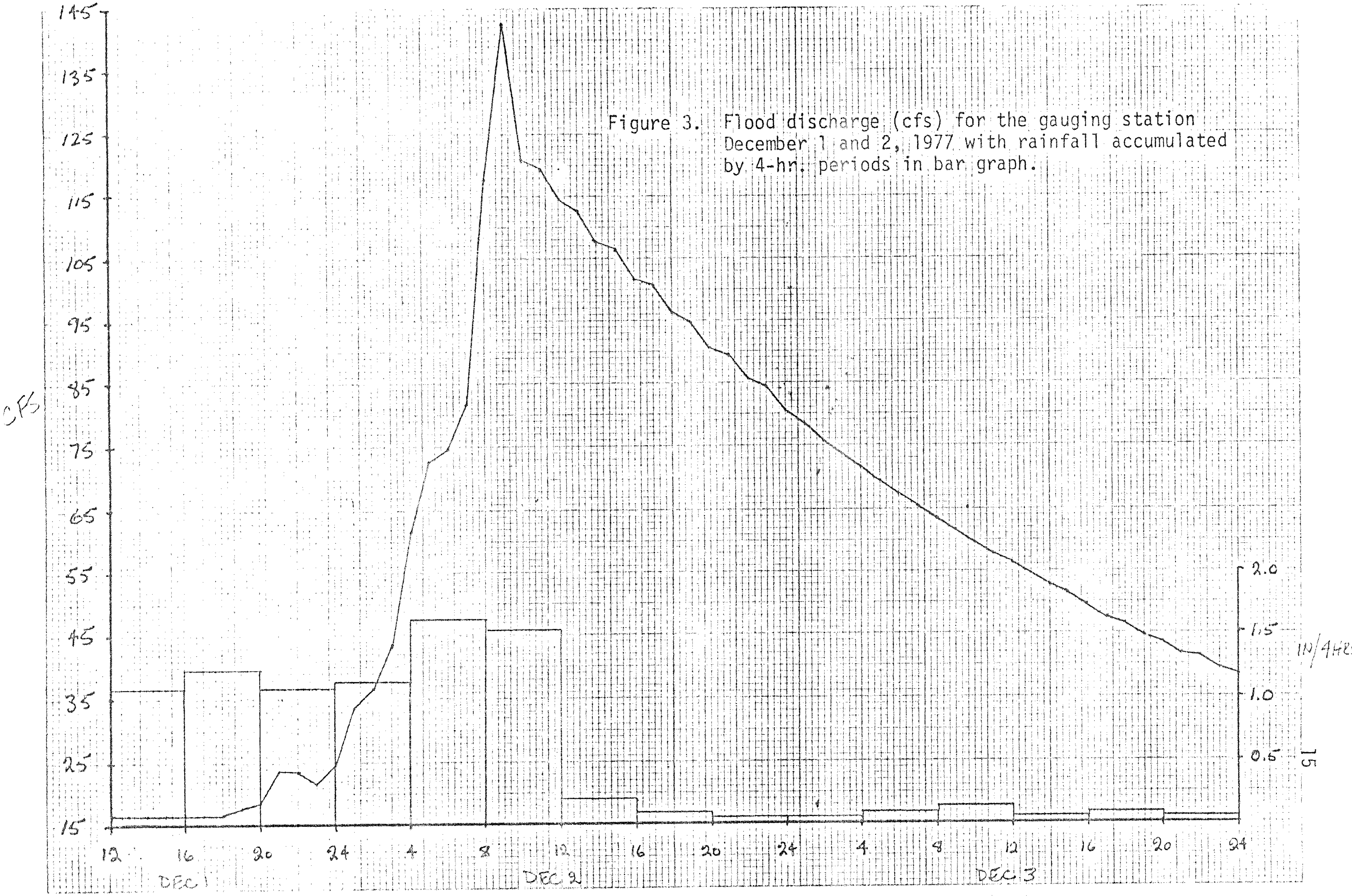

Figure 3. Flood discharge (cfs) for the gauging station December 1 and 2, 1977 with rainfall accumulated by 4-hr. periods in bar graph.

from noon December 1 to noon on December 2. Numerous small slumps and slides had already occurred blocking flow in ditchlines in portions of both the 6240 and 6241 roads from storms in late November. The December storm blocked the 6240 road with a large slide at the borrow pit.

The channel above the culvert at the Wildhorse 2 station reverted to its original channel and the road was topped by overflow. Estimated peak flow at WH 2 was near 200 cfs. At WH-GS, the culvert could not accommodate the flow as water backed up 6 to 7 ft. above normal high water on the upstream fill of the culvert.

The backwater formed by the pond upstream from the culvert during peak flood flow sustained a substantial volume of bed load deposit. The fact that the pond formed and stored a sufficient volume of water reduced the peak flow recorded at WH-GS. As the flood receded, bed material was transported downstream filling in the cross-section at the gauging station where discharge is usually measured. This change in the channel caused a shift in the datum requiring establishment of a new stage-discharge equation. The dynamics of the fill/scour process and other stage changes required hand calculation of discharge, assuming certain factors relating due datum change. If these assumptions are in error, inaccuracies could exist in the predicted discharge of WH-GS between the flood recession on December 2 and 3 and a datum shift on January 12. The new equation developed gives accurate flow predictions after January 12. The hydrograph for the flood is shown in Figure 3 along with the hourly rainfall rates.

The Manning sampler at Wildhorse 3 was the only of four ~~three~~ samplers not lost by channel shifts. Numerous fill failures and slumps diverted water on the roads, resulting in significant transport of suspended material. The road was cleared on January 12, 1978 with cleaning of the ditches continuing through January.

RELATIONSHIPS OF SUSPENDED SEDIMENT AND NTUs

Tables 3 and 4 show two analyses of the relationships of suspended sediment concentrations and the optical property of sediment samples in

Table 3. Relationships of suspended sediment concentration and NTUs for phases of the hydrograph at three locations in Wildhorse Creek.

Station	Phase of Hydrograph	Number of Observations	Coefficients a	b	R^2
Wildhorse 1					
	All	336	7.55	2.73	0.76
	Rising	19	13.06	2.76	.96
	Falling	64	11.63	0.84	.57
	Steady	74	7.47	1.44	.84
Wildhorse 2					
	All	323	22.21	2.84	.68
	Rising	28	16.03	1.93	.98
	Falling	75	5.34	3.85	.90
	Steady	82	12.43	1.70	.90
Wildhorse 3					
	All	317	-14.91	20.49	.87
	Rising	56	14.87	2.69	.48
	Falling	128	-19.84	23.31	.93
	Steady	133	4.65	3.29	.68

Table 4. The distribution of NTU readings for ranges of suspended sediment in milligrams per liter.

Total Observations = 172

	NTU								
mg/l	0.0-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-9.9	10.0-19.9	20.0-29.9	30.0-45.0
0.0- 10.0	42	63	22	1					
10.1- 20.0		5	10	8					
20.1- 30.0	1			2	1	1			
30.1- 40.0			1	1		2			
40.1- 50.0						1			
50.1- 60.0					1	1			
60.1-100.0						1	2		
100.1-150.0							1	1	
150.1-200.0							1		
200.1-250.0							2		1
250.1-300.0									1

NTUs (equivalent to JTUs). Table 3 analyzes certain of the Wildhorse Creek data by watersheds for rising, falling and steady stages of the hydrograph, then combines all data into one analysis. For example, Wildhorse 1 for 336 observations had a linear relationship:

$$\text{Suspended sediment (SS)} = 7.55 + 2.73 \text{ (NTU)}$$

This equation has a simple correlation coefficient of 0.87 and a coefficient of determination of 0.76. The relationship of falling stages is much more variable ($R^2 = 0.57$) than rising stages ($R^2 = 0.96$). The column labeled b coefficients show the relationship of suspended sediment as milligrams per liter to NTU readings. A small coefficient indicates lesser amounts of suspended sediment with increasing NTUs, while a large coefficient indicates rapidly increasing amounts of suspended sediment with increasing NTUs.

Relationships of NTUs and suspended sediment for Wildhorse 2 are more consistent than the other two sub-basins. These relationships also are stable when segregated into rising, falling and steady state discharge. At low levels of NTUs, there is relatively little difference among the three equations. At higher levels, however, the falling stage would have rapidly increasing suspended sediment indicated because of the large coefficient. These relationships are even more pronounced in Wildhorse 3 where very large coefficients were found for all stages and particularly for falling stages. The analyses for all stages were probably dominated by the increased number of determinations made for falling stage.

Table 3 shows that statistically significant associations between suspended sediment and the NTUs can be developed. However, the variability in the relationships developed is indicated in Table 4 where the range of sediment concentrations in milligrams per liter is shown on one axis and the range in NTU values on the other axis. For example, for suspended sediment concentrations between 0 and 10 milligrams per liter, there were 128 observations which ranged from near 0 NTU reading to almost 3.9 NTU. Fewer observations were taken in the 10.1 to 20 milligrams per liter range showing a range from 1 to 3.9 NTUs.

This variability can also be identified by the fact that in the range of 0 to 0.9 NTUs, suspended sediment varied from near 0 to slightly less than 30 mg/l. In a like manner, in the range of 5.0 to 9.9 NTUs, suspended sediment ranged from 20.1 to slightly less than 100 mg/l. Suspended sediment ranged from 60 to about 250 mg/l in the 10-19 NTU range. From these data, it may be concluded that while relationships do exist between suspended sediment concentrations as measured in milligrams per liter and NTUs, they are not sufficiently accurate to provide a highly reliable prediction tool.

SUSPENDED SEDIMENT SOURCES

Levels of suspended sediment monitored after August 25, 1977 in Wildhorse Creek and various sub-basins have two potential sources: 1) natural erosion and channel processes, and 2) Man-induced sources resulting from forest road construction. The confounding factors of the December 1 and 2, 1977 flood and a lack of background data on natural processes for a major portion of the watershed limits the ability to interpret causes of sustained low levels of suspended sediment transported under weather conditions when the stream ~~flow~~ water should have been clear.

The sequencing and movement of Manning samplers at Wildhorse 3 provided a range of sediment transport characteristics for this small undisturbed portion of the watershed prior to July 1977. These data will be compared (Table 5) with sediment transport at WH 2 and 1 to interpret the impacts of the pioneered road to station 33+00 on the 6241 road, and hauling use and rain related impacts on the 6240 road between the mouth and the WH 2 station.

The first significant storm recorded in the study was in February 1977 which produced sediment concentrations with a range of .3 to 63 mg/l on February 22 and 23 at WH 3. At this time, WH 3 represented the undisturbed conditions of a pristine forest. Rainfall associated with this storm was 1.67 in. from February 21 through 23. The larger portion of the watershed,

Table 5. Discharge and suspended sediment concentrations with total sediment load transported for pristine conditions of WH 3 and road altered conditions for WH 1 and WH 2.

Date 1977	Storm Precip. (in.)	WH 1 Discharge cfs	WH 1 Sediment Concentration Max. mg/l	WH 1 Sediment Concentration Min. mg/l	WH 1 Sediment Load T/sq.mi	WH 2 Discharge cfs	WH 2 Sediment Concentration Max. mg/l	WH 2 Sediment Concentration Min. mg/l	WH 2 Sediment Load T/sq.mi	WH 3 Discharge cfs	WH 3 Sediment Concentration Max. mg/l	WH 3 Sediment Concentration Min. mg/l	WH 3 Sediment Load T/sq.mi
Feb. 22		10.2	9.0	2.8	0.03	6.9	8.0	3.6	0.04	3.83	63.0	2.3	0.21
Feb. 23	1.60	8.2	6.0	2.2	0.02	4.5	9.0	6.0	0.05	3.07	45.0	0.3	0.13
Feb. 28	3.24	20.0	216.0	94.0	1.13	14.4	22.0	12.0	0.17	11.98	43.0	43.0	0.46
Mar. 1	.77	20.4	103.0	68.0	1.07	17.7	8.0	6.0	0.14	12.57	91.0	24.0	2.63
Mar. 2	.11	19.3	283.0	26.0	2.15	14.3	9.0	5.0	0.13	11.67	37.0	12.0	1.09
Mar. 3	.53	20.6	166.0	58.0	1.55	15.4	122.0	3.0	1.23	12.58	209.0	37.0	5.42
Mar. 4		15.6	36.0	24.0	0.46	17.0	21.0	14.0	0.28	13.12	33.0	23.0	1.50
Mar. 5		17.7	25.0	16.0	0.27					10.13	20.0	12.0	0.71
Mar. 6	.66	15.9	12.0	11.0	0.14					8.42	12.0	9.0	0.36
Mar. 8	.27					14.0	279.5	14.7	2.27	10.68	82.2	9.3	1.52
Mar. 9						16.2	159.8	50.5	2.32	12.88	27.9	14.1	1.04
Mar. 10						16.6	22.7	13.6	0.43	13.98	13.9	7.2	0.57
Mar. 11	.31					14.6	23.6	12.1	0.35	12.04	10.1	4.6	0.34
Mar. 12	.07					16.0	18.6	12.9	0.34	12.82	12.5	4.5	0.40
Mar. 13	.24					15.2	13.5	13.0	0.19	12.18	9.2	3.4	0.28
Mar. 14		18.6	11.0	5.1	0.08					10.79	2.9	2.6	0.08
Apr. 22	.06	10.5	7.9	6.6	0.06	5.0	7.0	3.8	0.04	4.04	2301.3	5.2	12.69
May 4	2.93	16.0	21.4	15.4	0.22	10.0	20.9	7.8	0.21	7.48	18.9	5.9	0.36
May 5	.16	16.2	20.8	11.5	0.19	10.2	33.3	8.5	0.27	7.27	18.1	5.4	0.33
May 6	.37	15.6	63.5	11.3	0.36	10.0	45.4	8.4	0.34	8.08	24.5	7.6	0.53
May 7		14.6	41.8	9.3	0.23	8.7	37.3	7.8	0.21	6.71	27.2	6.8	0.46
May 8	.54	16.6	15.2	12.4	0.17	11.0	18.0	9.3	0.21	8.93	17.1	9.6	0.34

as monitored at WH 1 and 2, shows very low concentration of suspended sediment ranging from 3.6 to 9 mg/l for WH 2 and 2.2 to 9 mg/l for WH 1. In tons per square mile, both WH 1 and WH 2 were very low (.02 to .05 t/sq.mi) as compared to WH 3 which ranged from 0.13 to 0.21 t/sq.mi).

A rainstorm started in late February with 0.89 in. on the 26th, 1.36 on the 27th, and 0.99 on the 28th, continuing on the 1st of March with 0.77 in. and a total of 0.64 in. in the next two days. Comparisons of sediment concentrations produced by WH 3 and 2 indicate very little coming from the 33 stations of road pioneered above the sampling location of WH 2. The undisturbed watershed produced sediment concentrations varying from 12 to 209 mg/l while the WH 2 station varied from 3 to 122 mg/l. Significant quantities of sediment were produced by the haul road between WH 1 and 2. Maximum concentrations of suspended sediment recorded at WH 1 ranged to 283 mg/l. Unit area production of sediment was actually greatest for the undisturbed portions upstream in WH 3. On March 3, it produced 5.42 t/sq.mi as compared with WH 2, 1.23 and WH 1, 1.55 t/sq.mi.

Sediment contributed at WH 1 on the previous day (March 2) shows the definite impact of a road. In the upstream undisturbed area, WH 3 produced 1.09 t/sq.mi while WH 2 produced 0.13, even though impacted by 33 stations of new road. Downstream, WH 1 produced 2.15 t/sq.mi with the source of additional material undoubtedly from the 6240 road. Our notes for February 11 and 22 indicate the road was very muddy with overland flow occurring from the roads and ditches, particularly on the 22nd. With additional rain, the roads, particularly with hauling and other activity, will produce a significant quantity of suspended load.

Discontinuities in the data caused by malfunction of the automatic samplers do not allow for exact mass budgeting of sediment transport between the stations. Table 6 shows an approximation of the total tons of sediment transported in Wildhorse Creek for the storms of late February and early March. Missing records from WH 2 may underestimate the quantities of sediment transported. Relationships between WH 3 and 1 show a rough indication of the tons of sediment produced in association with forest roads.

Table 6. Suspended sediment transport for WH 1, 2 and 3 in tons per day for February 28 through March 13, 1977.

Date	Sediment Transport (tons/day)		
	WH 1	WH 2	WH 3
Feb. 28	3.9	0.3	.3
Mar. 1	3.7	.3	1.7
2	7.5	.2	.7
3	5.4	2.3	3.5
4	1.6	.5	1.0
5	.9	-	.5
6	.5	-	.2
8	-	4.3	1.0
9	-	4.4	.7
10	-	.8	.4
11	-	.7	.2
12	-	.7	.2
13	-	.4	.2

A storm in late May produced the values for May 4, 5, 6, 7 and 8. This storm had just under 3 in. of rain occurring on the 2, 3 and 4. In total, this storm produced 1.2 tons from WH 3, 2.3 tons from WH 2, and 4.4 tons from WH 1. In this case, the production in t/sq.mi was relatively uniform among the three stations, indicating that most of the sediment had natural origins in or adjacent to the stream banks.

The role of seasonal dynamics is difficult to explain in that ordinarily storms early in the winter will produce more sediment transport for equivalent rainfall and discharge than storms late in the winter. Man's activities do change the sediment transport process in that in a natural state, the sources of sediment available for transport are frequently a limiting factor in the sediment transport process. After disturbance, however, significantly increased sources of sediment are available and stream power then becomes the limiting factor in sediment transport. These factors may be demonstrated to some extent in Table 8 where rainfall in late February induced significant sediment movement in WH 3, which was not measured at WH 2. A storm on May 6th, 7th and 8th produced over an inch of rain which caused significantly greater transport of sediment in both actual quantity and t/sq. mi past station WH 2 than originating with station WH 3. It is quite possible that portions of the load transported by WH 3 in early March were stored in the channel and transported to WH 2 on the next storm.

Monitoring of the road construction activities in late August 1977, as the upper crossing (above WH 3) of Wildhorse Creek was being prepared, provides the most detailed information on sediment and its source. In the record of activities, it is indicated that as grading approached the upper crossing, "two springs were uncovered ~~with~~ approximately 100 ft. of crossing that required individual drainage and affected tractor trafficability." (Rombach memo Sept. 13, 1977)

Other records indicate these springs, when disturbed, flowed down the road and were diverted. We recorded 1.86 in. of rainfall on August 23 with 0.26 in. on the 24th and 0.52 in. on the 25th. Table 7 summarizes the changes in suspended sediment concentrations immediately below the road building activity at the location indicated as WH 4 in Figure 2.

Table 7. Suspended sediment concentrations and quantities produced over time during site preparation and culvert installation on WH 3 sub-basin.

Date 1977	Time	Rain (in./day)	Sediment Concent. mg/l	Sediment Transport Ton/Time
Aug. 25	0915	0.52	57.5	0.04 tons/2.5 hrs.
	0945		470.4	
	1015		225.3	
	1045		262.9	
	1115		201.3	
Aug. 25	1145		518.0	
	1545		195.0	0.29 tons/16 hrs.
	1945		90.0	
	2345		305.0	
Aug. 26	0345	0.24	129.0	
	0745		951.0	0.67 tons/24 hrs.
	1145		1040.0	
	1545		336.0	
	1945		96.0	
	2345		56.0	
Aug. 27	0345	0.01	65.0	
	0745		25.9	0.08 tons/24 hrs.
	1145		30.3	
	1545		43.2	
	1945		25.6	
	2345		129.0	
Aug. 28	0345	0.39	234.0	
	0745		51.0	0.22 tons/24 hrs.
	1145		194.0	
	1545		128.0	
	1945		20.2	
Aug. 28	2345		35.4	
Aug. 29	0345	1.74	28.3	0.02 tons/8 hrs.
	0745		23.3	
Aug. 29	0805		328.6	0.011 tons/45 sec.
	0805		3663.0	
	0805		33,955.0	
Aug. 29	0807		66,389.0	
	0815		36,539.0	1.3 tons/30 min.
	0822		31,879.0	
	0830		18,522.0	
	0837		2,599.0	

Table 7
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Date 1977	Time	Rain (in./day)	Sediment Concent. mg/l	Sediment Transport Ton/Time
Aug. 29	0845		8,694.0	
	0900		4,963.0	0.74 tons/4.5 hrs.
	0915		12,444.0	
	0930		4,290.0	
	0945		6,728.0	
	1000		4,848.0	
	1015		2,358.0	
	1030		1,683.0	
	1045		1,238.0	
	1100		1,938.0	
	1115		874.0	
	1130		859.0	
	1145		894.0	
	1200		477.0	
	1215		384.0	
	1230		470.0	
	1245		531.0	
	1300		759.0	

Streamflow was constant at .6 cfs when monitoring was initiated. Streamflow remained fairly constant through the culvert installation reach, even though significant rain occurred.

On the morning of August 25, as the grade was being pioneered into the culvert location, concentrations of suspended sediment increased from 57 to over 200 mg/l. This change in concentration transported .04 ton of sediment in 2.5 hrs. Later in the day, sediment increased to 518 mg/l transporting .29 ton in the next 16 hrs. Work continued on the 26th with fill placed on the near side and the tractor crossing the stream to continue the pioneering work. High concentrations of suspended sediment were sustained throughout the morning of August 26 ranging to 1040 mg/l. Total sediment transport was .67 ton in 24 hrs.

There is no record of any activity over the weekend, Aug. 27th and 28th. Variation in suspended sediment levels is probably related to rainfall rates and surface runoff from disturbed soil areas. Increased construction activity with the actual installation of the culvert took place coincidentally with significantly increased rainfall (1.74 in./day) on August 29. Sediment produced from the actual culvert installation started about 8:00 o'clock on August 29. At that time, the background sediment levels averaged 12.1 mg/l.

As the tractor was working in the creek bed, preparing the bed and installing the culvert, suspended sediment increased from 328 to 33,900 mg/l in less than a minute. The increase continued to 66,389--two minutes later--decreasing to 36,500 mg/l at 8:15. Following completion of the work in the stream channel, suspended sediment concentrations reduced rapidly to less than 1000 by 11:15. For the balance of the day, suspended sediment concentrations varied between 384 and 894 mg/l. A total of 7.4 tons of **0.74 tons** sediment was produced in 4.5 hrs. of the most active work in and adjacent to the stream. The total sediment production related to pioneering for the culvert location, starting on August 25 through installation of the culvert on the morning of August 29, was 3.34 tons recorded at WH 4.

The station at WH 2 recorded 6.23 tons from 5:00 a.m. August 25 through 9:00 a.m. August 31. Sediment concentrations at the WH 2 station reflected in part the activity of preparing the upstream culvert along with the increased rainfall in the days previous to the culvert installation. Maximum suspended sediment concentrations recorded at WH 2 on August 25 were 146 mg/l as compared with 518 mg/l at station WH 4. Again, on August 26, the maximum concentration at WH 2 during the work day was 144 mg/l at 1:15 in the afternoon as compared with 1040 at 11:45 in the morning at WH 4. Over the weekend (Aug. 27 & 28), WH 4 sustained, on the average, greater variation in suspended sediment concentrations than recorded at downstream stations. Concentrations ranged from 42 to 92 mg/l at WH 2, while they varied from 20 to 234 just below the work area (WH 4).

During the culvert installation, a travel time of 4 hrs. was identified for increased levels of suspended sediment to be transported 3/8 mile between the two sampling locations (WH 4 to WH 2). Sediment concentrations varied throughout the day (Aug. 29) at WH 2 ranging from an average of 59.6 mg/l for samples taken between 1:00 and 4:00 in the afternoon, increasing to 922 mg/l for samples taken between 9:00 and 11:00 in the evening. Concentrations declined rapidly on August 30, starting at 425 mg/l at 1:00 a.m., declining to 14.7 in 24 hrs.

SEDIMENT TRANSPORT--DECEMBER 1-2, 1977 FLOOD

The lack of background data prevents an exact interpretation of changes in transport of sediment by the major flood of December 1 and 2, 1977. Table 8 summarizes the changes in flow rate over time with the quantities of suspended sediment transported and the tons. Samplers were set to sample every two hours compositing four samples to a bottle, accumulating three bottles per day. The sampler at WH 3 was the only sampler to survive the flood, providing the only record of sediment transport during the flood. These data are summarized in Table 6 (Table 8) which shows by date and time the average discharge with the associated average concentration of suspended sediment. The intense rainfall started about noon on December 1, resulting in rapidly increasing concentrations of suspended sediment. Flow tended to lag but

Table 8. Suspended sediment concentrations and quantities produced during the December 1 and 2, 1977 flood from WH 3.

Date 1977	Time	Discharge (cfs)	Sediment Concent. mg/l	Sediment Transported	
				Tons	Tons/Mi²/Hr
Dec. 1	0345	3.7	25.0	0.08	-
	1145	3.7	113.3	0.38	0.1
	1945	4.2	802.4	3.0	.6
Dec. 2	0345	14.0	2828.0	36.0	7.0
	1145	25.9	3754.2	88.0	17.1
	1945	20.6	1037.3	19.0	3.7
Dec. 3	0345	16.2	577.3	8.4	1.6
	1145	12.8	388.0	4.5	.9
	1945	10.0	158.8	1.4	.3
Dec. 4	0345	7.7	135.6	0.94	.2
	1145	6.0	76.4	0.41	.1
	1945	4.6	54.1	0.22	-

increased rapidly after midnight on December 1. This increase in discharge was associated with a very rapid increase in suspended sediment concentration. Peak flow averaged 25.9 cubic feet per second for the 8 hrs. preceding 11:45 a.m. on December 2. The average concentration of suspended sediment as sampled at 4 discrete time intervals was 3754 mg/l transported, 88 tons or the equivalent of 17.1 t/sq.mi/hr. Following the peak rainfall intensities, suspended sediment transport declined rapidly showing the usual departure in quantities of suspended sediment transported by falling stages as opposed to rising. For example, with an average flow of 4.2 cfs on the rising stage, average sediment concentration was 802 mg/l. On the falling stage, only 1037 mg/l was associated with a flow of 20.6 cfs.

A storm later in December had 5 consecutive days (Dec. 11 through 15) of 1 in. or more rainfall ending with 3.11 in. on December 15. The magnitude of flooding from this storm was significantly less as the rainfall was extended over a much longer period of time. In a similar fashion, suspended sediment transport seemed significantly lower with a peak concentration of 500 mg/l occurring at WH 3 (flow to 6.5 cfs). Maximum sediment transported was .3 t/sq.mi/hr.

Cleanup after the flood in January undoubtedly contributed significant amounts of sediment at times. However, the record of activity is not sufficiently accurate to precisely pinpoint quantities related to a particular activity. The activity record indicates, starting on January 12, that the road was cleared of slides and on January 26 the ditches were being cleaned. Rainfall was persistent in early January but few days registered more than a few tenths. The exception to this was January 5 which recorded 1.5 in. and January 21 with 1.68 in. WH 1 experienced a drastic increase in suspended sediment concentration early in the day on January 21. Concentrations went from 3 to 5 mg/l to 233, then 235 mg/l between midnight and 6:00 a.m. on January 21. There was a significant increase in streamflow recorded going from 13 and 14 cfs to over 40 cfs at WH 1. WH 2 upstream recorded a change from background levels of 1 to 7 mg/l and increased to 206 mg/l in samples accumulated between noon and 4:00 on January 20.

WH 3 did not contribute significant amounts of sediment during this period.

The station at WH 0 had been reactivated and recorded a total of 21.9 tons transported in four days between January 26, 1978 and the end of the month. Sediment was consistently produced at an average of about .25 t/hr showing little or no diurnal variation, with a suspended sediment concentration range from 67 to 94 mg/l. Discharge remained relatively stable varying from 22.6 to 32.2 cfs. Records are not available for WH 1 but WH 2, on January 26 and 27, produced an average of 0.08 t/hr. Sediment production above station WH 3 remained insignificant.

The significantly increased concentrations of suspended sediment in Wildhorse Creek must reflect a maintenance activity. Late in the day on January 30, suspended sediment dropped to 8 to 10 mg/l.

SUMMARY

The impacts of forest road construction on non-point sources of suspended sediment were investigated for portions of two winters in Wildhorse Creek, a tributary of the Kalama River in Cowlitz County, Washington. Results of the study were unavoidably confounded by a series of factors:

1) Lack of monitoring facilities prior to initiation of road construction.
2) Unusually low annual precipitation in the first year of the study, and
3) A long return interval flood prior to a major phase of road construction.

The specific objectives of the study were satisfied by detailed examination of suspended sediment concentrations and sediment transport during a culvert installation on the major tributary of Wildhorse Creek. Suspended sediment concentrations increased very rapidly when tractors entered the stream channel. In a matter of less than a minute, the suspended sediment concentration increased from 328 to 33,955 milligrams per liter. With a flow rate of 0.6 cfs, .011 ton of sediment was transported in 45 seconds. Two minutes later as the culvert was being installed, suspended sediment concentrations peaked at 66,389 mg/l. In the next 30 minutes, 1.3 tons of sediment were transported from the construction site by the stream. Sediment concentrations declined very rapidly to less than 1000 mg/l three hours later. The station downstream 3/8 mile reported a maximum suspended sediment concentration of 922 mg/l after culvert installation. A 4-hr. travel time was estimated for sediment to travel 3/8 mile between the two stations.

Statistically significant relationships were established for three study stations between suspended sediment concentrations and turbidity

as measured by NTUs. The coefficients of determination (R^2) ranged from .48 to .98, usually with strongest relationships found on rising stages. Generally, the most variable relationships were found when all stages are combined in a single analysis. Even though statistically significant relationships were found, there are large variations in either NTUs recorded for a given range of suspended sediment concentration or large variation in the range of suspended sediment concentrations for a given range of NTUs.

It may be concluded that sediment transport processes are extremely variable, dominated in particular by duration and intensity of rainfall but also affected by many random factors. Very significant increases in sediment transport are recorded when forest road construction activities take place within the live stream channel. The impact and duration of increases in sediment transport are very dependent on pre- and post construction rainfall rates and durations.

In this study, it is impossible to interpret low concentration (less than 10 mg/l) sources of sediment which persist during periods of little or no rain.