Soil and Watershed Characteristics in Relation to Turbidity of the Prineville Reservoir

Special Report 453
February 1976

Agricultural Experiment Station
Oregon State University, Corvallis

PREFACE

During the years following the devastating 1964-65 flood, observers have increasingly become aware of persistent turbidity in the Prineville Reservoir and the Crooked River downstream. In early 1970, local representatives of state and federal agencies formed a steering committee to assess probable causes of the turbidity and measures to control it. The committee, under the chairmanship of Thomas Bunch, recognized the complexity of the problem and requested assistance from the Oregon State University Soil Science Department and others in developing a program of investigation.

A preliminary step was to sample the Crooked River above and below the Prineville Reservoir for evaluation of suspended sediments and water quality at OSU under laboratory conditions. These analyses indicated some probable causes of turbidity including suspended clay, electrolyte concentration and a probable source, the 2,500 square mile Upper Crooked River watershed.

A proposal for a more detailed two-year investigation was prepared by OSU at the request of the committee and was implemented in October, 1971. Financial support and cooperation of the U. S. Bureau of Land Management, U. S. Forest Service, Oregon Wildlife Commission, U. S. Bureau of Reclamation, and the Oregon Agricultural Experiment Station, were arranged through the steering committee. Other cooperators included the Federal Cooperative Extension Service, U. S. Soil Conservation Service, and the Department of Environmental Quality. During the course of study, reports have been submitted to the steering committee periodically and several meetings were held to inform cooperating agencies of progress of the study.

The conclusions and recommendations of this report are based on data and observations obtained over a highly variable two-year period. Additional data over a longer time period are needed to more adequately quantify the effects of year-to-year weather differences. Although the investigation was necessarily limited in scope and duration, it has permitted aquisition of much data needed for understanding the nature and causes of turbidity in the Prineville Reservoir. The work will aid resource and land use management agencies in reducing soil loss and turbidity in the Prineville Reservoir watershed and in similar watersheds of Eastern Oregon.

ABSTRACT

The causes and nature of high turbidity levels in the outflow from Prineville Reservoir in Central Oregon were investigated. Long-term turbidity was correlated with highly erodible soils derived from soft, tuffaceous sedimentary rock. These soils and sediments are high in smectite clay and show significant amounts of amorphous material. Short-term stream sediment loads as high as 12,000 ppm, resulting from high intensity convective storms, were not necessarily correlated with sources of long-term turbidity.

Certain livestock grazing, timber harvest, road building and fire prevention practices were observed that contribute to erosion and turbidity problems. Recommended management practices include stream channel stabilization and better soil-vegetation management, especially on the more erodible rangeland watersheds.

C. E. Silvernale, Research Assistant in Soil Science
Dr. G. H. Simonson, Professor of Soil Science (Survey and Soil Classification)
Dr. M. E. Harward, Professor of Soil Science (Clay Mineralogy)
Department of Soil Science

ACKNOWLEDGMENTS

This study was carried out as part of Oregon Agriculture Experiment Station Project 38, Sources and Nature of Turbidity in Selected Oregon Reservoirs. Project advisors were Dr. C. T. Youngberg, Professor of Soil Science (forest soils); Dr. P. C. Klingeman, Assoc. Prof. Civil Engineering (watershed hydrology); Dr. Byron Thomas, Soil Scientist and Dr. Ed Burroughs, Hydrologist, U. S. Bureau of Land Management; Dr. Jerry Swank, Hydrologist, U. S. Forest Service; and Dr. Dillard Gates, Professor of Range Management.

Personnel of cooperating agencies who aided in planning or in field investigations included Tom Bunch, Crook County Cooperative Extension Service; Don Robbins and Mike Rollins, U. S. Bureau of Land Management; Richard Herrig and Len Mathison, Oregon Wildlife Commission; Carl Anderson, U. S. Forest Service; Floyd Oliver, U. S. Bureau of Reclamation; Kent Ashbaker, Department of Environmental Quality; LaSelle Cole; Prineville Irrigation District; Garry Schaefer, Joel Norgren, and Alexandra Silvernale, Soil Science Dept., OSU.

TABLE OF CONTENTS

Table of Contents
continued

Table of Contents
Continued

LIST OF TABLES

List of Tables
Continued

LIST OF FIGURES

LIST OF PLATES

SOIL AND WATERSHED CHARACTERISTICS IN RELATION TO TURBIDITY OF THE PRINEVILLE RESERVOIR

C.E. Silvernale, G.H. Simonson
and M.E. Harward

INTRODUCTION

Reservoir discharge into the Crooked River in recent years has been reported to be sufficiently turbid to noticeably reduce recreational use, particularly fishing. The effect of turbidity on the wildlife habitat, particularly on fish, is not known but this has been under study by the Oregon State Wildlife Commission. Concern over water quality in the Prineville Reservoir and its downstream discharges has culminated in a study to determine why the reservoir remains turbid for long periods of time.

Public reaction to degraded water quality is pronounced when the pollution is readily observed, as is the case for the Crooked River and the Prineville Reservoir. From the standpoint of recreational water, appearance or clarity is used by the general public to judge whether the water is "clean".

A visual effect of cloudy water is termed turbidity[1/] and its component parameters are usually judged to be color, suspended solids, and visibility. Turbidity itself can be a measured parameter and is a blend of these components.

The Upper Crooked River watershed in Central Oregon encompasses some 6,475 square kilometers (km^2) (2,500 mi^2) consisting primarily of range and forest lands.

In a resource area of this magnitude, soils, vegetation, geologic formations and management of these resources vary. To evaluate these differences and as a means of pinpointing predominant sources of turbidity, study sites were selected on the major tributaries of the reservoir. Smaller sub-basins that were undergoing land use changes, or appeared to be contributing large quantities of sediment, also were included for evaluation.

Turbidity in the reservoir has two possible major sources: (1) the reservoir proper and (2) the watershed. Preliminary laboratory analysis prior to this study indicated that smectites (montmorillonite group of clay minerals) were in part responsible for the turbidity. The water samples analyzed in the preliminary study were obtained from above and below the reservoir and had similar turbidity levels, indicating the watershed as the dominant source. The watershed soils were known to have generous amounts of smectite present and were badly eroded in places.

1/ Turbidity defined: turbidity is an expression of the optical property of a solution which causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. It is expressed in Turbidity Units (TU's) which recently have been expressed in Formazin Turbidity Units (FTU's) by the HACH Chemical Co., manufacturers of the Model 2100A Turbidimeter used in laboratory analysis for this report.

The study reported here investigated different aspects concerning the nature, origin, and possible control measures of turbidity in the reservoir and its sources in the watersheds. The scope and duration of the study were somewhat limited by logistics, personnel, and level of funding. The objectives were designed within these limitations in an attempt to determine the relationships between reservoir turbidity and the sub-basins on the watershed with respect to the clay mineralogy and other characteristics of the soils and associated geologic formations.

As the study progressed, preliminary data on sediment loads, siltation rates, volumes of discharge, and erosion of channel were provided at the request of cooperating agencies.

Purpose, Scope, and Objectives

The study was designed to develop relationships between reservoir turbidity and properties of soils in the watershed.

Because clay remains in suspension longest, and the physical and chemical properties of clay constituents vary, the clay mineralogy of the soils and associated geologic formations was of particular interest. Erodibility and suspension characteristics of these soils and formations were some of the physical parameters evaluated.

Initiation of the study was concomittant with a soil resource and erosion survey in progress by the Bureau of Land Management (BLM) on Bear Creek, a sub-basin of the Crooked River watershed. Therefore, the scope included supplementing BLM findings with respect to sediment transport, turbidity information and clay mineralogy of soils in the Crooked River drainage basin.

Methods included the analysis of soils for dispersibility and clay mineralogy, a reconnaissance study of the Crooked River drainage system, semi-quantitative evaluation of kinds and amounts of materials entering the reservoir from the Bear Creek and Crooked River drainages, analysis for clay minerals and analyses for the associated chemical properties of the reservoir and outlet samples.

The specific objectives of the study were:

1. To determine the physico-chemical properties of the clay minerals of watershed soils and their contributions to the turbidity of the reservoir.

2. To determine the contribution and source(s) of sediment in the watersheds.

3. To identify the soil types and related geologic formations that most significantly contribute clayey sediments resulting in turbidity.

4. To establish relationships between soils, land use, and managment with respect to erosion and turbidity.

DESCRIPTION OF THE STUDY AREA

The Prineville Reservoir is in the Upper Crooked River sub-basin of the Deschutes River Basin. This subbasin encompasses about 631,323 hectares (1,559,999 acres). The major portion is essentially the eastern two-thirds of Crook County with minor acreages in Wheeler, Grant, Harney, and Lake counties (Figure 1).

The watershed of the Upper Crooked River varies in elevation from 0.95 kilometer (km) to 1.93 km (3,100 to 6,300 feet). The major portion of the study area occurs below 4,000 feet. In association with elevation differences, there are variations in total precipitation, form of precipitation, temperature, and vegetation. At lower elevations, the major

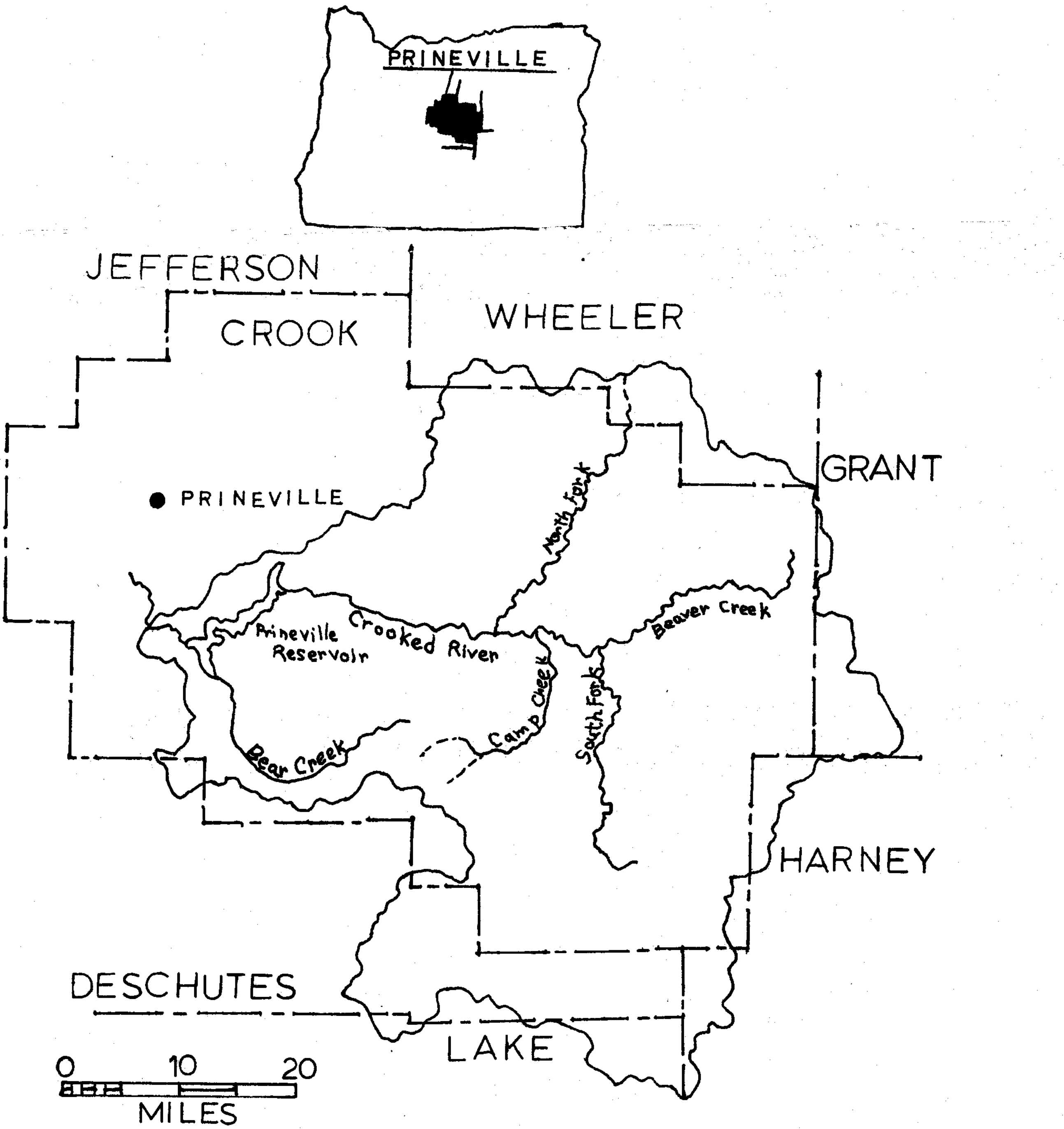

Figure 1. Geographic location of study area showing the major tributaries of the upper Crooked River Basin and the Prineville Reservoir.

part of the yearly precipitation is rain; at the higher elevations the major part is snow. This pattern is reflected in the mean runoff hydrograph for the basin, Appendix A-1. The first peak of the season relates to early winter rains; the second is associated with spring snowmelt.

The physiographic areas of the Upper Crooked River Basin are (1) semiarid irrigated valley lands and basins; (2) grassland-shrub uplands which are semiarid to subhumid rangelands, including rolling hills of clayey sediments like those of the Bear Creek and Camp Creek drainages, rolling hills of old marine sediments like those in the Izee area and upper-basin lava plains typified by the South Fork drainage of the Crooked River; and (3) the cold, subhumid forested plateaus and highlands of the Ochoco and Maury Mountains (Norgren et al, 1969).

The geology of the area is quite variable, including some of the oldest bedrock in Oregon. Large portions of the study area are underlain by basic lavas and tuffs ranging in age from Mid-Tertiary Columbia River Basalt to the older Early-Tertiary, clayey tuffaceous sedimentary Clarno and John Day formations. Much older, Cretaceous to Paleozoic, marine sedimentary formations underlie the headwaters of the Crooked River in the Suplee-Izee area.

Stream gradients in the watershed vary from 270 feet per mile in upper reaches to less than 10 feet per mile near the inlet to the reservoir.

Two principal streams supply the reservoir: the Bear Creek drainage and the Crooked River. Major tributaries of the Crooked River are the North Fork, South Fork, Beaver Creek and Camp Creek, (Figure 2). Bear Creek drains 8.7 percent (%) of the basin or 541 km^2. The Crooked River drains 91.3% of the basin or 5,514 km^2. The major tributaries to the reservoir and their relative percent of the total watershed area are listed in Table 1.

Table 1. Relative percent that each major Tributary[a/] is to the total area of the Upper Crooked River Drainage Basin.

Major Tributary	Area			Percent
	km^2	hectare	acres	of total
Bear Creek	541	54,065	133,595	8.7
Beaver Creek	1,300	131,346	324,556	20.6
Camp Creek	448	44,917	110,990	7.1
North Fork	827	83,021	205,145	13.1
South Fork	2,085	208,434	515,040	33.0
	5,201	521,783	1,289,326	82.8[b/]

Total watershed area 6,314 km^2 (631,416 hectares or 1,559,999 acres)

a. A tributary is considered to be one that empties directly into the Crooked River or, in the case of Bear Creek and some smaller tributaries, empties into the Prineville Reservoir.

b. 17.2% of the total remains in the minor tributaries to the Crooked River and minor tributaries emptying directly into the reservoir.

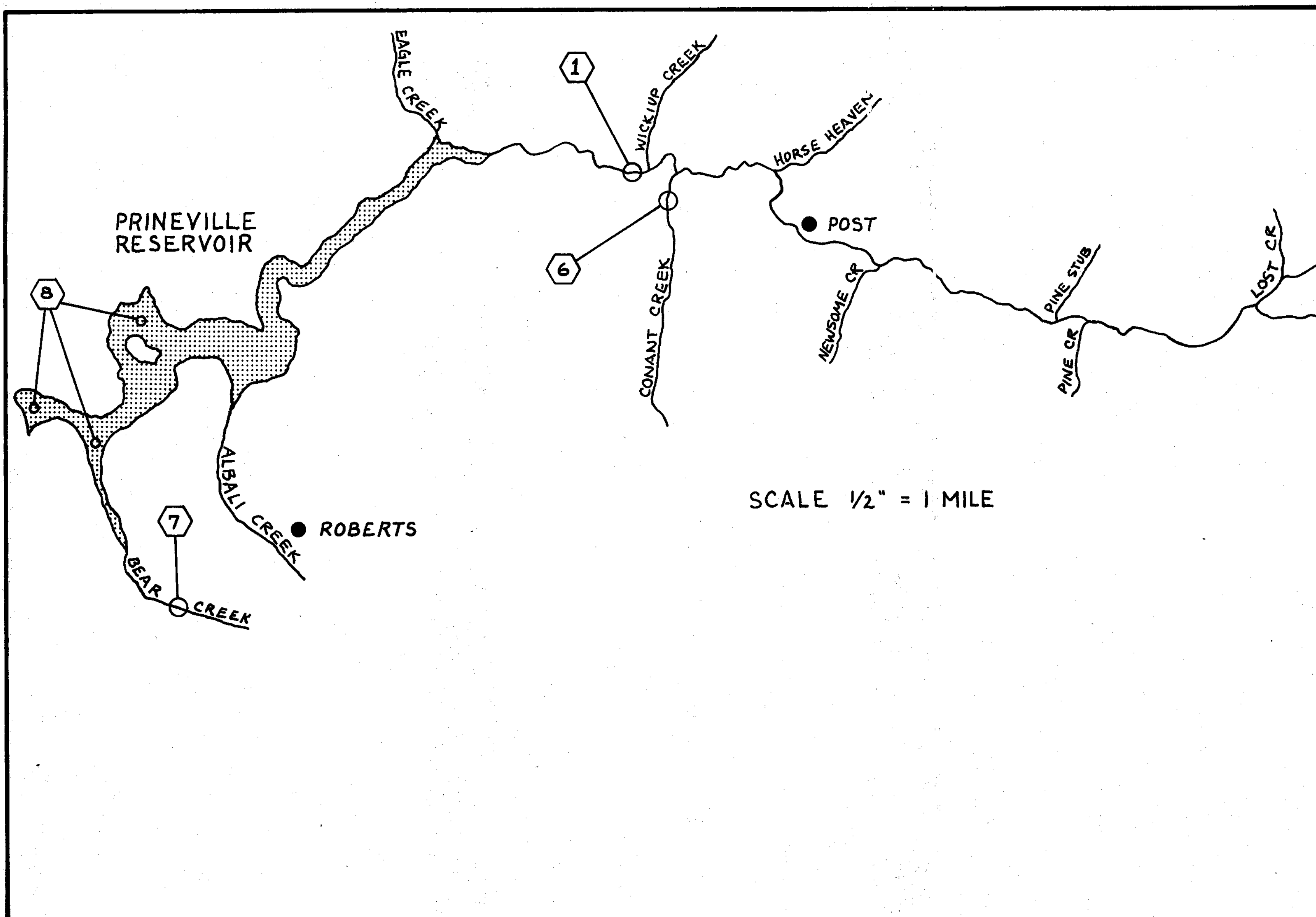

Figure 2: Sampling Station Locations on the Tributaries to the Crooked River and the Prineville Reservoir. (scale 1/2 inch = 1 mile)

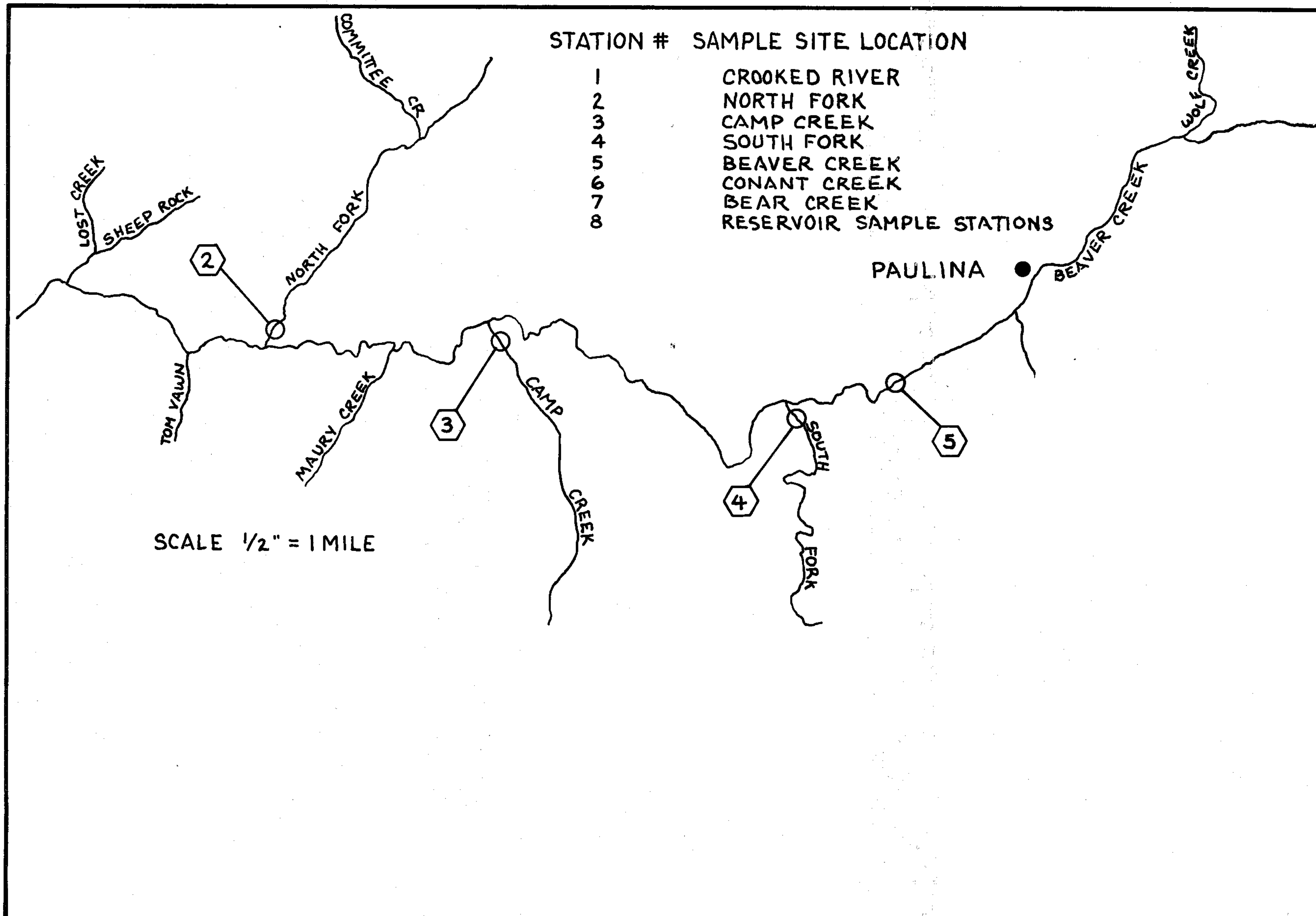

Figure 2: con't

Soils of the watershed can be categorized into three groups: (1) soils formed from alluvium on floodplains, terraces, fans, and pediments; (2) those formed under intermediate precipitation from lava, tuff, and shale, colluvium derived from these rocks and some surficial ash; and (3) soils formed on forested highlands from volcanic ash, soft tuffaceous rocks, and very stony soils formed over basalt.

Soils formed from alluvium tend to be deep, medium-textured, often well drained, and stable in the landscape. The predominant soil associations are the Powder-Courtrock, Ochoco-Prineville, and the Ayres-Nouque. The Powder-Courtrock association also includes the Metolius, Polly, and Veazie series. The soils of this association are found on the floodplain of the Crooked River.

The Ochoco-Prineville and Ayres-Nouque Associations are found on terraces and fans, respectively. Included in the Ochoco-Prineville association is the Hack series. The Ayres-Nouque association also includes the Deschutes, Cribble, and Shev series. Basalt plateaus with an ash mantle are included in the soil-landscape.

Soils derived from tuffs, breccias, and related colluvium tend to be fine-textured, slowly permeable and have darker epipedons with moderately deep to deep profiles. Dominant associations including soils of this nature are the Hankins-Hankton, Simas-Tub-Ginser, and the Prag-Tub-Rarey groups. Component series are Anawalt, Arron, Bakeoven, Deskamp, Fopiano, Day, and Roba.

Those soils formed on ash in the forested highlands are coarse textured, deep, well-drained and light in color; those formed on basalt are darker, shallow, stony to extremely stony and have fine loamy textures and those formed on soft tuffaceous bedrock are dark, clayey, and generally deeper. Most prominant associations used to categorize soils formed from these materials are the Anatone-Klicker-Hall Ranch and Hankton-Hankins-Klicker and their component soils. Other major component soil series are Boardtree, Whistler and Tolo. These series and others are characterized by their contribution to turbidity in this report.

A soils-landscape map of Crook County showing additional associations, with component series indicated in the legend, is presented in Appendix C-1. The map and legend are preliminary data, developed as part of the Oregon ERTS investigation (Simonson, et al., 1975). Taxonomic classification of the soil series noted is given in Appendix C-2.

The major land use is rangeland at the lower elevations and forestry in the Maury and Ochoco Mountains. Water production, wildlife, and recreation are also important. In 1972, portions of Bear Creek and Camp Creek were developed into private hunting reserves. Campgrounds, trails, and riparian sites are being established. The added traffic and development may have a significant effect on these watersheds and only time can tell if the effect will be beneficial or detrimental.

PRINEVILLE RESERVOIR WATERSHED STUDY

Since the Upper Crooked River basin is composed of several smaller basins, studies of individual watersheds were designed and conducted to obtain information on sediment load, nature of sediment, source of sediment, and the potential of subwatershed soils to contribute to siltation and turbidity in the reservoir. Soil and sediment samples were characterized in the laboratory and the data were used as a basis for predicting the turbidity potential of these materials.

The sediment was also measured in the reservoir to estimate the siltation that has taken place since the inception of the reservoir.

Sediment Load to the Reservoir

The amount of sediment being contributed to the reservoir could be determined by continuously measuring the sediment transport at the points where the Crooked River and Bear Creek discharge into the main reservoir body. Limited funds, time, and personnel did not allow for such a task and, therefore, was beyond the scope of this study. Consequently, the major tributaries were monitored during periods of major runoff for the runoff seasons of 1972 and 1973, with emphasis given to the peak events during these periods.

The data for runoff periods, winter 1972 and 1973 on Crooked River and Bear Creek are presented (Table 2). Data for March 13 and 14, 1972, on Crooked River are estimated, using runoff data available from the United States Geological Survey (USGS) gaging station number 14079500, near the confluence of North Fork and Crooked River. The estimates are necessary because these dates were peak runoff times and the established downstream sampling station was inundated. Since the USGS station occurs 18 river miles upstream from the sample station, an additional 250 square miles would contribute runoff. Of this downstream portion, roughly one-half is forested land and snow melt from above 1.4 km (4,500 ft) elevation would be expected. Therefore, the runoff was estimated to have increased downstream and have a greater sediment-carrying potential during this peak runoff event that seasonally results from the winter snow melt.

The sediment contribution to the reservoir by Bear Creek is considerable at peak runoff times (see March 13, 1972, Table 2). As shown graphically, (Figure 3), Bear Creek can and does carry a large sediment load while it is flowing at peak runoff, but it has a much shorter response time and shorter duration period than the Crooked River. Also related here is an elevation difference that results in a difference in snow melt volumes. Bear Creek has less that one-fourth of its 541 km^2 (209 mi^2) area forested and this occurs above 1.4 km elevation (4,500 ft). Crooked River drainage, excluding Bear Creek, has about one-third of its 3,587 km^2 (2,229 mi^2) area in high elevation forest land that contributes to the spring snow melt runoff. Therefore, its duration of peak flow from snow melt, even if synchronization occurred (which would seldom happen on a watershed of this magnitude with both north and south aspects) is longer than that of Bear Creek. The hydrograph for Crooked River (Appendix A-2) indicates a prolonged flow in excess of its base flow; the hydrograph for Bear Creek (Appendix A-3) indicates a shorter time at maximum runoff volumes than Crooked River and a shorter duration of increased flow. Thus, it is possible to visualize the potential of each stream to contribute sediment to the reservoir during periods of peak runoff. Bear Creek carries an unusually high concentration of sediment to the reservoir, but because of its short duration of flow, its total sediment contribution is much less than that of the Crooked River, which flows with high sediment loads for a longer period of time.

Tributary Sediment Loads

Turbid waters from other tributaries to the Crooked River were likewise sampled at peak flow. These sample stations (Figure 2) were used to monitor the contribution of smaller tributaries to the overall sediment load carried to the reservoir. Since stream gradients for the tributaries are higher (Appendix B), it can be expected that the slower

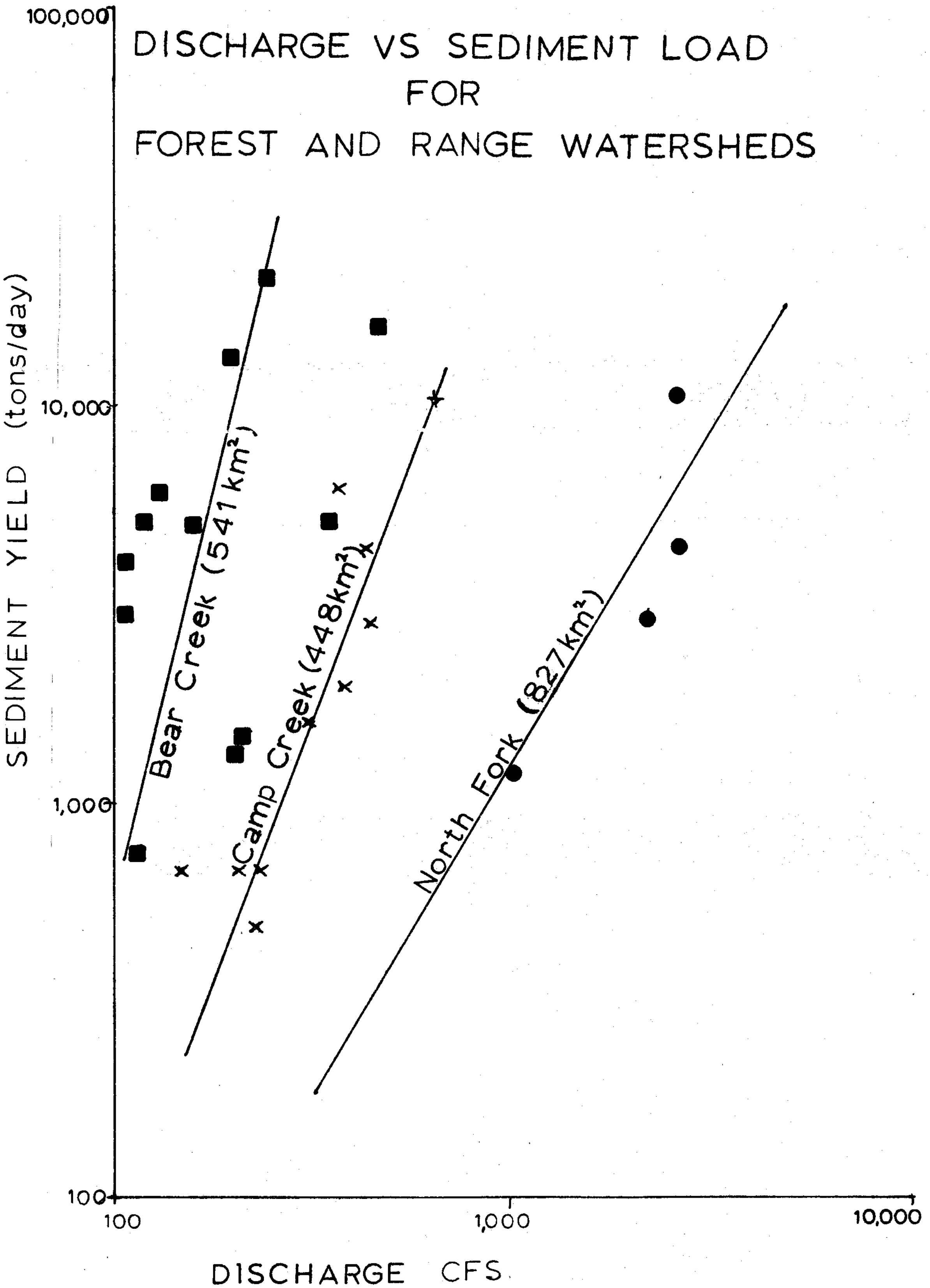

Figure 3. Sediment yield versus discharge for the Bear Creek, Camp Creek, and North Fork watersheds during the major runoff events of Water Year 1971-1972.

Table 2. Sediment loads and related turbidities being delivered to the Prineville Reservoir by winter and spring runoff events from Crooked River and Bear Creek inlets.

		Crooked River Sampling Station				Bear Creek Sampling Station			
		1972		1973		1972		1973	
		FTU	Thous. Tons/Day	FTU	Thous. Tons/Day	FTU	Thous. Tons/Day	FTU	Thous. Tons/Day
January	15							46	0.01
	16							31	0.01
	19			19	0.4				
	20							24	0.01
	22	130	4.5			484	5.4		
	23	125	2.1			225	0.8		
	29			4	0.2				
February	19	140	2.1						
	20	260	7.9			226	0.7		
	21	74	1.9						
	28							145	0.02
March	2								0.01
	3	180	8.9						
	5			9	0.6				<0.01
	6	150	8.0*						
	7	90							
	13	700*	18.0			7,500	16.6		
	14					145	5.1		
	15	650	11.6						
	16			4	0.4	225	1.4		
	27								
April	7	150	8.0						
	18					49			
Total			73.0		1.9		29.9		0.06
Average			7.3		0.5		5.0		.01

*Estimated using FTU vs mgm/l curve

velocities of the Crooked River would be less able to carry the complete contributed load from these streams because of reduced stream energy. This can readily be seen by the sediment deltas of cobbles and gravel at stream confluences. The confluence of Horse Heaven Creek with the Crooked River is an example (Plate 1). The gradient of the Crooked River at this point is 10 feet per mile and that for Horse Heaven Creek is about 93 feet per mile. The deposition is limited to those particles greater than 4 millimeter (mm). Figure 4 substantiates this in that particles greater than 2 mm can be expected to be deposited when velocities are about one foot per second. Horse Heaven flows at about 4-5 feet per second and Crooked River at this point is about 2-3 feet per second.

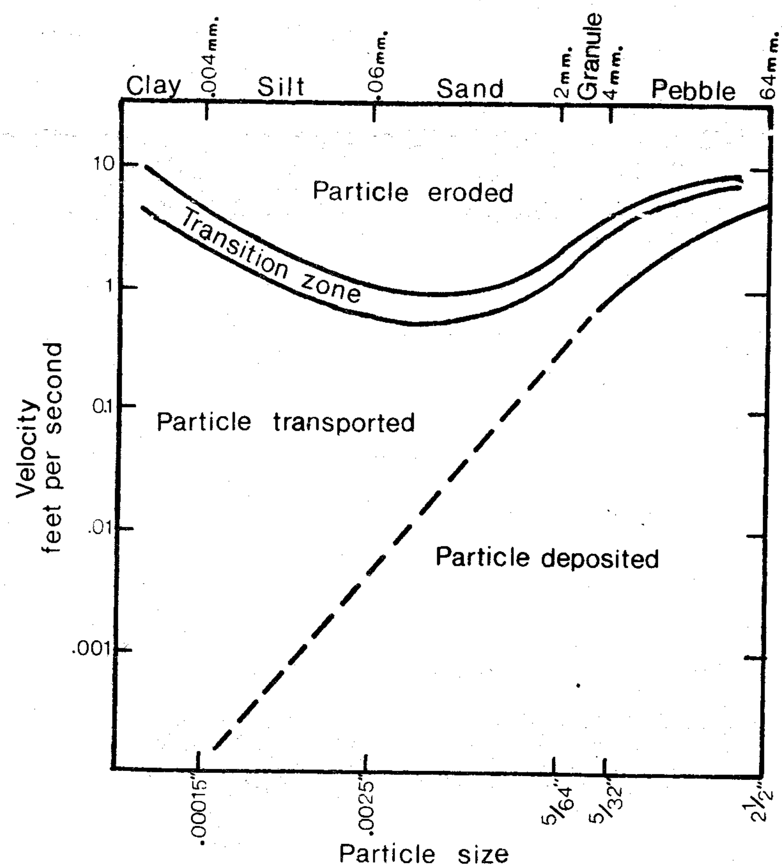

Figure 4. Relationship between stream velocity, erosion, transportation, and deposition of different size particles (Leet and Judson, 1965).

It is readily apparent from Figures 4 and 5 that particles in the silt and clay range are more easily carried at lower velocities and therefore stay in suspension longer. In the tributary streams that converge with the Crooked River the larger transported materials are deposited and the silt and clay sized materials are transported further downstream and to the reservoir. Some, particularly the silts, eventually settle in the quiescent waters of the reservoir. The clay either remains suspended in the reservoir or flocculates, depending on the physical and chemical interactions between clay and water.

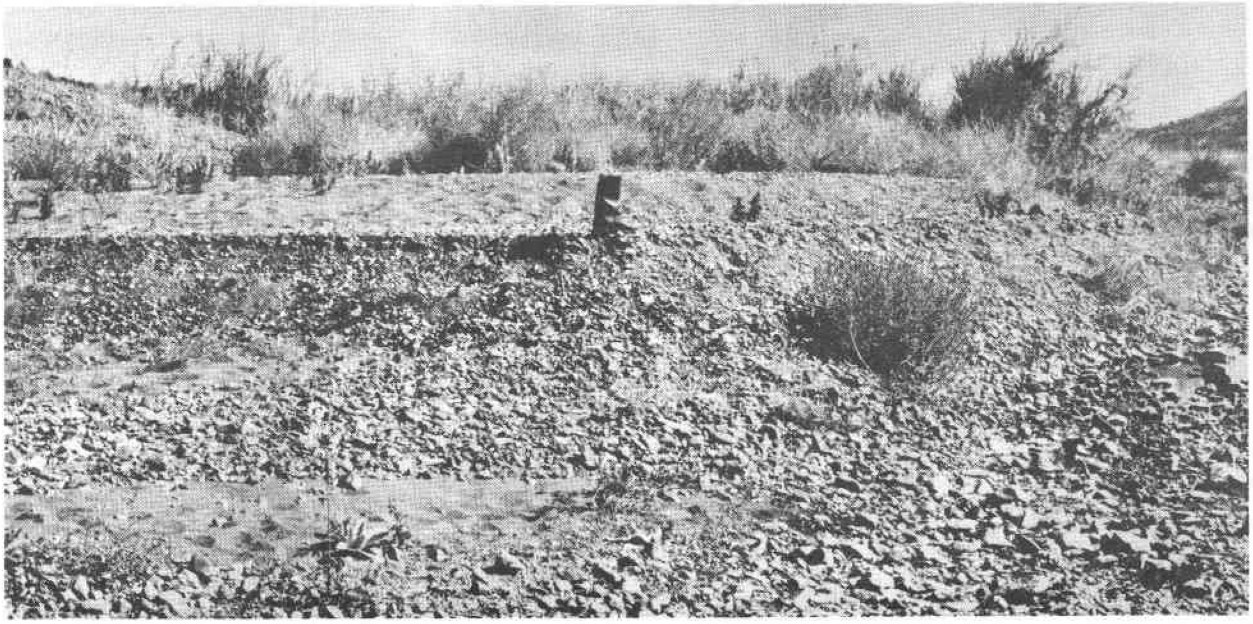

Plate 1. Cobbly sediment bar at the confluence of Horse Heaven and the Crooked River. Deposition resulted after runoff of spring snow melt in March 1972. Boot in center of picture is 30 cm (12 inches) in height. Excavation to the left of boot was to establish sediment bar depth; 45 cm (18 inches). Total gravel deposit volume was about 113.2 meters^3 (148 yd^3).

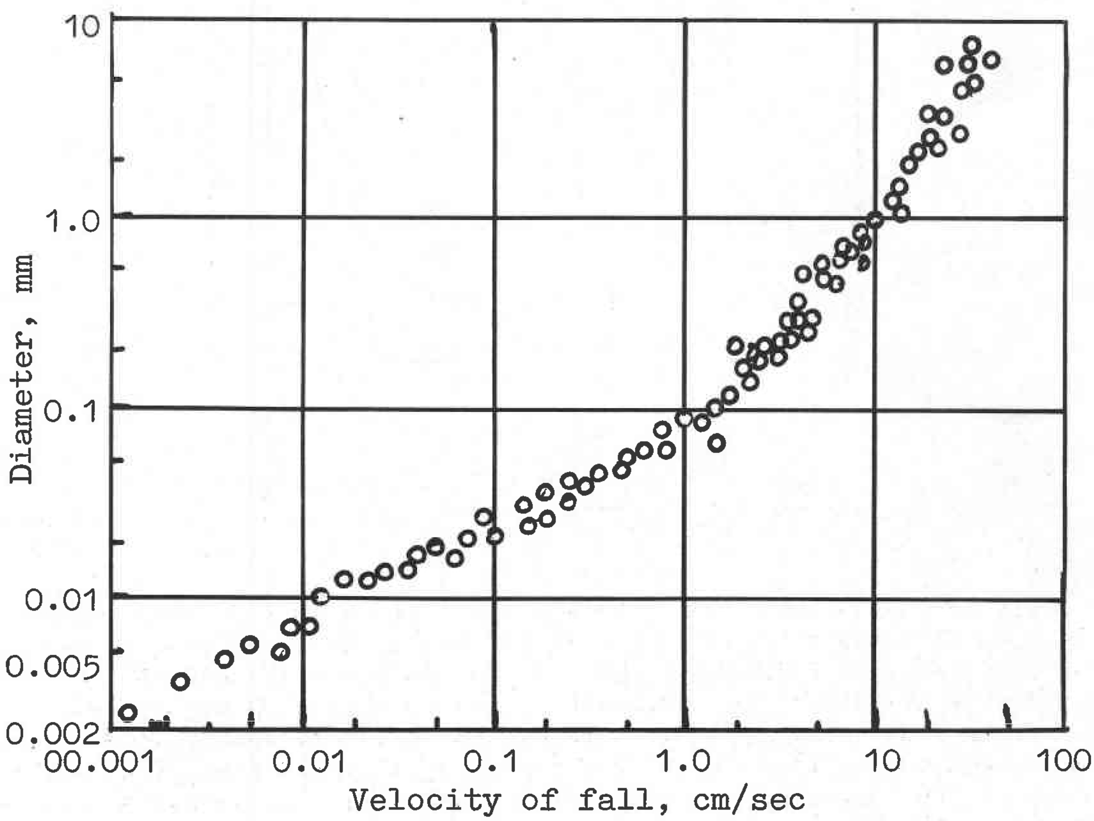

Figure 5. Settling rate of sand (quartz) particles in water. (In Morisawa 1968, from Lane 1938).

North Fork as an example

Sediment transport versus stream discharge for North Fork, Camp Creek, and Bear Creek (Figure 1) suggest that North Fork with its larger area delivers a greater discharge to the Crooked River than does Camp Creek and Bear Creek.

It appears that North Fork contributes a considerable sediment load. The three highest sediment discharge points on the North Fork line of the graph, however, can be attributed to a debris dam created by large snags during the spring snow melt of 1972. This dam rechanneled a major portion of the stream during flood stage into a revegetated and otherwise healed abandoned channel. The soil removal was estimated to be 5,550 m^3 (7,259 cubic yards or about 4.5 acre feet). This was not the only damage attributable to this debris dam. When the dam dissipated, a large flush of water resulted that removed an undeterminable amount of soil by channel bank erosion for some distance downstream. Damage below the immediate area of the debris dam was considerable. Comparison of 1953 aerial photos with present ground conditions suggest a recent considerable channel shift. This was attributed to the 1972 debris dam for the most part.

Subsequent channel erosion further downstream was not quantified because the tortuous course that the North Fork follows does not allow easy access throughout. Investigation above and below the falls, however, revealed a basalt armoured channel that would erode slowly and not add noticeably to turbidity.

The water of North Fork was clear during most of the runoff season with the exception of the above event. Turbidity measurements were usually low as were values of suspended sediments.

STUDY METHODS AND ANALYSIS

Field Procedure

A reconnaissance of the Crooked River watershed was made in October, 1971. Use was made of topographic sheets, Oregon's Long-Range Requirements For Water, Appendix I-5, and geologic maps published by the Department of the Interior, U.S.G.S. Major tributary watersheds were traversed to observe the stream channels, landscape, and land uses. On the basis of this preliminary study, decisions were made on streams to be monitored, locations of sampling stations, and frequency of sampling.

Sites representing these areas and their soils were designated and soil profile descriptions prepared (Appendix C-3). Coincident with the reconnaissance of these larger and more prominent sub-basins, a cursory inspection of the much smaller tributary basins was completed. Most of these small subbasins occur in the Maury Mountain range and appeared to be contributing considerably to sedimentation of the reservoir. For this reason a high proportion of the soil data is drawn from the Maury Range.

It appeared that unusual amounts of bank erosion occurred during the 1972 spring snowmelt runoff on the Crooked River. Many thousands of cubic feet of channel bank had been removed as a result of the river dissipating its flood stage energies on the banks, especially at meander bends. Major meander bends on the river between Post, Oregon, and near the upper extremities of the reservoir were staked in the fall of 1972 to determine the bank erosion along this portion of the river.

Cross sections (Appendix D) of the stream channel at each sampling location were determined and stakes placed 100 feet apart on the downstream side of these sites to assist in the velocity measurement. Velocity measurements were made by the floating block technique. This method was used because for the reaches used the floats corresponded favorably to the 0.6 measurements as determined by the Price current meter.

Laboratory Analysis

Water samples

Suspended sediments: Turbidity of the water sample suspensions was measured using a HACH Turbidimeter Model 2100A. The turbidimeter (or nephelometer) works on the principle that suspended particulant matter reflects light at differing angles and intensities. The nephelometric principle of turbidity measurement responds only to the particulant reflected light that is orthogonal to the direction of propagation. The HACH Turbidimeter 2100A is a 90^{o} Nephelometer. The response of a 90^{o} Nephelometer is a linear function of turbidity. The degree of turbidity is recorded in Formazin Turbidity Units (FTU). Problems are encountered when suspensions are of extremely high turbidities. It was found that the instrument would not accurately record turbidities in excess of 1,000 FTU. Registered readings were frequently in the 200-400 FTU range and thus unreliable. Samples that exceeded 100 FTU were routinely diluted and checked against the original reading. This routine provided more reliable results because it also was a check on the correctly recorded values.

Often, knowledge of the actual concentration of suspended sediment is desired. In an attempt to correlate FTU readings with gravimetrically determined data, Appendix E is presented. This correlation is offered only as a guide and is not suggested to be valid for all samples, because of the variability of material in suspension from different watersheds.

Water chemistry: Soluble calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) in filtered samples were determined by atomic absorption spectroscopy, using the Perkin-Elmer Model 306. The results are reported in milliequivalents per liter (meq/l), and parts per million (PPM). Conductivity (a measure of electrolyte content) were determined on a 25 mm aliquot using a conductivity bridge. The results are reported as micromhos per square centimeter ($\mu mhos/cm^2$). The pH of the water was determined on samples using a glass electrode pH meter.

Soil analysis

Clay mineral identification: Soil samples were agitated in distilled water by repeated stirring. After the required time for sand and silt to settle (Jackson, 1956) had elapsed, the clay was siphoned off. The clay was then recovered from suspension by flocculation with 1<u>N</u> NaCl.

Separate portions of the recovered clay were saturated with Mg and K using 1N chloride salts and washing to remove excess salts. Samples were then prepared for X-ray diffraction analyses by spreading the clay on petrographic slides (Theisen and Harward, 1962). The characterization treatments used for clay mineral identification included: equilibrating the Mg - saturated slide at 54% relative humidity, saturation with ethylene glycol and with glycerol; equilibrating K-saturated slides at 54% relative humidity, and heat treatments of 105°C, 300°C, and 550° C with subsequent analysis under dry air conditions. X-ray diffractograms were obtained using CuK alpha radiation and a Geiger-Muller tube equipped with a focusing monochrometer. (For details of the methods and identification criteria, see Harward, 1971, and Brown, 1961).

Particle size analysis: Particle size distributions were determined on less than 2 mm separates using the methods of Kilmer and Alexander (1949). Thirty percent hydrogen peroxide was used to digest the organic matter for organic matter removal. Since the soils are from a semiarid region, Pasteur-Chamberlin F-20 filters and 750 ml of distilled water were used to remove salts that might interfere with the particle size determination. Samples were suspended with an airjet stirrer operated at 20 pounds per square inch (psi) (Chu and Davidson, 1953). A 300 mesh sieve (0.05 mm) was used to separate the sand fraction before performing the pipetting.

Natural dispersibility: Ten grams of less than 2 mm air dried soil were placed in Boyoucous cylinders, saturated with approximately 50 ml distilled water, and allowed to equilibrate for 18 to 24 hours. The volume was then brought to 1,130 ml and the suspension placed in a constant temperature room (20°C) for 24 hours. Then the samples were shaken end to end 30 times. Twenty-five milliliters of suspension were removed from a depth of 10 centimeters (cm) at 4, 8, 24, 48, 96, and 144 hours, respectively. Turbidity (FTU) of the aliquot was determined on the HACH Turbidimeter Model 2100A. This procedure was repeated using duplicate samples suspended in reservoir water to determine their behavior in a more natural medium.

Cation exchange capacity: Four grams of soil were saturated with sodium acetate and centrifuged until a clear supernatant could be decanted. Ninety-five percent ethanol is used for washing to prevent hydrolysis of the saturating ion. After this wash, ammonium acetate is used to replace the previously attached sodium ion with the ammonium ion. The supernatant containing the replaced sodium is recovered by centrifugation (USDA Agriculture Handbook #60). Cation exchange capacity (CEC) was determined by measuring the exchangeable sodium on the atomic absorption spectrophotometer.

Exchangeable cations: Exchangeable cations were determined using an extract from a 2:1 water to soil suspension which had been equilibrated 30 minutes before filtering through a number 42 filter paper. This is a modification of the saturated-soil-paste method used to determine soil conductivity. The modification was suggested (USDA Agricultural Handbook #60) to recover only those exchangeable cations (EC) that would be exchanged under conditions similar to natural soil and water systems of this semiarid region.

Suspended sediment analysis

Clay mineral identification: The procedure of Theisen and Harward, 1962, was used as outlined under clay mineral identification of soils.

Particle size: The sediments were sieved through a 300 mesh (0.05 mm) screen to determine, after drying, the percent of material smaller than 0.05 mm. This separation is used because material less than 0.05 mm is considered to be more easily transported and more likely to remain in suspension than the coarser fraction, once the stream velocity is reduced.

Amorphous material: Samples (usually one liter) were shaken and allowed to stand for 30 minutes. That material remaining suspended after this time was siphoned off and flocculated with 1N $MgCl_2$ and then washed free of excess salt. Free iron and other sesquioxides were removed by treatment with acid ammonium oxalate and boiling 0.5 N KOH treatments (Dudas and Harward, 1971). The calculated weight loss after this treatment is taken to be the percent of amorphous materials.

Electron microscopy: Samples from the reservoir, streams, and soils believed to contribute the most to turbidity were analyzed by the Transmission Electron Microscope (TEM). The electron micrographs were then used to interpret the physical properties of the solid portion of the turbid suspension. The analysis and interpretations were performed by Dr. D. D. Dingus using TEM through the courtesy of the Department of Botany, Oregon State University. Procedures used are given by Dingus (Ph.D. Thesis, 1973).

INDIVIDUAL WATERSHED RESULTS

NORTH FORK

Most of the North Fork 830.2 km^2 (320.54 mi^2) drainage area is located in the north central portion of the study area. A major portion of the watershed is forested. Management is provided predominately by the U. S. Forest Service with a lesser portion of the basin being administered by the Bureau of Land Management.

The parent materials of the soils from which the sediments originate include Middle Miocene Picture Gorge Basalt of the Columbia River Group. These basalts overlie the older John Day formation (Middle Oligocene and Lower Miocene) except in the Big Summit Prairie area (Swanson, 1969). Pumice soils are abundant in the North Fork watershed. These soils have formed from the volcanic tephra of ancient Mt. Mazama in the Cascades of Oregon (now Crater Lake). Pumice from the eruption of Mt. Mazama (circa 7000 years before present (bp) was deposited in a northeasterly lobe (Harward and Youngberg, 1969) to a depth of 50 cm in the study area (Lindstrom, 1972). Soils of this origin are common in several of the smaller basins of the North Fork watershed. For instance, soils within the Committee Creek drainage were found to be very high in pumice. X-ray diffraction data from these samples indicate predominantely amorphous material in the clay fraction, with only a suggestion of smectite (montmorillonite) type clays.

Committee Creek soils are represented by watershed soil samples CEIA and CE2A. These samples were obtained from a previously logged area and an essentially undisturbed adjacent area, respectively. Visual inspection of the logged area suggested minor erosion after the logging operation. Slopes in the logged area varied between five and ten percent. The catchment basin above (which was also logged) was inconsequential in size and would tend to keep runoff small, thus reducing the erosion hazard. However, evidence of what does happen in pumice soils after disturbance was noted in the main channel of Committee Creek (Plate 2).

Debris and pumiceous soil material were deposited behind a debris-jammed road culvert, causing subsequent overflow onto the road and the formation of a new portion of channel. General inspection of the area suggested that much of the sediment resulted from barren strips that at one time may have been spur roads or skid trails where water had a tendency to concentrate. Because the area was visited after the fact, a measure of the extent of erosion as a result of the soil disturbance was not possible.

Roba Creek, another small watershed within North Fork's drainage net, had soils analogous to those found in the Committee Creek tributary of North Fork. Roba Creek was undergoing logging at the time of sampling. The intention was to monitor Roba Creek for sediment contribution and turbidity characteristics. However, the spring runoff of 1973 was insufficient to warrant sampling and, therefore, documentation was not possible. Sampling, however, would have been designed to observe and record the erosion phenomena of the deep pumice soils. It is apparent that once water is concentrated in a pumiceous soil, transport is easily achieved. Since infiltration capacities are usually very high, the probability of water concentrating and forming channels is not normally of concern. However, where disturbance may cause water movement in channels to be impeded, or water bars are not provided during road construction (Plate 3), concentration of runoff causes rapid erosion.

Nature of sediments: Sediments coming from North Fork reflect, in part, their pumiceous origin. They are relatively coarse grained ($>50\mu$, Table 3), they have low turbidities, and their x-ray diffraction patterns suggest a relatively high proportion of amorphous material (Appendix F).

The main stream channel of the North Fork is well armored, with harder younger basalt present along much of its reach. The nature of the channel is not expected to be too different from those portions inspected, except in the Big Summit Prairie region where the older John Day formation is present (Swanson, 1969). There the older tuffaceous sedimentary rocks, which are softer and more highly weathered, are present. The sediment load and resulting high FTU (see Table 3, February 19, 1972, and Figure 2A) could have originated from the Big Summit area during what was the first runoff event of the year for that portion of the basin. Stream channel sloughing would add fine grained soils to the runoff waters which could be carried to the sampling station. Materials of $<50\mu$ size (98% of sampled sediment) would be readily transported (Figure 5) to the sample point. With stream gradients (Appendix B) of fifty-six feet per mile (56 ft/mi) and velocities of 3 to 10 feet per second[2/] it is readily apparent from the graph that materials of this particle size will be carried beyond the sampling point.

Materials of this size ($<50\mu$) would be easily transported from the North Fork down the Crooked River to the reservoir. These silt-size and finer materials could remain in suspension in the reservoir. This would

---

2/ As measured at the sampling station. Velocities could be expected to be larger closer to Big Summit where gradients average about 72 feet/mile.

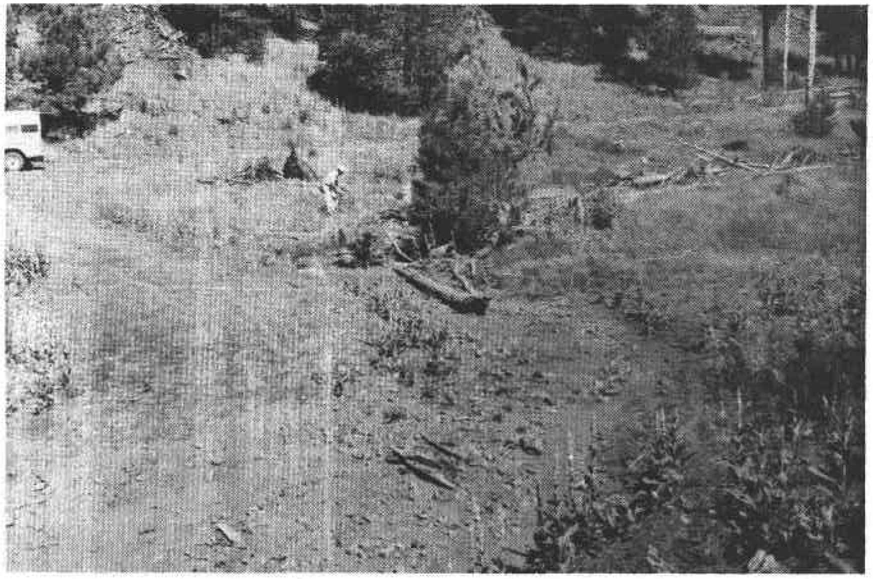

Plate 2. Committee Creek (July, 1972). Pumice soils transported by stream runoff were deposited on road (foreground) after culvert was sealed by debris. Man in center of photo is attempting to determine the extent of erosion and amount of deposition.

Plate 3. Soil high in pumice after seasonal runoff. Soils of this texture have a high potential for erosion under some conditions. Once water is channeled in them they are readily dislodged and transported leaving deep, usually narrow, gullies as shown here.

Table 3. North Fork of The Crooked River Sediment Particle Size

Sample Date	FTU	Particle Size (%<50μ)[a]
01/22/72	35.	ND[b]
01/23/72	4.4	ND
02/19/72	150.	98.4
02/21/72	19.	53.5
03/13/72	95.	64.19
03/14/72	30.	88.14
04/07/72	6.2	ND
09/20/72	9.5[c]	ND
01/19/73	7.2	71.6

a. 1 micron (μ) is 1/1000 of a millimeter, therefore this value is equivalto the percent less than 0.05 millimeters.

b. Not determined; insufficient concentration to obtain particle size information.

c. FTU caused by organic matter in suspension.

be especially true if they were of proper physical and chemical composition. Information specifically pertaining to the soils within the Big Summit Prairie and their performance in reservoir water was beyond the scope of this study. However, data from watersheds of comparable geologic composition to that of Big Summit suggest that the soils would not noticeably contribute to long term suspension and turbidity in the reservoir (See Table 4; Appendix G - Reservoir water, soil samples SP2B, EE1A, EE2A, and EE2B). The soils formed from the red tuffaceous geologic materials of this nature are usually dramatic in their short term effects. When in suspension they often appear reddish-orange which leaves an indelible impression on the observor, but not in the reservoir. The long-term turbidity (after 144 hours (hrs) of such soil material in reservoir water was usually far below that detectable to the naked eye.

Clay Mineralogy: The clay mineralogy as determined by laboratory techniques indicate a mixed mineralogy. The x-ray diffraction techniques used to characterize the less than 50μ portion of the suspended sediment being contributed to the Crooked River by North Fork indicate the presence of montmorillonite (Appendix F). The diffraction patterns also show a 9.17Å zeolite peak and a small 7.12 angstrom (Å) kaolinite peak. The zeolite suggests the deep erosion of soils, as discussed for the channel rerouting with respect to Committee Creek. The zeolite source is most probably from the weathering of old basalt flows. Basalts of the area have been studied geologically and shown to have zeolite present in vugs (Swanson, 1969). These older, more weathered basalts are more easily eroded and during runoff events the eroded material is transported downstream to the sampling point.

Water chemistry: Waters entering the Crooked River from the North Fork Watershed have a mean sodium to calcium ratio of 0.48. The pH range is 6.8 to 7.5 with a mean of 7.02 pH units. Conductivities range from 155 to 341 μmhos/cm^2 (mean 223 μmhos/cm^2). When compared to the reservoir values, the sodium to calcium ratios are similar but there is a considerable difference in magnitude of the concentrations. The levels of sodium are not high in the North Fork and probably would not cause dispersion of the suspended solids. This is apparent in sample number 910 that had a FTU reading of 7.2 when sampled. After standing for 72 hours the turbidity equaled 2.7 FTU, which is imperceptible to the naked eye. Other samples collected from North Fork over the project study period reflected similar traits.

Table 4. Comparison of Elemental Analysis to Physical and Chemical Properties of Runoff Water For North Fork.

	PPM[a]				FTU	Conductance	pH
Sample No.	Ca	Na	Mg	K		(μmhos)	
901	8.0	4.2	2.4	T[b]	35.0	202	7.0
902	9.0	3.3	2.1	T	44.0	202	6.8
903	12.0	4.5	2.4	.08	150.0	155	7.1
904	10.0	3.6	2.4	.38	19.0	171	7.0
905	2.8[c]	8.4	.9	1.06	95.0	236	7.0
906	8.0	2.4	.9	0.02	30.0	239	6.8
907	10.0	2.2	2.7	.32	25.0	239	7.0
908[d]	17.0	2.1	1.5	T	-	-	-
909[d]	27.0	10.8	5.4	1.38	6.2	-	-
910	14.0	3.0	2.1	.08	7.2	341	7.5

a. See appendix for meq/liter

b. Trace (less than 0.02 ppm)

c. Strontium not used as an anticomplexing agent; therefore Calcium measured is that excess not tied up as a complex.

d. Low flow characterization sample.

SOUTH FORK

The South Fork Drainage area encompasses some 2,085 km^2 (805 mi^2) and is the largest watershed in the study area. A major portion of the drainage basin is owned and controlled by private individuals or corporate ranches. Of the total area, some 746 km^2 (288 mi^2) essentially do not contribute runoff in most years. This is a result of the many internally drained basins in the southernmost part of the watershed.

Considering the total drainage area available for production of runoff, one would expect that the South Fork would have a relatively large runoff compared to the other smaller watersheds. However, when we compare runoff data for the same period for other basins, we see that South Fork ranks third in total runoff for the period considered (Table 5).

Table 5. Seasonal High Discharge and Area Rank for the Four Major Watersheds of the Study Area.

Sample Date	Discharge (cfs) for the major spring runoff 1972. South Fork	North Fork	Beaver Creek	Camp Creek
03/13/72	846	2581	2738	444
03/14/72	2280	2500	1975	235
03/15/72	866	2320	1189	229
Total (cfs)	3992	7401	5902	908
Area Rank	1	3	2	4
Discharge Rank	3	1	2	4

Beaver Creek, North Fork, and Camp Creek decrease in size in that order and for at least two of the watersheds, North Fork and Beaver Creek, the discharge usually exceeded that of South Fork. This trend holds throughout the water year.

Several factors explain this apparent anomaly, one of which has already been mentioned, that being the presence of internally drained subbasins of the watershed that comprise about a fourth of the South Fork drainage. Other factors are elevation, vegetation, drainage density, and soils. The most important for consideration in this discussion are elevation and soil.

Elevations in the South Fork watershed are proportionately lower than North Fork and Beaver Creek (Norgren, et al., 1969). With the exception of only a few high points, most of South Fork lies at or below the 1,371 km elevation, and therefore does not receive as much precipitation in the form of snow as do the other two watersheds. Much of the precipitation falls in the form of gentle winter rains. The 8-10 inches of average annual precipitation is spread out over the winter months and is rapidly absorbed by the shallow loamy soils which comprise South Fork's upper lava plains (Norgren, et al., 1969).

Much of the area is underlain by vesicular dictytaxitic basalt flows with some lacustrine tuffaceous sedimentary rocks of Pliocene age (Walker, G. W., et al., 1967). The tuffaceous sediments are capable of causing high turbidity and large sediment yields (see Camp Creek), but fortunately occur in that portion of the South Fork that contributes very little to the seasonal runoff. Convective storms have the potential to erode the shallow soils and contribute to the sediment load and turbidity in the reservoir. However, the lava plains of the watershed have insufficient relief to promote convective storms.

Nature of sediments: Sediment contribution of the South Fork to the Crooked River, and ultimately to the reservoir, is small when viewed in relation to other tributaries (see Bear Creek, Camp Creek, and Beaver Creek). The turbidity values of the stream passing the sampling point are low (Table 6).

Table 6. Sediment Transport and Turbidity Parameters for the South Fork; Water Year 1972.

Sample Number	Sample Date	Sediment Load (ton/day)	Turbidity (FTU)	Percent of Sediment Sample <50μ	Secchi Disc.[a]
1101	01/22/72	149	40	ND[b]	ND[b]
1102	01/23/72	ND[b]	17	ND[b]	14
1103	02/20/72	108	27	34	12
1104	03/13/72	1517	50	93	5
1107	03/14/72	2690	30	92	7
1108	03/15/72	1038	25	93	12
1109	04/07/72	7	13	91	4-5[c]
1113	01/19/73	625	9	81	ND[b]

a inches below the surface of the stream
b ND -- not determined
c feet below the surface of the stream

Most of the sediments are of small particle size. Usually more than 90% is less than fifty microns (<50μ) in diameter. Material of this size (silt and clay) is readily carried to the reservoir. The low FTU is suggestive, at least, that the material in suspension and being transported, even though predominantly clay size has little potential to cause turbidity. This is further supported by the depths to which the Secchi Disc information shows the unaided eye can see objects beneath the surface[3/].

Clay mineralogy: Laboratory examination of the sediments by x-ray diffraction show that the clay fraction has small quantities of 2:1 clays. It appears for the most part that the sediments are high in non-crystalline components and, therefore, amorphous to x-ray. This indicates that the tuffaceous sediments reported by Walker, et al., are not noticeably contributing to the material in suspension within the study area. Tuffaceous sediments of the study area usually have well defined x-ray patterns as evidenced by those obtained for Camp Creek (Appendix F). The source of the non-crystalline material is thought to be from recently (geologically-speaking) weathered volcanic tephra that have had insufficient time to weather to a predominance of crystalline clays. This appears at least to be the case in the x-ray pattern considered to be representative of the South Fork clay mineralogy (Appendix F).

Water Chemistry: In the South Fork waters it is possible the sodium salt concentration is high enough to be a flocculative agent. This would explain the seemingly low turbidity of the South Fork's waters. But when these waters and their dissolved solids load arrive at

3/ Secchi Disc readings are subjective and depend to a large extent on the amount and type of illumination when the reading is obtained. However, it is a quick and easy field technique for comparting streams of different turbidities.

the reservoir the concentration might be such as to act as a dispersing agent when diluted[4/], thereby becoming more nearly aligned with the sodium concentrations encountered in the reservoir. Water originating from the South Fork watershed generally has a sodium to calcium ratio (Na/Ca) greater than one and occasionally exceeds two (Table 7). Conductivity measurements and pH generally reflect the presence of excess sodium to calcium. Conductivity usually exceeds 100 µmhos/cm^2 and pH values are approaching alkaline. However, the water flowing out of South Fork would be considered a "low hazard" irrigation water (USDA Handbook #60).

Table 7. Sodium/Calcium Ratio for Runoff Waters of the South Fork of the Crooked River.

Sample #	meq/liter Na	meq/liter Ca	Na/Ca ratio
1101	0.78	0.95	0.82
1102	1.83	0.75	2.44
1103	0.91	0.45	2.0
1104	0.83	0.70	1.19
1107	0.87	0.85	1.0
1108	1.61	1.05	1.51
1109	1.35	1.55	0.87
1112	2.52	1.10	2.32
1110	2.70	1.05	2.65

BEAVER CREEK

Beaver Creek drains some 1300 km^2 (507 mi^2) of which approximately one quarter is forested and under the auspices of the United States Forest Service. The remaining portion of the watershed is low-lying range and irrigated crop lands of the Paulina Valley. Beaver Creek, the second largest watershed in the study area, and occupies the easternmost portion.

The drainage density is most significant in the northern reaches of the drainage basin. Paulina Creek is the major subdrainage in this part of the basin, followed by Wolf and Sugar Creeks, all of which drain forested lands. Because their headwaters are within the high elevation forestlands, these creeks receive spring runoff due to snowmelt. The southern tributaries of Beaver Creek drain more range and valley lands and do not receive the amount of precipitation that occurs in the northern portion of the watershed.

The parent materials from which soils are formed in the northern portion of the watershed originate from Columbia River basalts or pumice mantles. The valley areas are of the Middle Pliocene and Pleistocene Rattlesnake Formation and basalt and basaltic cinder materials that ring

4/ Sodium in concentration of 0.05 gms per liter is used in laboratories as a dispersing agent for some clay systems.

recent alluvial valley fills. The Paulina Basin is underlain by volcanic and fluviatile deposits of welded and waterlaid rhyolitic tuffs, gravels, and finer fluviatile deposits. The last is overlain by the Rattlesnake Formation in areas and is possibly equivalent in age (Lower Pliocene) to the upper part of the Columbia River Group (Brown and Thayer, 1966).

Sediment-producing areas and depositional areas were observed to be few in number. However, it appeared that Wolf Creek was eroding and downcutting in the vicinity of Wolf Creek Camp. In evidence were large cobbles and raw stream banks. Similar recently sloughed materials from channel banks were noticed on portions of Paulina Creek. These erosional features are apparently geologically active but not noticeably accelerated by man's activity in the immediate area. Obviously, there are several factors involved in the watersheds' runoff response and sediment contribution. Some of these factors which influence direct runoff are times of year that major runoff and storm events occur, the storage capacity of the total watershed, land use, storm characteristics, vegetation, and soil properties. These factors are applicable to all the watersheds reviewed following similar lines of reasoning.

The major runoff event normally occurs in March (Table 8 and Appendix A), with some earlier runoff at the start of winter. Watershed storage capacity in general is reflected in the soils of the basin. Much of the soils of the upper basin's rolling hills are either loamy and shallow, or moderately-deep, well-drained fine loamy soils (Norgren et al., 1969). This soil pattern is similar to that found on the adjacent North Fork watershed. It would appear that the soils found on the watershed are capable of absorbing much of the 14-17 inches of precipitation reported to occur in the area (Norgren, et al., 1969). Soils, followed closely by storm characteristics such as intensity and duration, are probably the major controlling factors in sediment production.

Much of the Beaver Creek watershed outside the forested areas is irrigable valley and basin lands that have moderately deep soils used for such crops as alfalfa and small grains (Norgren, et al., 1969). It is well documented that vegetation stabilizes stream banks (Hudson, 1972; Ag. Infor. Bul. No. 324; Beasley, 1972). Stabilization by natural vegetation was evident along the lower reaches of the watershed streams. Forage production is the major land use of these lower reach valley and basin plains, and could contribute to the apparent stream channel stability noted during reconnaissance. Other studies in the area have had similar findings (Stream Bank Erosion in Oregon, 1973).

Nature of sediments: Sediment loads from Beaver Creek recorded during the study period were generally low except for periods of maximum runoff. When sampled, the water passing the sample station appeared only slightly turbid. This observation is further documented in the low FTU values (Table 8). Samples 202 and 210 were allowed to remain standing for 72 hours at room temperature and their turbidity noted. It was found that the samples did not remain noticeably turbid and registered 9 and 5 FTU respectively, which is far below what is considered turbid water for this basin (Department of Environmental Quality Water Quality Standard, 1971). This indicates that sediments originating from the Beaver Creek drainage would not noticeable contribute to turbidity in the reservoir.

Table 8. Sediment Characteristics and Quantities Produced by Beaver Creek Runoff Events in 1972 and 1973.

Laboratory number	Sample date	Sediment (tons/day)	Turbidity (FTU)	Secchi Disc. (inches)
201	01/22/72			
202	01/23/72	523	43 (9)[b]	8
203	02/20/72	626	67	8
204	03/13/72	10,533	160	2
205	03/14/72	5,846	40	5
206	03/15/72	2,765	42	8
207	04/07/72	ND[a]	10	18
208	09/20/72	5	34	ND
210	01/19/73	103	18(5)[b]	ND

a. ND - not determined
b. FTU after standing undisturbed for 72 hrs.

The sediment loads reaching the Crooked River are small when compared to watersheds like Camp Creek and Bear Creek (Tables 10 and 14), which are also noticeably smaller in area. Most of the coarser sediments were observed to be deposited in upper reaches close to mountain sources. Deposition of the coarse material was noted during reconnaissance prior to stream monitoring and succeeding investigations throughout the study period.

Clay mineralogy: X-ray diffraction analyses indicate that the clay fraction of the sediments being produced in the Beaver Creek watershed is predominately 2:1 type clays. The diffraction patterns (Appendix F) suggest the presence of montmorillonite and other 2:1 clays of the smectite group. The small peak intensity, marginal resolution, and broad nature of the peaks suggest the presence of poorly crystallized clays.

Only those samples that noticeably contributed to long term turbidity were analyzed as outlined in the methods section for amorphous material. In view of the low FTU values for the Beaver Creek sample (Table 8) no laboratory analysis for amorphous material was made. The apparent lack of amorphous material is important, in absence suggesting the material creating the broad 15Å peak on the x-ray diffraction pattern is crystalline, albeit poorly so.

Water chemistry: The average sodium to calcium ratio (Na/Ca) for Beaver Creek is generally 0.34, except during low flow, such as that for sample #208 (Table 9). An increase in Na, Ca, Mg, and K concentrations is thought to be due to a reduction in dilutional effects during low flow periods. Conversely, high runoff volumes tend to dilute the concentration of those elements being measured, even though there may be a larger quantity in solution.

Table 9. Water Chemistry of Suspended Sediment Samples for Beaver Creek During the Runoff Years 1972 and 1973.

Laboratory number	Elemental Concentration meq/liter Ca	Na	Mg	K	Conductance $\mu mhos/cm^2$	pH
201	.70	.26	.25	.02	128	6.9
202	.85	.39	.30	.02	169	7.2
203	1.20	.30	.25	.04	139	7.1
204	.80	.30	.25	.02	155	7.0
205	.80	.33	.30	.02	118	7.3
206	1.20	.34	.32	.02	112	7.3
207	1.40	.47	.48	.01	115	7.9
208[a]	1.85	1.50	.98	.04	124	8.4
209	2.55	.43	.32	.01	147	7.4
210	.95	.34	.33	.02	102	7.2

[a]Low-flow characterization sample

Conductance values are low and range from 102 $\mu mhos/cm^2$ to 169 $\mu mhos/cm^2$ (average 132.8 $\mu mhos/cm^2$). This suggests that the total salt concentration is low. The conductivities are the lowest for any watershed in the study area and are likely attributable to the chemical nature of the geologic parent materials and soils present in the Beaver Creek drainage. The low salt (especially sodic salt) concentration is further evidenced in the hydrogen ion measurement. With pH values near neutral and low conductivities, these waters would have a "low" salinity hazard (USDA Handbook #60, 1954). This is a measure of the use for irrigation and the effect this water would have on soil and crops. However, it does suggest that waters coming from Beaver Creek are not likely to adversely affect the chemistry of the Prineville Reservoir. The waters from Beaver Creek most nearly correlate with those of North Fork and this is probably a result of climatic, vegetative, geologic, and soil similarities.

CAMP CREEK

Most of Camp Creek's 66.8 km^2 (173 mi^2) drainage area is located southeast and south of the Maury Mountains. The drainage encompasses the east end of the Maurys and extends south almost to Hampton, Oregon. Elevation ranges from 1,087 m (3,566 ft) at the confluence with the Crooked River to 1,816 m (5,959 ft) at Arrow Wood Point in the Maury Mountains. The major portion of the watershed area lies south of the Maurys and a predominance of the runoff comes from these mountains and the Logan Butte region (elevation about 1,585 m (5,200 ft). Runoff from the southern portion of the watershed originates in high, but relatively level, sage brush-juniper covered range country with a complex dendritic drainage pattern of intermittent streams that eventually form the south fork of Camp Creek near the center of the watershed. These intermittent tributaries to Camp Creek have dissected the surface of the drainage basin. Camp Creek has deeply incised alluvial deposits to depths of 20 feet or more along much of the mainstream channel. An early account of the erosion was published in 1905. The following is excerpted from that report:

> "Recent erosion - The floor of Price Valley [Camp Creek], when seen from its north or south border, presents the appearance of a smooth sagebrush-covered plain. In crossing the valley, however, one finds that its surface is intersected by arroyos, or small canyons, through which water flows during the wet season. Joining the main trenches are several branches, each of which has characteristics of a young stream-cut canyon. The main trench, which follows the longer axis of the valley, ranges from 60 to 100 feet in width, is approximately 25 feet deep, and has several vertical walls throughout the greater portion of its course. The walls of the arroyos reveal admirable sections of the unconsolidated silts of recent date which floor the valley, and together with the recent erosion that has taken place, present facts of much interest."
>
> Preliminary Report on the Geology and Water Resources of Central Oregon, I.C. Russell, 1905.

The deterioration of Camp Creek has been documented by Russell and he notes that the degradation started about 1880. The downcutting is attributed to the removal of once abundant bunch grass through overgrazing by sheep (Russell, 1902). An 1875 survey map and survey notes of T18S R21E indicate that the area was meadow with an occasional marsh and the stream was not gullied as it was when Russell arrived on the scene (Personal communication, H.H. Winegar, Oregon Wildlife Commission). Present day reconnaissance attests that much of the degradation recorded by Russell is still present and remains the heritage of Camp Creek.

Camp Creek has received varied and sundry treatments over the years, including a herbicide hazard experiment in 1967. During the experiment, 300 acres were sprayed with low volatile esters of the defoliant 2,4,D (Norris and Moore, 1967). Other studies are still in progress, one of which is the systematic removal of juniper for better wildlife habitat, range improvement, etc. In some instances, seeding to grasses follows the removal (personal communication, Harold Winegar, Oregon Wildlife Commission). This practice is a recent innovation and may have other beneficial effects regarding soil moisture when the felled trees are left lying at the site. The felled trees provide browse and good forage through the first winter for deer and elk.

The parent materials of the soils from which the sediments originate are Eocene and Oligocene andesite flows, breccias, and sedimentary rocks in the higher reaches of the watershed, and Oligocene and Miocene John Day Formation closer to the main-stream channel. Immediately adjacent to the stream channel is alluvium of Recent deposition (Walker, et al., 1967). It is in this Recent alluvium that the downcutting of Camp Creek is most dramatic with its vertical gray walls of stratified silts. Most striking in the area, beside the broad expanse of sage, are the raw sediment and bedrock exposures that dot the landscape. These are usually south-facing, devoid of vegetation, and are composed of grayish white, fluviolacustrine deposits. The weathering and eventual transport of these geologic materials have resulted in the deep, somewhat poorly drained saline soils along the major portion of the stream's reach, which have been mapped by Norgren et al., 1969. The soils are usually light gray in color and, when in suspension, take on a green-gray cast which was found to be characteristic of the sediments transported from the Camp Creek watershed.

With the establisment of seven cross-sections for sediment collection, Camp Creek was the most intensely sampled watershed of the area. Six of the sample sites were established to assist the Oregon Wildlife Commission in a revegetation-fencing study along three miles of the mainstream above Severence Reservoir [Maury Mountain Reservoir]. Several beneficial aspects are being realized from that study and progress reports are available from the Wildlife Commission.

Nature of sediment: Sediment concentrations originating from Camp Creek are high (Table 10) and generally consist of material that can be readily transported to the Prineville Reservoir. These materials are predominantly silt and clay and usually contribute to a very high turbidity (FTU). The sediments were found to remain in suspension longer than those of other watersheds studied and to be present in higher concentration.

Table 10. Sediment Transport, Relative Turbidity, and Particle Sizes in Suspension for Camp Creek.

Laboratory Number	Sample Date	Sediment Concentration (tons/day)	Turbidity (FTU)	%<50μ[a]
301	01/23/72	483	400	ND[b]
302	01/22/72	4323	350	ND
306	02/19/72	682	380	ND
307	02/20/72	1953	390	ND
320	03/06/72	1666	320	96
325	03/07/72	697	340	97
326	03/13/72	2798	320	97
331	03/14/72	654	300	93
332	03/15/72	495	180	66
333	05/14/72	ND	ND	ND
334	09/20/72	2	4	ND
335	11/26/72	ND	66	71
336	01/19/73	29	31	84
337	05/28/73	ND	130	84

a. percentage of material passing a 300 mesh sieve
b. ND, not determined

One apparent fact from the data (Table 10) is that once the sediment transport exceeds 400 tons/day (about 1800 ppm at a discharge of 98 cubic feet per second [cfs]), the turbidity (FTU) reading remains in the 300 to 400

FTU range. This suggests that the material coming from the watershed has a maximum potential to cause turbidity, regardless of greater concentration[5/]. Once in the reservoir, this small particle-size material has the potential to remain in suspension, thus turbidity in the reservoir results, provided conditions are favorable.

Clay mineralogy: Diffraction patterns of the Camp Creek sediment's clay fraction suggest a well crystallized 2:1 smectite clay mineral. The x-ray data (Appendix F) indicates the predominance of montmorillonite.

The presence of a 9Å peak on the x-ray diffraction pattern is due to zeolite of clay size. The dispersion of zeolite is dependent on particl size instead of external exchange sites, because, unlike the "real" clays, the exchange sites are in cavities (Youngberg, et al., 1971). Zeolites are readily weathered when exposed to pedologic weathering processes or the soil-atmosphere interface and, therefore, are not normally found in surface horizons of the soil profile. Their presence indicates deep-cutting erosional processes on the Camp Creek watershed. The gullies, raw bedrock exposures, and stream banks observed on the watershed are probable sources of the zeolite that gives rise to the 9Å x-ray diffraction peak.

Dr. D. D. Dingus examined a sample representative of the Camp Creek suspended sediments using the Transmission Electron Microscope (TEM). The data further substantiate the presence of smectite (montmorillonite) (Plate 4).

Smectite (montmorillonite) is represented by the darker three-lobed material in the center of the plate, which is likely three coalesced particles. Electron micrographs, the x-ray diffraction patterns and the data (Table 10) suggest that much of the transported sediment contributing to high turbidity is montmorillonite.

Summer freshets were noted to transport a considerable sediment load. In May of 1972 a localized convective storm caused extensive sheet and rill erosion on a small sub-watershed of Camp Creek (about 40 acres). Silt and plant debris covered a portion of the access road to a depth of about 10 centimeters (Plate 5). The extent of clay-size material being carried in the stream and out of the watershed was indeterminant.

Water chemistry: The average sodium to calcium ratio for waters being transported out of the Camp Creek watershed during periods of maximum runoff is 0.63. This figure represents a usual elemental concentration of 0.70 meq of sodium/liter and 1.10 meq of calcium/liter. Water samples collected by single-stage samplers had average Na/Ca ratios of about one-tenth higher. This increase is probably the result of overloading of sediment in the single stage bottles because of pressure head differences once the rising waters overtopped the collecting nozzle. The higher concentration of sediment acts as a reservoir for the ions involved, thus higher readings resulted.

5/ This phenomenon may be related to instrumental parameters and characteristics not already considered.

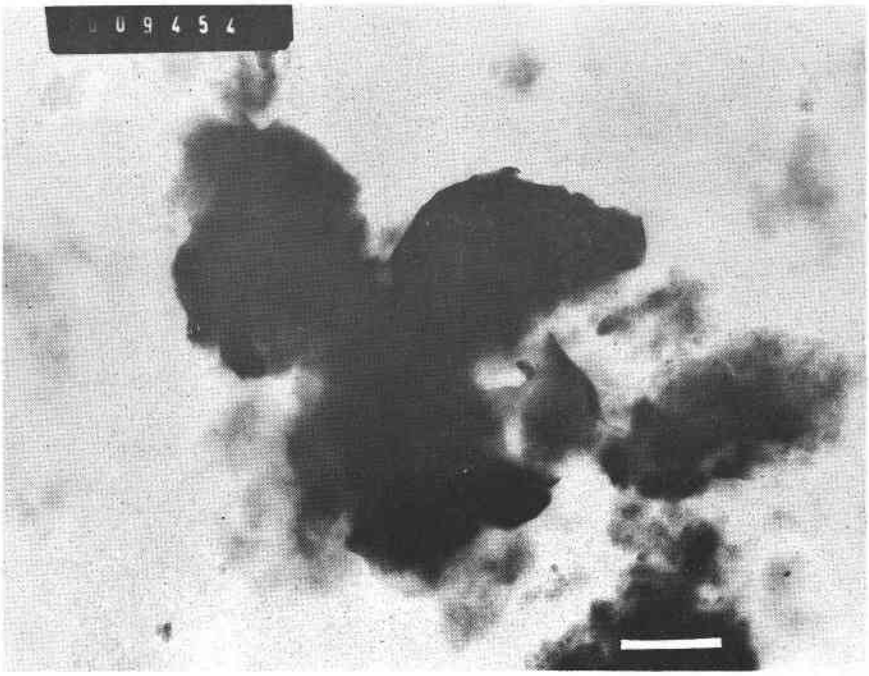

Plate 4. Electron micrograph showing 2:1 clay minerals (darker areas in center) coated by amorphous material (gray areas in lower center) for suspended sediment sample from Camp Creek. White bar lower right represents one micron (1μ). Interpretation of T.E.M. micrographs by Dr. D.D. Dingus.

Plate 5. Convective storm damage on Camp Creek, May 1972.

During periods of low flow, another effect was noticed. The low volume runoff carries a more concentrated elemental discharge because the waters are in contact with sediments and source materials longer. This extended contact time allows for more disolution to take place and more entrainment of the ions being measured. The increase in low-flow sodium to calcium ratio (ave. 1.39) values indicate that the solubility of sodium-bearing materials is greater and/or that sodium is more abundant than calcium along the low flow reach of the stream. The higher Na/Ca values also occurred in the first runoff events of the year (Samples #302, 306, and 336 in Table 11). This probably was the result of flushing and leaching of the salts precipitated when the water receded in the summer to low flow levels.

Table 11. Water Chemistry for Camp Creek Water Samples Collected During the Water Years 1972 and 1973.

Laboratory Number	Sample Date	Elemental Concentration meq/liter Ca	Na	Mg	K	Na/Ca	Conductance μmhos/cm[2]	pH
302	01/22/72	1.15	1.00	.30	.03	.87	69.8	7.4
306	02/19/72	1.40	.78	.32	.02	.86	77.5	7.5
307	02/20/72	1.05	.78	.30	.02	.74	80.6	7.2
320	03/06/72	.70	.65	.22	.04	.93	77.5	7.6
325	03/07/72	.90	.56	.22	.04	.62	77.5	7.5
326	03/13/72	.65	.36	.06	.03	.55	77.5	7.7
331	03/14/72	1.00	.70	.27	.04	.70	77.5	7.7
332	03/15/72	1.10	.70	.33	.05	.64	71.3	7.6
334	09/20/72	1.85	2.87	.84	.14	1.55	ND[a]	8.6
335	11/26/72	1.85	2.26	.81	.11	1.22	46.5	7.2
336	01/29/73	1.40	1.96	.61	.06	1.40	69.8	7.9
337[b]	05/28/73	.60[c]	2.83	.72	.07	4.72	54.2	8.2

a. ND: not determined

b. Sample taken from Severance Reservoir on Camp Creek.

c. Strontium not used in Ca determinations, thus calcium in the water sample is subject to interference which may show the calcium to be less than is really present.

Conductance values are quite low for the runoff waters, suggesting a low level of total salts in solution. The relatively low sodium to calcium ratio indicates that sodium salts (which are excellent electrolytes) are sufficiently low that one might predict the conductance values determined. However, the pH of the waters indicate that enough of the salts are in solution to noticeably disrupt sensitive equilibrium conditions. This is of importance with regard to the type of clays present in the suspended solids of the water samples. The 2:1 montmorillonite clays are easily dispersed in dilute concentrations of sodium, but flocculate when concentrations are above 10 ppm, which Na salt concentrations in Camp Creek closely approximate. Relative to sodium, calcium has a greater flocculating effect (L. D. Baver, 1949) but in the Camp Creek waters its concentration is lower than the required concentration and, therefore, the water chemistry promotes turbidity. The smectite clays coming from the watershed are dispersed in the dilute sodium-calcium solution being transported by Camp Creek. Water samples left standing in the laboratory for weeks remain turbid (200 FTU after 6 weeks; sample No. HHW#2, 1973) as a result of the sensitive chemical conditions. Other samples from this watershed were observed to remain turbid for even longer periods while awaiting laboratory analysis. These samples had been refrigerated at 34° - 38° for several months.

CONANT CREEK

Conant Creek drains 42.1 km^2 (16.25 mi^2) and has Lucky Creek as its only tributary. The headwaters for Conant Creek are Conant Basin and Coyote Butte with an elevation of 1524.6 meters (5,002 ft). Most of the watershed is privately owned and is used as pasture - rangeland and for dryland wheat and rye.

In the early 1970s, a major portion of the Conant Creek watershed was subdivided and, because of the sediment transport known to be associated with development (McGriff, 1972), Conant Creek was selected to be monitored for sediment transport and its contribution to turbidity in the Prineville Reservior. Sediment transport was recognized during preliminary reconnaissance to be of sufficient magnitude to have deposited numerous gravel bars in the lower reach of the stream. Also apparent was deep gully erosion along much of Lucky Creek and in the Conant drainage proper. The gullies have been carved to depths of 6.1 meters (20 feet) in some areas. Because of soil and erosion characteristics, the lower reach commonly has vertical walls while the upper reach of the channel has cut banks near 1:1 (45° inclination). Poorly constructed and ill-placed roads were noted to be gullied and rutted. Construction and engineering techniques were quite inadequate. The interest obviously was to develop quick and easy access with complete disregard of soil characteristics and erosional processes.

Those processes responsible for past erosion are still acting, as can be observed on the landscape where juniper (Juniperus occidentialis) are prevalent and have had roots exposed. The incidence of the exposed roots is common on the barren hills and along the stream channel where erosional processes are more evident. It was observed on the denuded ridges that 46 or more centimeters of soil had been eroded. This was apparent from the roots protruding from tree trunks 46 or so centimeters above the present ground surface.

A lineament (fault line) in the Lucky Creek portion of the basin (Swanson, 1969) near the present-day Bolletto Ranch marks a separation between soils of the watershed. Soils studied below the fault in the vicinity of the channel bank show a well developed solum which indicates a long period of stability of alluvial soils prior to the occurrence of the erosional features now recognizable.

The geologic formation predominating in the watershed is the Eocene-aged Clarno Formation. Principally, the area is composed of bedded volcanoclastic rocks, i.e. tuff, pyroclastic breccia, epiclastic volcanic siltstone, sandstone, and conglomerate (Swanson, 1969). The aforementioned geologic features are easily discernable throughout the watershed.

Nature of sediments: Measurement of sediment loads gave averages of 11.1 kg per hectare per day (10 pounds per acre per day) during high runoff events. Turbidity values up to 275 FTU's were recorded (Table 12). These high turbidity values are usually associated with discharge rates averaging about 5 cubic feet per second (cfs). Discharge rates of this magnitude are quite small when compared to other tributaries on the Crooked River drainage. The sediment load reflects the erosion conditions described earlier.

Table 12. Physical Parameters of Sediments Originating From Conant Creek Watershed - Water Year 1972.

Laboratory number	Sample date	Turbidity (FTU)	Sediment load (tons/day)	%<50μ[a]
401	01/22/72	250	74	90
405	02/19/72	175	33	44
406	02/20/72	250	65	ND[b]
407	03/15/72	275	33	70
408	04/27/72	150	ND	ND

a. Percent less than 0.05 mm passing a number 300 mesh sieve.

b. ND - not determined

A short distance below the sampling station, a decrease in stream gradient and velocity causes the coarser material (gravel and sand size material) to be deposited.

Estimated sediment volume deposited near the sampling station after the spring runoff was 2392 m^2 (84480 ft^3). Aggradation of the channel and deposition behind stream channel vegetation above the station were noted. The quantities of sediment being transported by stream flows of about 2,000 gallons per minute (gpm) during peak runoff indicate hydrologically unstable soil conditions on the watershed. These conditions are reflected in the proportion of the suspended sediment that is less than 50 microns (Table 12).

Clay mineralogy: Mineralogy for the portion of the sediment in the clay fraction subjected to x-ray diffraction analysis shows the major clay constituent to be montmorillonite (Appendix F), with a minor occurrence of zeolite. The diffraction patterns depict a well crystallized montmorillonite.

A broad increase in background at about 16 degrees, indicative of amorphous material, was not observed and, therefore, additional analysis for these materials was not performed.

Water chemistry: Waters originating from Conant Creek's watershed have an average Na/Ca ratio of 0.48, which corresponds to an average 2.36 meq/liter calcium and 1.02 meq/liter sodium. Also coming from the watershed is a relatively high concentration of magnesium (1.27 meq/liter). The concentrations of calcium and magnesium would tend to counteract the effects of sodium and this becomes apparent in the pH readings. Average pH values tend toward 7.8 pH units, while conductivity values have an average reading of 40 μmhos/cm^2. Halogen salts, especially those of sodium, give rise to higher conductivity readings if present in sufficient amounts.

Table 13. Chemical Qualities of Conant Creek Runoff Waters - Water Year 1972.

Laboratory number	Sample date	Elemental Concentration (meq/liter) Ca	Na	Mg	K	pH
401	01/22/72	1.75	1.39	1.08	.08	7.8
405	02/19/72	1.95	1.09	.96	.08	7.8
406	02/20/72	2.55	.74	1.27	.09	8.0
407	03/15/72	2.70	1.09	1.55	.09	7.8
408	04/27/72	2.85	.78	1.51	.06	7.7
409[a]	09/20/72	3.15	.74	1.90	.08	8.2

a. low-flow characterization sample

BEAR CREEK

Bear Creek drains 541 Km^2 (208 mi^2) and occupies the most southwestern portion of the Upper Crooked River Basin (Figure 5). It has an extensive drainage network that collects runoff from the southwest portion of the Maury Mountains to Antelope Reservoir and Soldier Creek on the east. The north edge of Rodman Rim is essentially its southern boundary. Elevations range from reservoir full pool level of 990 meters (3,250 ft) to west Maury Mountain with an elevation of 1,846 meters (5,054 ft). Nearly all of Bear Creek is range, both public and private, except for about 10 Km^2 (26 mi^2) that is forested with Ponderosa Pine (Pinus ponderosa) and some cultivated bottom lands. Stream gradients in the Bear Creek Drainage are steep, with Little Bear Creek having a steeper stream gradient than Bear Creek proper (Appendix B). Little Bear Creek accumulates runoff from the sparsely vegetated highlands on the southwest end of the Maurys. Much of the valley lands on Little Bear are in crop production from the Sheep Rock portion of the drainage to the confluence with the main stream.

Bear Creek's stream gradient profile is noticeably parabolic (Appendix B), becoming very steep near the Rodman Rim rim rock country. The gentler gradient throughout much of its reach has resulted in a well defined stream channel. In some portions severe downcutting and sediment transport have channels and near vertical stream banks. At some niche points, streambank healing is apparent. It is speculated that recent changes in range practice have resulted in the revegetation of the stream channel and definitely recognizable stream aggradation in areas directly affected by the changes. Other areas are in need of improved management programs that state, federal, and local agencies are planning to implement or have implemented. Recent findings indicate that 21.6 miles of Bear Creek are actively eroding and the erosion condition class was considered moderate in relation to other streams in the region of similar geology, soils, rainfall, topography, etc. (Stream Bank Erosion in Oregon, 1973).

Much of the Little Bear Creek drainage and the eastern half of the main Bear Creek drainage is composed of Eocene and Oligocene andesite flows, breccias, and sedimentary rocks (Walker et al., 1967). The main stream has etched its channel in the older John Day Formation and small alluvial deposits of unconsolidated fluviatile gravel, sand, and silt.

Bear Creek Buttes are volcanic landforms composed of basalts and andesitic agglomerates that have been modified by geologic erosional processes (Walker et al., 1967). Soils present on Bear Creek Buttes are shallow, light colored soils formed over hard bedrock on steep slopes (Norgren, et al., 1969). Other soils of the watershed are stony, shallow, clayey or some combination thereof formed on grass-shrub uplands ranging from semiarid to subhumid. Most of the soils mapped in the area have a high erosion hazard on slopes greater than 12% (Norgren et al., 1969). Most striking in the area are the brightly colored tuffaceous clay beds of the John Day Formation. The red, purple, green, and yellow exposures are recognizable at great distances and when wet turn to "jello-like" clay gels. It is considered fortuitous that in most cases these barren landforms are set back considerable distances from stream channels and are usually exposed on gentle slopes or in road cuts where erosional processes are at a minimum.

Recently the Bureau of Land Management has completed a soils inventory of the Bear Creek drainage. This portion of the present study was intended to supplement their study. Hydrology, in part, was included in the Bureau's study, along with management considerations.

Nature of Sediments: Sediment loads from Bear Creek are exceedingly high for the related discharge rates (Figure 1). About 25-40% of the sediment being transported during periods of highest runoff is greater than the fifty-micron particle size (Table 14). This indicates the stream's competence for large sediment loads at small discharge volumes and suggests that the bed load is of major importance.

Table 14. Sediment Discharge for Bear Creek During the Runoff Season of 1972 and 1973.

Laboratory Number	Sample Date	Discharge (Q)	Sediment Load (tons/hr)	Turbidity (FTU)	%<50μ
100[a]	01/22/72	180[a]	5390[a]	484[a]	97[a]
111	01/23/72	39	768	225	86
112	02/20/72	119	672	226	ND
114	03/13/72	451	16632	7500	60
115	03/14/72	347	5088	145	72
116	03/16/72	202	1368	225	77
117	03/20/72	128	744	180	43
118	04/18/72	9	ND[b]	49	74
119	12/17/72	6	3	17	85
120A[c]	12/18/72	7	9	26	90
121	12/22/72	12	22	83	87
122	12/26/72	8	9	9	73
123	01/15/73	8	10	46	86
124	01/26/73	8	11	31	91
125	01/20/73	5	6	24	74
126	02/28/73	10	16	145	83
127	03/02/73	9	13	50	ND
128	03/05/73	5	3	17	ND

a. Average for a continuous sampling period of seven hours.
b. ND - not determined
c. Sampled at different times on the same day by two different agencies.

Sediment transport of material in this size fraction (>50μ) is commonly about 78 kgm/ha/day (70 lbs/acre/day) and as much as 290 kgm/ha/day (259 lbs/acre/day) have been measured for major runoff events. Lower runoff volumes, those with relatively low velocities and low discharge rates, average about 0.18 kgm/ha/day (0.16 lbs/acre/day). This latter figure would more nearly represent the daily sediment discharge for the watershed, excluding peak discharge periods. Therefore, even though samples were taken periodically from December, 1972, through March, 1973, the discharge volume never filled the channel or flooded as expected for that period of the year. This same phenomenon was experienced throughout the sampled tributaries to the Crooked River and reflects the unusually low runoff for water year 1972-1973 (Appendix A).

Clay Mineralogy: The mineralogy of the suspended sediment passing the sampling station reflects generally that which is found on the watershed. X-ray diffraction patterns indicate the presence of the 2:1 clay montmorillonite, generally well crystalized, with a 7.2Å kaolinite, 1:1 clay, peak about 20% the height of the montmorillonite peak (Appendix F). The presence of the zeolite 9Å peak was noted on some diffraction patterns, but not of an intensity to be consequential. Low zeolite content may indicate that the sediment being transported originates from surficial or sheet erosional processes, rather than deep gully erosion reflected in some other tributaries. This is not to say that several erosional remnants of gullies are not present on the Bear Creek watershed, but only that sediment measured in the runoff seasons noted were predominately from surface soils. Other possibilities are that the zeolites are not as prevalent on the Bear Creek watershed or the areas where they are abundant were essentially non-contributing during the runoff periods sampled.

Transmission Electron Microscopy on the material being transported indicated only a small proportion of 2:1 clays, but a larger amount of organic material present. Algae are usually dormant during the colder months and therefore their presence would reflect poor storage prior to receipt. Other TEM micrographs from the 1972 runoff were suggestive of fine particles of kaolinite in suspension with the smectite minerals, and possibly another clay, Halloysite.

Water Chemistry: Chemical analysis of the runoff waters originating in the Bear Creek drainage show an average sodium to calcium ratio of 0.28 during high runoff periods which is relatively quite low when compared to the other watersheds. This suggests that the water coming from the Bear Creek watershed is comparatively lower in sodium and higher in calcium (Table 15) than that in the reservoir and other streams analyzed. The apparent effect that calcium has is one of flocculation of turbidity causing materials in suspension. The effect is really fortuitous because, if one considers the sediment transported by Bear Creek and its clay mineralogy, the potential for continued turbidity would be correspondingly large. This effect also explains why sediment transporting runoff from summer freshets apparently give rise to more turbidity in the reservoir. The short response time of the watershed, usually coupled with a short time of concentration before reaching the reservoir, reduces the effect of the calcium present in the soils on the watershed.

Correspondingly low conductance values (Table 15) were noted for the water samples and pH values centered around 7.5. A pH of this magnitude with low sodium concentrations and high magnesium concentrations indicate non-saline water conditions.

Table 15. Water Chemical Analysis for Bear Creek

Laboratory Number	Sample Date	Elemental Concentration (meq/liter) Ca	Na	Mg	K	pH
101[a]	01/22/72	1.15	.65	.62	.03	7.6
102	01/22/72	1.75	.56	.63	.03	8.0
103	01/22/72	1.80	.61	.62	.03	7.4
104	01/22/72	2.20	.61	.70	.03	7.7
105	01/22/72	2.00	.61	.65	.02	7.4
106	01/22/72	1.75	.78	.68	.02	7.3
107	01/22/72	1.75	.70	.68	.03	7.5
108	01/22/72	2.10	1.13	.70	.03	7.4
111	01/23/72	2.25	1.00	1.1	.03	7.5
112	02/20/72	2.10	.35	.98	.03	7.4
114	03/13/72	1.40	.04	.60	.03	7.6
115	03/14/72	2.00	.04	.70	.03	7.5
116	03/16/72	1.45	.04	.62	.03	7.0
117	03/20/72	2.30	.13	.82	.03	7.4
118	04/18/72	1.25	.26	.98	.02	8.0
119	12/17/72	1.25	.30	.70	.01	7.8
120A[b]	12/18/72	3.35	1.56	1.25	.06	8.2
120B	12/18/72	2.35	1.52	1.32	.02	7.6
121	12/22/72	2.35	1.26	1.40	.03	7.7
122	12/26/72	2.70	1.65	1.52	.03	7.9
123	01/15/73	2.45	1.48	1.38	.03	7.6
124	01/16/73	2.80	1.48	1.52	.03	7.8
125	01/20/73	2.80	1.52	1.58	.03	7.8
126	02/28/73	1.35	1.43	1.02	.05	7.1

a. Samples collected during even hour periods.
b. Sampled at different times on the same day by two different agencies.

OTHER STREAMS WITH SAMPLING STATIONS - SECONDARY

Streams of this category were sampled by "grab samples" on a less intensive monitoring program than the major tributaries to the Crooked River. Their watersheds, however, were critically reviewed with the same criteria and objectives in mind as the major tributaries.

EAGLE CREEK

Eagle Creek drains approximately 25.9 Km^2 ($10mi^2$), most of which is federally controlled land. O'Neil Creek is tributary to Eagle Creek and the watershed is dissected by Highway 380 from north to south. The confluence of Eagle and O'Neil creeks is located by Eagle Rock. The drainage appears to be docile and inconspicous in its contribution to runoff volumes, but when the potential for causing turbidity is considered, the creek becomes important. Stream gradients of 46.4 meters per kilometer (245 feet per mile) and a presence of the John Day Formation marks Eagle Creek as a source of turbidity causing sediments. The stream's water may be of a reddish or greenish color, depending on which portion of the watershed is contributing the most runoff. Investigations made during periods of runoff have shown that the source of discoloration originates above the confluence with O'Neil on the Eagle Creek watershed proper. Although point sources were not observed and specifically singled out, a few prominent red soils (Day series; Norgren, et al., 1969) lining the channel proper are visibly disturbed and exposed to erosional processes within the watershed. These red exposed soils are considered suspect for the reddish flows. The green flow origins were more elusive and probably came from one of the western branches near the upper reach of Eagle Creek.

Comments on Sediments: Samples obtained during runoff events were variable in their characterization, as might be expected for a small watershed. Discharge rates were usually between 5 and 6 cubic feet per second (cfs) and the water sampled had turbidity values ranging up to 290 FTU (Table 16).

Suspended sediments being transported out of the watershed were found to have a high percentage of particles with a size less than 50 microns. The small particle size is most likely responsible for the usually high turbidity values. Even when allowed to settle undisturbed for seventy-two hours, suspended sediments remain sufficiently turbid to still be considered aesthetically unacceptable. However, particle size alone may not be solely responsible for the turbidity. Type of material in suspension and size are both to be considered, as discussed in the soil analysis section of this report.

The clay mineralogy of the suspended sediment material, as determined by x-ray diffraction, reveals the presence of the 2:1 clay mineral montmorillonite. An additional peak located at approximately 9Å indicates the presence of zeolite. The montmorillonite is somewhat poorly crystallized and hydroxy-interlayers may be present. The presence of interlayers would suggest that the chemical-physical relationships existing in the suspended sediments are not simple. A tendency for the baseline to increase around sixteen degrees (Appendix F) indicated the presence of amorphous material in the system also. Analyses for amorphous material confirmed this.

Sodium and calcium values are considered low but the sodium to calcium ratio was 1.8. This relatively high ratio suggests that sodium may be of sufficient concentration in this system to affect the chemical equilibrium. In a sediment suspension of this nature, the potential for dispersion of the clay fraction would be high. Conductivity measurements (Table 16) further support this hypothesis. Values of conductivity ranging to 171 μmhos/cm are representative of a system with mobile particles and/or possessing electrolytes, both of which are present in the water samples.

LOST CREEK

The confluence of Sheep Rock and Lost Creek is located topographically above Highway 380. The combined stream then flows beneath Highway 380 at the junction of Teeters Road. The sample station for the combined drainages was the large retangular concrete culvert at the Highway 380 Junction. The drainage area encompasses 112.6 km^2 (43.46 mi^2), about one-third of which is forested, high-elevation, public lands. These high elevation portions of the watershed are geologically composed of Picture Gorge Basalts (Swanson, 1969) and, as noted for North Fork, are low producers of suspended sediments. During early reconaissance of the area it was found that higher portions of the watershed had few areas that were suspected of sediment transport or sources that would be capable of contributing to continued turbidity in the reservoir.

Comments on Sediments: During peak runoff events and runoff resulting from freshets on the watershed, a reddish-orange suspended sediment is transported in Lost Creek. The suspension is quite striking and readily contrasts with Crooked River waters at their confluence. The colored sediments were found to originate from the lower elevations of the watershed. In this portion of the drainage, the John Day and Clarno Formations are found (Swanson, 1969). These formations give rise to the red clayey soils that are mapped as Day-Ridgeway undifferentiated (Norgren, et al., 1969).

Stream sediments were sampled and analyzed for their contribution to sedimentation and turbidity potential to the reservoir. Significant amounts of the material being transported reflect the clayey nature of the aforementioned soils. More than 95% of the transported material sampled was found to be less than 50 microns. This particle size has a good probability of being carried to the reservoir. The turbidities are comparatively high when viewed with respect to PPM of sediment being transported. Further analysis carried out in the laboratory substantiated that turbidity remained after 72 hours settling time was allowed. Sample 804 was used to illustrate this tendency toward continued turbidity (Table 16). A residual turbidity of 44 FTU is sufficiently intense to be observable in the reservoir.

The suspended sediments in the system are characterized by a well crystallized 2:1 clay, montmorillonite. Also apparent from the diffraction patterns (Appendix F) is a 7.2Å peak, which corresponds to a 1:1 clay mineral of the Koalin Group, (kaolinite), and a 9Å peak corresponding to zeolites. The peaks of these two minerals are of about equal intensity, but somewhat dwarfed by the smectite peak.

NEWSOME CREEK

Sherwood, Gibson, and Hammer Creeks are tributaries to Newsome. The 77.7 km^2 (30 mi^2) catchment is predominately forested, deriving its runoff waters from the north slopes of the Maury Mountains. The discharge rate during spring runoff is small when compared to other catchments of similar hydrologic characteristics. In part this is explained by the water-holding capabilities of the deeper soils that normally occur on north aspects. Many of the soils are formed on deep deposits of volcanic ash. The origin of these soils is similar to those of the North Fork.

Much of the area is geologically similar to the Clarno formation, but it appears that the density of vegetation and ash-manteled soils of north aspect have subdued the erosional processes that have given rise to high sediment transport in other watersheds of similar geology.

Comments on Sediments: Chemical and Physical analysis of the suspended sediments indicate low concentrations and low turbidity values (Table 16). However, the samples were collected in the winter of 1972 and possibly do not reflect a complete picture of conditions on the watershed. Evidence still vivid on the watershed indicates that the soils of the basin are readily eroded if water is concentrated on them. The erosion takes place rapidly and cuts deeply (Plate 3).

Chemical analysis of the water samples show that sodium concentrations approximate the magnesium and are about one-half that of calcium. Conductivity readings are low and pH averages 7.5 units.

DRAKE CREEK

Wildcat and Shotgun Creeks are tributaries of Drake Creek. Essentially one-half of the 42.4 km^2 (16.36 mi^2) catchment is under the auspices of the federal government, and it is on these public lands that the streams originate. Geology generally is identified as Quaternary landslide debris and in localized areas documented as presently active (Swanson, 1969). The watershed of Shotgun Creek contains exposed Clarno Formation (Swanson, 1969), but its influence usually is not noted in runoff because the volume of Shotgun Creek is small. Shotgun appears to be intermittent in nature and has discharge rates that are quite low throughout much of the year.

Chemical analysis reveals a similarity to the waters from Newsome Creek, but with reduced concentrations (Table 16). The Na/Ca ratio is low (0.26), which also is reflected in the conductivity values.

TOM VAWN CREEK

Tom Vawn Creek originates from the north slopes of the Maury Mountains. Like other small watersheds of the study area it appears docile and insignificant much of the year. The most striking features in the watershed are the barren gray and buff colored exposures of the upper beds of the John Day Formation (Swanson, 1969). These steep clayey slopes, devoid of vegetation, are readily observable south of Highway 380. The brighter, more colorful, lower portion of the formation is exposed on the north side of the highway. Because the geology and soils of the Tom Vawn watershed are similar to those of the Camp Creek basin, the sediments have physical and chemical properties that are analogous (Table 16).

HORSE HEAVEN AND WICKIUP CREEKS

These two tributaries to the Crooked River have south aspects, similar geologies, (Swanson, 1969), soils (Norgren, et al., 1969) and hydrologic characteristics. Both are "flashy" streams (short response times) that transport coarse gravelly materials that originate from coarse, non-sorted volcanic breccias. Observations noted on aerial photos and field evidence indicate the materials are deposited at the confluence with the Crooked River or shortly thereafter downstream. Coarse gravel bars are readily discernible on aerial photos immediately downstream of the confluences. An indication of the coarse nature of the suspended portion is also reflected in the data from laboratory analysis (Table 16). Approximately one-half of each of the suspended sediment samples collected consisted of a particle size greater than 50 microns. The streams are sources of coarse sediments that may cause aggradation of the Crooked River channel but are likely not to be transported to the reservoir.

Occasionally Horse Heaven will flow with a turbid reddish-orange color. The Day-Ridgeway undifferentiated soils which occur in parts of the watershed (Norgren, et al., 1969) are likely sources of this intermittent colored runoff. This further indicates those portions of the watershed responding to hydrologic conditions prevailing at the time.

PINE STUB CREEK

Pine Stub originates from a watershed with similar geologic conditions as Horse Heaven but tends to flow reddish-orange during all runoff events. Pine Stub is an intermittent stream and, therefore, dry several months each year.

CHARACTERIZATION OF THE CROOKED RIVER AND THE PRINEVILLE RESERVOIR

CROOKED RIVER

For this report, the portion of the Crooked River to be considered begins at the Beaver Creek sampling station (T17S, R23E. Sect. 7; Bench mark 3,645 feet) and terminates immediately below the Prineville Dam. The Upper Crooked River, with a drainage basin of approximately 5,776 km^2 (2,230 mi^2) (exclusive of the Bear creek drainage which empties directly into the reservoir near the dam), is composed of the tributaries discussed in the preceding sections of this report. The individual geologies, suspended sediment characteristics, and water chemistry of the tributaries contribute to that which is the Crooked River. The essence of the hydrologic conditions contributing to the river have been discussed. It follows that the Crooked River is the whole of the many parts and has but a few properties characteristic unto itself.

The 1964-65 flood created channel-blockage problems and in some instances diversion of the river from its usual course. Post-flood activity was directed to channel repair such as clearing and realignment. Still visible below the town of Post, Oregon, in some areas, is the old channel and berm remnants used to contain and direct the water during repair. Reconnaissance in the area makes one aware that the river is responding to hydrologic forces during each major runoff event and as a result, has developed meanders and created new channel segments or widened old portions. This phenomena was readily recognized after the 1972 spring runoff; the river claimed new territories and abandoned other portions along its reach. This reapportionment was most prevalent below Post, where several thousand cubic yards of once stable and agriculturally productive riparian land were eroded and transported downstream toward the reservoir.

TABLE 16

Physical and Chemical Parameters of Sediment-Water Samples Derived from Secondary Stream Monitoring Stations, 1972

Name of Creek	Laboratory Number	Sample Date	Turbidity (FTU)	%<50μ	pH	Conductivity (μmhos/cm)	Elemental Concentration (meq/liter)			
							Ca	Na	Mg	K
Eagle	601	01/22/72	290	98	7.5	171	.40	.65	.05	.03
	602	01/23/72	150	95	6.8	161	.45	1.1	.08	.02
	603	02/19/72	250	83	6.9	163	.55	1.2	.02	.04
	604	12/17/72	96	85	7.6	147	.50	.87	.18	.03
	605	12/18/72	215(87)[a]	93	7.2	170	.60	.80	.18	.03
Lost	801	01/22/72	290		6.9	148	.45	.09	.12	.03
	802	01/23/72	200		7.2	141	.55	.09	.15	.03
	803	12/18/72	330		7.1	81	.60	.74	.18	.06
	804	12/17/72	420(44)[a]		7.0	133	1.20	.78	.18	.06
Newsome	144	12/17/72	11	73	7.5	45	2.45	1.17	1.05	.01
	145	12/18/72	115	78	7.7	42	2.55	1.17	1.12	.02
Drake	142	12/17/72	74	78	ND[b]	64	1.25	.22	.40	.03
	143	12/18/72	64(18)[a]	98	7.0	71	1.60	.52	.48	.04
Tom Vawn	147	12/18/72	1120	98	7.6	53	1.30	1.22	.32	.04
Horse Heaven	97	01/22/72	48	65	7.1	110	1.45	.61	.38	.04
	98	01/23/72	56	54	7.0	124	1.25	.56	.33	.04
	99	02/19/72	200	73	7.1	124	1.20	.46	.26	.04
	100	02/20/72	125	79	6.6	171	0.85	.65	.18	.04
Wickiup	133	01/23/72	35	52	7.4	99	1.05	.04	.40	.01
	134	02/19/72	880	65	7.2	122	2.05	.36	.40	.01
Pine Stub	127	02/19/72	280	100	7.5	119	.50	.40	.12	.02

a. Samples allowed to stand undisturbed for 72 hours to determine residual turbidity.
b. ND - not determined.

Because of the requirements that a sample station be located where the cross section of the channel is stable and accessible during most runoff events, it was necessary to choose as the sampling point the steel bridge crossing on Conant Basin Road (Appendix D). The bridge spans the Crooked River 9.7 km (6 mi) upstream from the uppermost extremity of the reservoir. The bridge affords the necessary accessiility and channel stability required for a controlled sample station. It was also possible to intercept all tributary waters, except those of Eagle Creek, at this site.

Nature of sediments: Suspended sediment loads quantified during peak runoff events (Table 17) reflect the tremendous potential that the Crooked River has for sediment transport. Sustained discharge rates of 203,880 m^3/hr (2,000 cfs) and sediment loads of 3,629 tons (metric)/day (4,000 tons/day) for periods of 3-5 days, or longer, show that the Crooked River is capable of contributing significant amounts to the siltation process of the Prineville Reservoir. During one continuous four-hour sampling (Table 17, samples 501-504) in January 1972 , an average 146 tons (metric)/hr (162 tons/hr) passed the sampling station. Relative to other events of greater discharge, values of sediment transport in this range appear to be below the norm. These events indicate that the usual sediment transport rate is more nearly in the range of 315-360 tons (metric)/hr (350-400 tons/hr) and is estimated to double and possibly even triple during extreme events. A doubling was suspected to occur during the 1972 spring runoff, and interpretation of several years discharge data indicates that event to have had about a two-year return frequency (Appendix A). A study conducted on streambank erosion showed that 40 mi (64.4 km) of the Crooked River (about the total length studied) is considered to be moderately eroded. This rating of the erosion is based on regional severity ranges and constitutes some 4,701 square yards of erosion per mile of eroded length (Streambank Erosion in Oregon, 1973). Measurements conducted during the present study show that at meander bends in the river, where much of the river's energy is dissipated and maximum erosion occurs, the water has removed 1910 m^2 (2286 yd^2) and 37,677 m^2 (45,101 yd^2) over 91.4 m (300 ft) and 125 m (410 ft) segments, respectively (Plate 6). For comparison, the same meander is shown in Plate 7, one year later. The figures are equivalent to volumes of 5,090 m^3 (6667 yd^3) and 111,160 m^3 (14,616 yd^3) at the sites. These figures, coupled with other information, provide evidence of river migration and flood plain erosion and since they represent only two meanders, are only small fractions of the total. Figures such as these are considered low estimates of the erosion occurring. Similar evidence has been recognized as valid in other regions too (<u>Sediment Transport in Rivers and Reservoirs, 1970</u>). This is because of the difficulties encountered in measurement of sediment loads. Hewlett and Nutter (1969) cite Holeman (1968) for his work on the Potomac, which showed that sediment yields of 170 tons/mi^2 were only five percent of the total material detached and transported within the basin.

Table 17. Suspended Sediment Characterization and Quantification for the Crooked River - Water Year 1972

Laboratory Number	Sample Date	Turbidity (FTU)	PPM	Ton/hour	Discharge (cfs)
501	01/22/72	125	758	169	2000
502	01/22/72	130	837	188	2000
503	01/22/72	125	778	174	2000
504	01/22/72	125	520	116	2000
505	01/23/72	125	477	88	1652
506	02/19/72	140	473	89	1669
507	02/20/72	260	1380	329	2125
508	02/21/72	74	335	80	2118
509	03/03/72	180	966	371	3500
510	03/06/72	150	1075	ND	2500
512	03/07/72	ND[b]	768	ND	638
513s	03/13/72	ND	1000[a]	18000	6690
513	03/15/72	ND	1088	11568	3948
514	04/07/72	150	1380	8048	2160

a. Estimated using runoff records from USGS and sediment concentrations of other runoff events.
b. ND; not determined

Of the suspended sediment passing the sampling station, a mean of 82% is less than 50 microns (<50μ in equivalent diameter). Values of particles <50μ range from 73 percent to 98.5 percent with the mode being near 75%. Therefore, the high percentage of material (18%) >50μ being transported reflects the potential energy the Crooked River has for carrying tremendous sediment loads. The ability to transport considerable amounts of bed-load material is observable after spring runoff events. Large volumes of cobble-sized material (7.62 cm to 26.5 cm) are found in many mid-channel bars throughout the river's lower reach. The channel bars are most prominent below Post, Oregon.

Clay Mineralogy: X-ray diffraction of that material less than 50 microns showed a predominance of montmorillonite. Other clay minerals present with reduced peak intensities were a 10 Å micaceous mineral, a 9 Å zeolite mineral, and an indication of a 1:1 clay mineral of the Kaolin group at 7.3 Å (Appendix F). In actuality, the mineralogy of the Crooked River reflects the individual mineralogies of its tributaries, as would be expected. The broad peaks on the diffraction pattern generally reflect a somewhat poorly crystallsized mineral. The diffraction pattern shows an increase in baseline at approximately 16 degrees which reflects the presence of amorphous material. Additional chemical analysis confirmed that an average 45 percent amorphous material, by weight loss, was present. The effect and significance of amorphous material in relation to turbidity is discussed in the section on Watershed Soils.

Bank Erosion: During the peak spring runoff event of 1972, an extensive amount of bank erosion was observed to be occurring. Subsequent to the runoff, major portions of the Crooked River channel downstream from Post, Oregon, were studied to determine soil volume removed. In some instances the flood waters displaced thousands of cubic feet of valuable farm land, causing the river channel to migrate several tens of feet from its pre-flood location. The major erosion and channel changes were observed to be coincident with the larger meander bends in the river.

Because the 1972 runoff event was considered to have a flood return of Tr=5[7/], it was felt that the frequency of such erosion warranted an attempt to quantify it. Those portions of the channel reach measured and studied on the ground were located on high altitutde aerial photographs (NASA U-2 Imagery, 1972) and studied for their physical-visual characteristics. Using the known areas as a reference, other areas were noted and their physical characteristics extrapolated. These areas were then compared to earlier photos to establish their relative age. Only those areas meeting the physical-visual characteristics similar to the measured sites were included in total volume calculations.

Actual volume of soil loss during the 1972 spring runoff event for 12 major erosional cuts is presented (Table 18).

Table 18. Streambank Erosion on the Crooked River for the Peak Runoff Event of Water Year 1972

Site Number[a]	Volume Displaced[b] x 10^3		
	ft.^{3}	yd.^{3}	m^3
1	149	5.5	4.2
2	148	5.5	4.2
3	24	0.9	0.7
4	71	2.6	2.0
5	76	2.8	2.2
6	98	3.6	2.8
7	165	6.1	4.7
8	98	3.6	2.8
9	77	2.8	2.2
10	53	2.0	1.5
11	92	3.4	2.6
12	149	5.5	4.2
Total volume:	1.2 x 10^3	45.2	34.1

a all sites are located below Post, Oregon, and above the Eagle Creek confluence.

b figures rounded for presentation

7/ Tr: the Return Period for extreme events and is the reciprocal of the probability that event will occur.

The total volume represents about 0.37 ha-m (3 ac-ft) of soil or about 2,000 square yards per measured river mile. This figure is below that reported in Streambank Erosion in Oregon. The seeming conflict can be explained on the basis that the figures presented in this report pertain only to the major erosional areas below Post and make no attempt to include the total erosion present along that portion of the reach. It is expected that total figures would exceed those reported in Streambank Erosion. The accumulated measured length for this report involved only 0.7 mile, which leaves an undetermined amount of lesser erosion over approximately 11.3 miles.

Water Chemistry: The sodium to calcium ratio for the Crooked River is 0.75 with average sodium and calcium values of 0.57 and 0.76 meq/liter respectively. These figures reflect the dilution-leveling effect through summation of all the river's tributaries and their individual contributions. Magnesium (0.29 meq/liter) also is lower in concentration then found on some of the tributaries (Table 19).

Conductivity values more nearly reflect the mean in the range of values determined for the tributaries. The average conductivity is 128 μmhos/cm, which is intermediate between a low of 40 μmhos/cm and a high of 223 μmhos/cm for the tributaries.

A measure of the hydrogen ion activity gives rise to a mean of 7.2 pH units with a modal 7.1. This mode reflects the near neutral pH of the Crooked River water. This in turn indicates the dissolved solids and salts in total and suggests that the combined nature of all the contributing watershed has a tendency toward neutrality. During low flows pH values increase to 8.3 units, which reflects the substantial increase in sodium to calcium (Na/Ca) ratio of 1.45. This trend was noted in about every watershed studied and is discussed in the section on Camp Creek.

Table 19 Chemical Analysis of Suspended Sediment Waters Sampled From the Crooked River, 1972-1973

Laboratory Number	Elemental Concentration[a] Ca	Na	Mg	K	Conductance μmhos/cm	pH
1972 Runoff Year						
501	.50	.36	.20	.04	139.5	6.7
502	.55	.36	.15	.04	151.9	6.8
503	.80	1.20	.20	.04	133.3	6.9
504	.85	.59	.22	.04	136.4	7.1
505	.85	.46	.21	.04	108.5	7.1
506	.95	.59	.31	.01	103.8	7.0
507	1.05	.56	.27	.01	108.5	7.1
508	.85	.83	.26	.04	124	7.0
509	1.05	.52	.26	.04	105.4	6.9
510	.90	.57	.27	.05	117.8	7.6
512	.65	.34	.22	.03	156.5	7.1

a. Reported in meq/liter

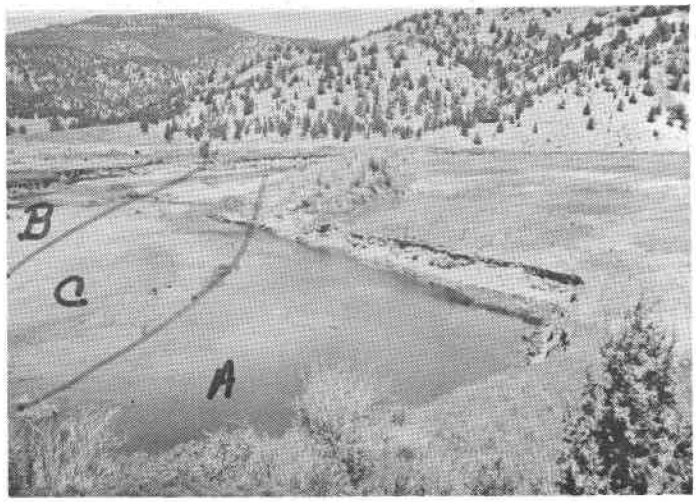

Plate 6: Newly formed meander bend formed during the 1972 spring runoff event. Area A represents the approximate removal of 5,500 yd^3, Area B represents about 2,000 yd^3. Area C is the approximate stream channel position prior to the runoff event.

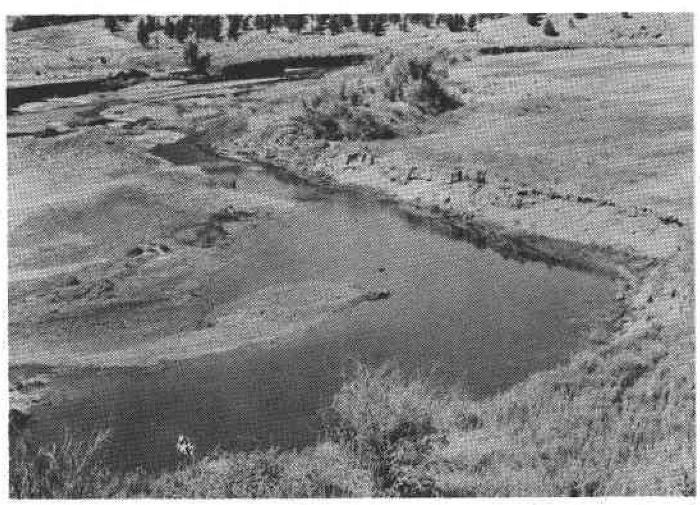

Plate 7: Same meander bend as that depicted in Plate 6 but with considerable additional soil loss. Bushes in foreground and log protruding out of the water at extreme left center of plates are the same. (Photographed Spring 1974)

Table 19. con't.

Laboratory Number	Elemental Concentration Ca	Na	Mg	K	Conductance µmhos/cm	pH
513	.50	.30	.22	.03	148.8	7.1
514	.75	.33	.26	.02	ND[c]	7.5
515[b]	1.75	2.54	1.14	.12	ND	8.3
1973 Runoff Year						
516	.75	.53	.36	.05	99.2	7.4
517	.85	.55	.35	.04	155	7.5
518	1.45	.72	.40	.06	124	7.4
519	1.40	1.21	.68	.08	57.3	7.1
520	.30	.48	.30	.04	108.5	7.5
521	.32	.56	.35	.05	108.5	7.7
522	.26	.35	.20	.03	325.5	7.1

b. Low-flow characterization sample--September 17, 1972

c. ND--not determined

PRINEVILLE RESERVOIR

The Prineville Reservoir has a total length of 23.3 km (14.5 miles), a capacity of 19,112 ha-m (155,000 ac-ft) and, when filled to pool elevation of 985.5 meters (3234.8 ft. msl.), has an area of 125.5 ha (3,100 acres). The recognized multiple use is flood control and recreation. The dam was constructed by the Bureau of Reclamation between 1958 and 1962, assuming flood control status in late 1962.

Shoreline Characteristics: Around the perimeter of the reservoir are three basic shoreline types. These include hard and soft rock exposures, localized deposits of buff-colored volcanic ash, and soil. The soils of primary interest are the more spectacular red and purple clays.

The hard rocks consist of basalts and act as shoreline rip-rap. In areas where armouring by rock is most prevalent, soil loss from wave erosion, and other erosional processes has obviously been minimized. Softer rocks consist mainly of red and green tuffaceous sedimentary materials. The mechanism by which these materials are involved in the complex erosional processes of the reservoir environment relate to their degree of hardness. The harder tuffs in their bare state act as a revetment against which waves and currents dissipate their energies with minimal erosion. Generally the red tuffs appear softer and erode accordingly. The softer tuffs respond to wave action and slake readily. The tuffs initially detach as plate-like fragments with generalized dimensions of 5 mm by 2 cm, are variable in length, but usually do not exceed 2.5 cm. This platy material settles by saltation-like movement toward the bottom of the reservoir while partially slaking down to clay-size particles. During the disintegration of the red tuff, high shoreline turbidity is created. The preponderance of this turbidity is usually within 2 meters of the shoreline and has turbidity values of 90 FTU or more.

Localized deposits of volcanic ash on gentle slopes in the draws or cove slopes provide excellent beaching areas. These are usually "homesteaded" by campers throughout the recreation season. The volcanic ash is slowly being eroded into the reservoir depths and, in time, these areas will be lost unless precautions are taken for their preservation. The pumiceous material is estimated to be less than one percent of the shoreline.

The majority of the reservoir shoreline consists of soils that are less affected by erosion and appears stabililzed, at least for the present. However, of primary interest are the red and purple clays of the Day-Ridgeway complex, or soils with similar characteristics. These soils tend to crack when dry, slough when wet, and are generally found over red tuffaceous material similar to that previously discussed. These colorful soils are very clayey in nature and large portions of them have been removed by wave action on the reservoir. When observed during low pool levels these soil areas frequently have banks 1 1/2 meters high with shoreline distances from full-pool to low-pool levels of approximately 18 meters. In one area studied, an estimated 1435.5 m^3 (1850 yd^3) of soil had been removed. During low-pool reconnaissance it was estimated that these kinds of soils occupied 2-3 percent of the total shoreline.

All the conditions discussed with respect to shoreline reconnaissance were found to predominate below Jasper Point.

Thermal and Turbidity Characteristics: The temperature cycle of the Prineville Reservoir is representative of reservoirs in Oregon. Youngberg, et al., 1971 found that a western Cascades reservoir behaved similarly. Higgins and Colonell, 1973, in other regions of the U.S. had similar findings. Explanations of the processes involved are available in textbooks dealing with limnology. Mortimer, 1969, reviews the thermal processes from the viewpoint of eutrophication--a related pollution problem. The general physical factors involved in the thermal characteristics are discussed by Mackenthum et al., 1964, and the concepts are related to the Prineville Reservoir, as described below.

Sometime during the spring the reservoir has a nearly uniform temperature profile throughout. At this time the water is near its maximum density. Through climatic warming, the reservoir begins to receive heat, primarily from solar sources. When the surface waters are heated evaporation begins and the warming process is inhibited, causing convective currents, which in turn cause a heat loss. As this phenomena evolves, the surface of the reservoir begins to react to these epilimnological disturbances (including winds), causing wave action to begin. The added mixing of surface waters then causes a downward movement of heat and results in temperature distributions similar to that shown in Figure 6. The temperature distribution shown is typical of temperate lakes and reservoirs that have sufficient depths for this phenomenon to occur.

The upper region (Figure 6) is called the epilimnion and is more or less uniformly warm, turbulent, and well mixed. The lower region is the hypolimnion, which is cold, relatively undisturbed, and reaches the bottom. The transition between the epilimnion and hypolimnion, where temperatures decrease most rapidly, is termed the metalimnion (or thermocline, Machkenthun et al., 1964).

Thermal and turbidity profiles (Figures 7, 8, 9) with obvious thermoclines, epilimnions, and hypolimnions present show the resemblance of the Prineville Reservoir profile to the hypothetical profile. Between data collection periods the reservoir was undergoing draw-down for irrigation

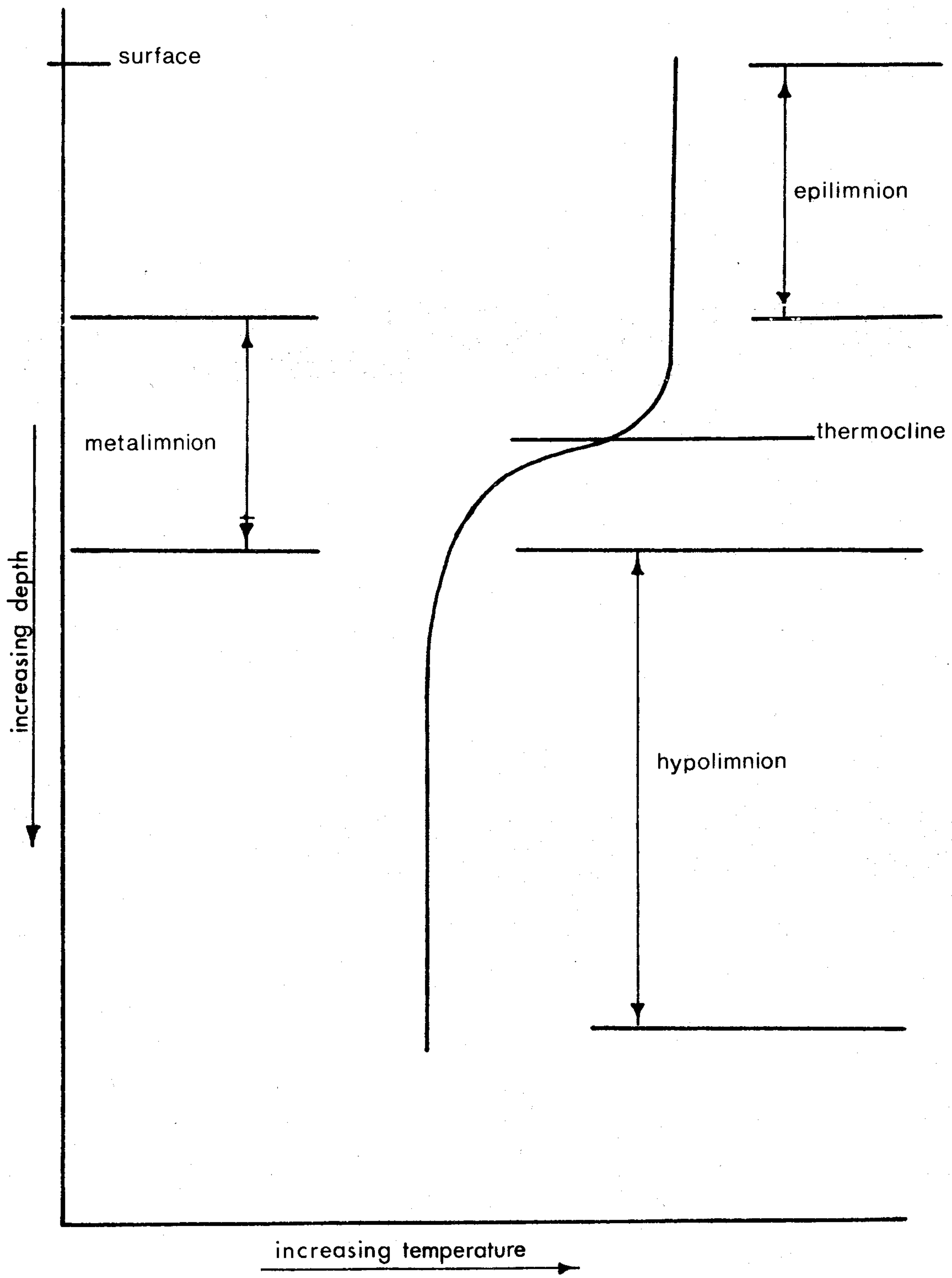

Figure 6: Hypothetical temperature profile in a temperate region reservoir after the formation of the thermocline.

purposes and in preparation for seasonal flood control. It is interesting to note that the thermocline descends within the reservoir during the season. This is thought to be in response to the draw-down and also characteristic of the reservoir cyclic nature to achieve a "starting point" for the upcoming season. The reservoir is referred to as having "turned over" when the temperature profile is more or less uniform throughout its depths.

When the temperature and turbidity profiles are considered collectively (Figures 7, 8, 9), points worthy of note are: (a) an increase in turbidity below the thermocline, (b) a general lessening of turbidity near the dam, (c) decreasing turbidity in the profile with increasing thermocline depth, (d) a slight increase in surface turbidity just before algal bloom, and (e) the turbidity profile below the surface essentially remains undisturbed even after the reservoir achieves a near uniform temperature profile.

Turbidity noticeably increases below the thermocline. This can result from a combination of increased water density and material settling out of suspension. The increased water density and viscosity would slow particle settling time (Stoke's Law) and material of larger size would be retained in suspension.

Increased turbidity with depth is pronounced when the thermocline is more fully developed and appears more intense at the Antelope site than at the Dam (Figure 8). Three possible explanations for this are: (1) cooler, more turbid waters entering from the Crooked River that, because of the thermal stratification inherent in the reservoir, remain closer to the bottom, (2) waters nearer the dam site usually experience less disturbance from wind, motor boats, etc., and, therefore, less mixing of the profile occurs, and (3) there may be an inexplicable sphere of influence as a result of the sampling station's proximity to the outlet of the dam.

A general decrease in turbidity with increasing depth to the thermocline is explained by the inverse of causes for increased turbidity below the thermocline.

The increase in surface turbidity just prior and during algal bloom, although slight, could be of consequence to the reservoir turbidity but was not studied. Surface samples analyzed in the laboratory reflected the algal presence. However, the algal presence was more striking on the reservoir when it literally covers the surface. With increased depth the algae becomes highly dispersed and almost imperceptible to laboratory instrumentation.

Even though the reservoir achieves a near uniform temperature profile in October (Figure 9), the turbidity values within the profile remain in the same order of magnitude as prior to the "turnover". The characteristic "bow" in the curve associated with the earlier thermocline remains, though it is less discernable and several meters deeper.

Clay Mineralogy: Material suspended in the reservoir was subjected to study using transmission electron microscopy (TEM). Results indicate that the surface 20 feet (above the thermocline) has a mixed mineralogy. The TEM micrographs reflect a preponderance of smectite in a field of non-crystalline gel and small, but well-crystallized, kaolinite. The mineralogy is similar to that interpreted to be present in x-ray diffraction patterns for the Antelope sample site (Appendix F). A small amount of kaolinite is indicated by relative peak intensities in diffraction patterns. The general appearance of "gel-like" coatings adhering to the clay minerals is interpreted to be amorphous material.

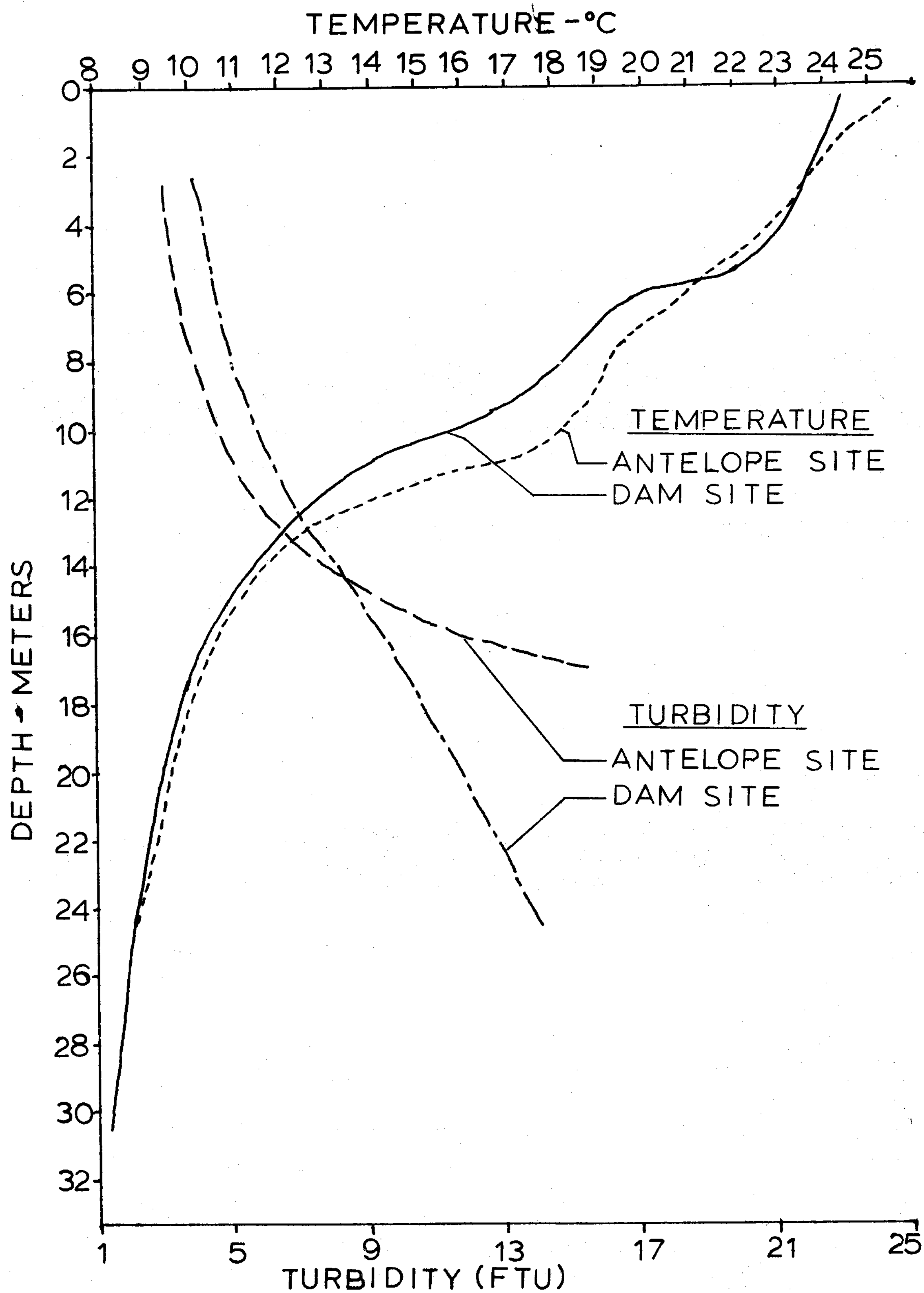

Figure 7: Prineville Reservoir Temperature Profile - August 8, 1972

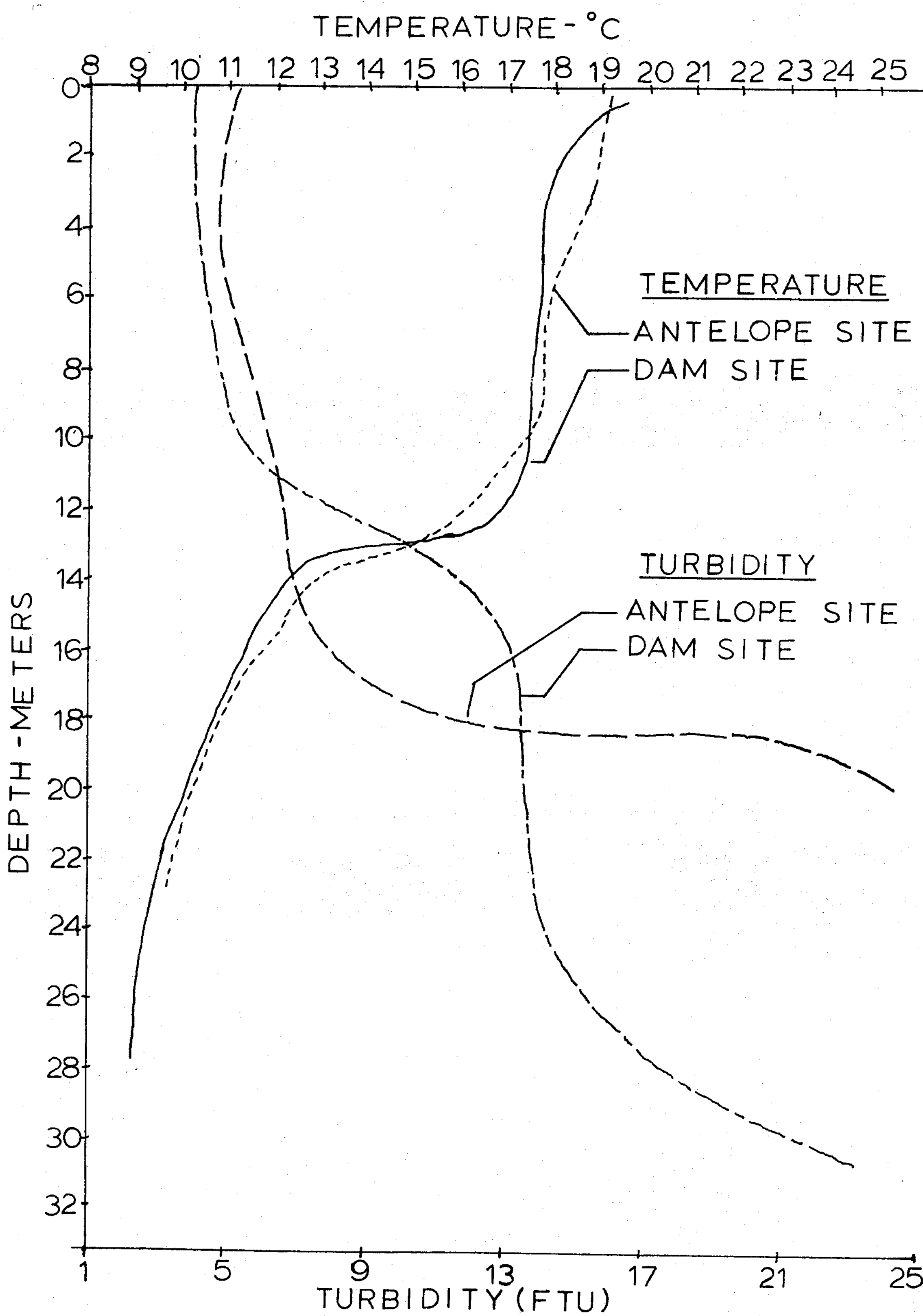

Figure 8: Prineville Reservoir Temperature Profile - September 13 & 15, 1972

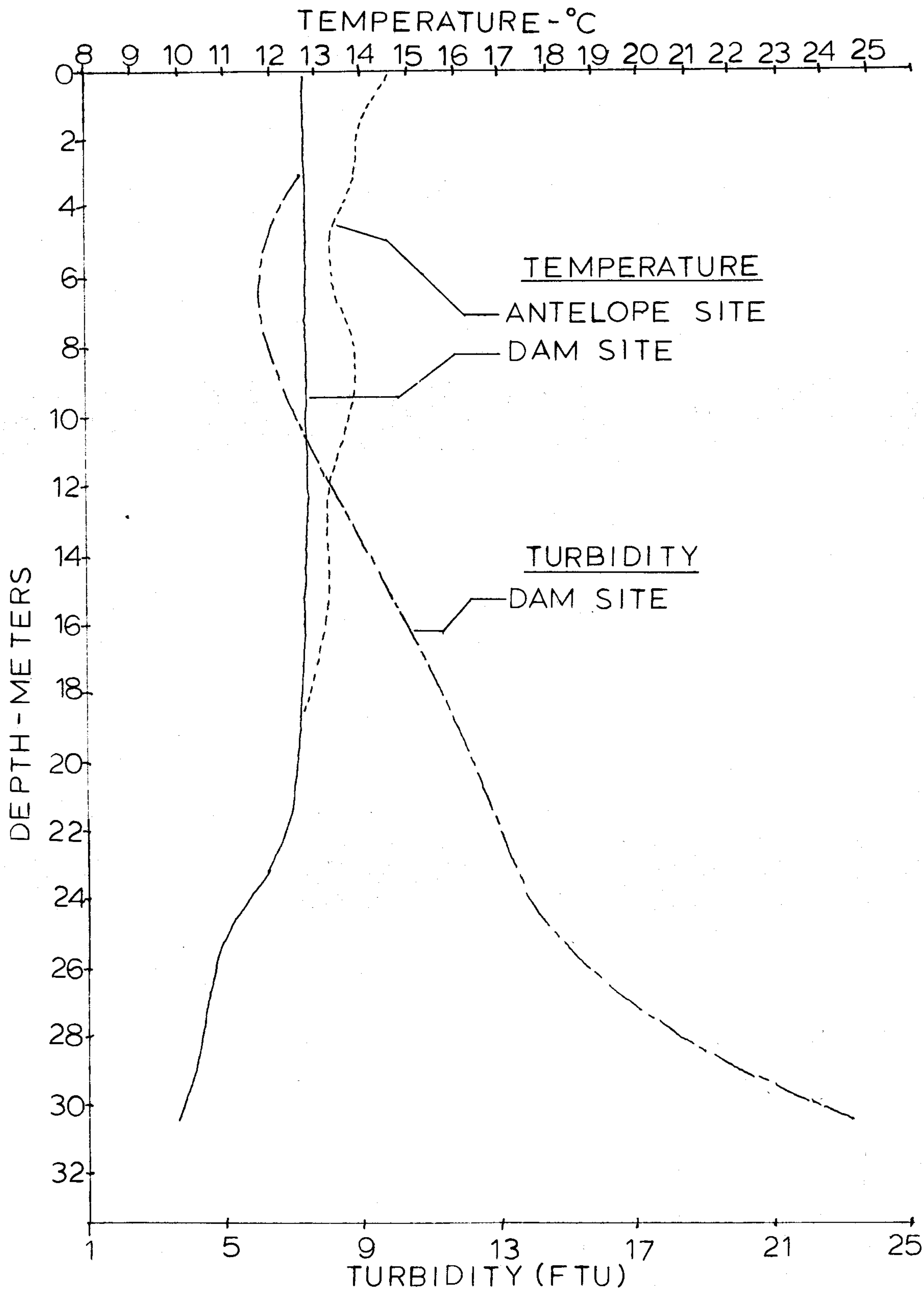

Figure 9: Prineville Reservoir Temperature Profile - October 20, 1972

Water samples obtained from below the thermocline studied by TEM (Plate 8) were found to have similar micromorphologies. The occurrence of crystalline clays seemed to increase, as did the amount of amorphous gel on the crystalline materials. The increase in concentration is reflected in the Temperature-Turbidity Profile Graphs by increased turbidity below the thermocline (Figures 7, 8, 9).

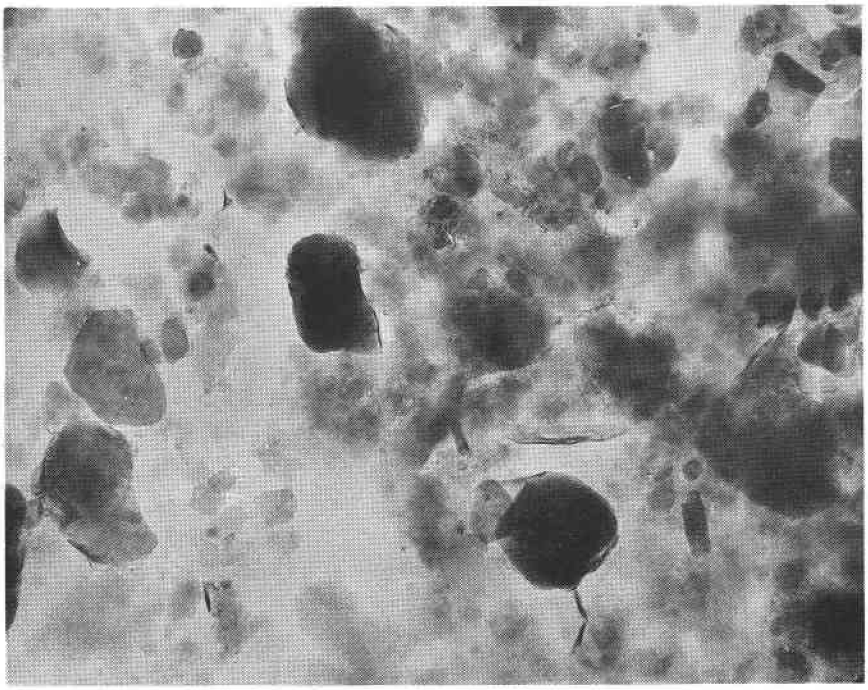

Plate 8: TEM of water sample obtained below the thermocline of Prineville Reservoir, June 21, 1972.

In general, it appears that the crystalline material occurring in the surface 8 meters is more discernible and seemingly has fewer gel-like coatings than that situated below the thermocline.

Clay Mineralogy: TEM analysis on water samples obtained during the runoff season from Bear and Camp Creek indicated that the suspended material originating in the Bear Creek drainage had fewer amorphous coatings and appeared to be higher in proportion of crystalline clays. X-ray diffraction analysis of the water samples suggests that the Camp Creek samples had better crystallized smectites. However, estimates of amorphous material by dissolution treatment indicated that Camp Creek samples have more amorphous material than the Bear Creek samples. The data obtained are from representative samples similar to those in the TEM micrographs (Table 20).

The Crooked River is intermediate in amorphous materials between Camp and Bear Creeks. The two reservoir samples appear to reflect the total range.

Table 20. Amorphous Material Dissolution Treatments for Water Samples

Sample Source	Sample Number	Percent Amorphous Material
Bear Creek	100S	29[a]
	114	31
Camp Creek	302	61
	306	53
	307	48
	312	56
Crooked River	504	37
	505	70[b]
	506	46
	507	29
Prineville Reservoir	1304[c]	27
	1305	43

a. Sample obtained from erosion control reservoir SW 1/4 SE 1/4 sec. 30 T18S, R17E on Bear Creek Drainage.

b. Weight loss during analyses may be excessive because of extreme dispersion of sample.

c. Dates for reservoir samples 1304--May 13, and 1305--April 22, 1972.

Sedimentation of the Reservoir: Agencies participating in the study expressed concern about the siltation of the reservoir. Interests evolved around the sediment load being transported annually by the Crooked River and Bear Creek, and the deposition occurring within the reservoir.

Around the perimeter of the reservoir, sedimentation is prevalent and recognized by braided-channel patterns. The deposition of sediment results from the slowing of stream waters upon entering the reservoir during higher pool elevations. Subsequent downcutting of this sediment occurs when the reservoir pool elevation is lowered.

A complete analysis of the siltation processes within the Reservoir was beyond the scope of the study project. However, in an attempt to supply the agencies with needed information, an estimate of sediment deposition was obtained. The basis of the estimate is field reconnaissance data collected in November 1972. At the time of data collection, the reservoir was near seasonal low-pool (elevation 3,211.8 ft.). Because the data collected were confined to that sediment above low-pool, it only approaches the minimum amount of siltation subsequent to the reservoir's installation. An engineer's topographical survey sheet[8/]

[8/] Engineer's topography sheet furnished courtesy Ochoco Irrigation District, LaSelle Coles, Director.

of the pre-reservoir terrain was used as the base map for calculations of sediment volumes. Measurements of the sediment deposition at various locations on the reservoir were obtained at inflow deltas, siltation flats, and channel deposits. The data were compared to the engineer's topographical sheet prepared prior to the inception of the reservoir. Deposits in unmeasured areas were approximated on the engineer's topographical sheet and the volumes extrapolated (Table 21). Summation of the individual cross-sections and channel section volumes yields the total volume for the tributary arm of concern.

Necessarily, innundated portions of the reservoir were not measured because of lack of more sophisticated underwater measuring equipment.

Sediment Volumes: The estimated total volume for Bear Creek is slightly over 50% of that estimated for Crooked River (Table 21). This proportion is probably too high because sediment deposits in the Bear Creek arm are more accessible and, therefore, measurements are easily obtained. The inundated channel of the configuration for the Bear Creek arm more nearly approximates an inverted acute triangle. The sides are steeper and closer together than the flatter, more plate-like configuration associated with the Crooked River arm. Therefore, the geometry of Bear Creek is more adapted to measurement and extrapolation techniques.

The Crooked River arm more nearly resembles an obtuse inverted triangle, being more trapezoidial in its appearance. The size, shape, length, and inaccessibility of the Crooked River arm with a larger portion inundated even at low-pool, restricts and prevents measurement over much of the area. The volume estimated above low-pool elevation reflects sediment deposition on what used to be the flood-plain of the Crooked River. It is reasonable to expect that much of the sediment being transported to the reservoir by the Crooked River is carried further into the main body of the reservoir by stronger channel currents near the main channel during peak inflow events. This relates directly to the competence of the river during these peak events which often occur during seasonal low-pool periods.

The sediment deposition estimated to have occurred totals 137.5 million cubic feet; this figure constitutes 2% of the total volume of the reservoir. However, it must be remembered that the calculated volume of deposition is a minimum estimate and that the true value is likely a few percent greater.

The figures for sedimentation of the reservoir average about 687,500 tons/year. Using data collected for the calculation of the sediment transport (Table 2), an average of 52,508 tons/year seems in great disparity. There are, however, at least two reasons that will help explain the conflict, (1) the lack of continuous measurement and (2) record low precipitation for Water Year 72.

First, the data used to calculate the yearly contribution were derived during periods of peak runoff and then not continuously throughout the event. At times of intermediate runoff, sampling was sparse at best. Therefore, data for inclusion into the estimate of yearly sediment contribution is necessarily restricted. For a complete analysis of sediment delivery to the reservoir, a continuous sampling of suspended sediments is required. Obviously such a monumental task was not feasible.

Table 21: Sediment Calculation for Prineville Reservoir
Base: Engineer's Topographical Survey

Bear Creek Arm

Cross-section	Width (ft.)	Depth (ft.)	Volume[a] ($ft.^3$)
# 1	500	60	15.0×10^6
# 2	440	55	12.1×10^6
# 3	560	45	12.6×10^6
# 4	280	25	3.5×10^6
# 5	240	20	2.4×10^6
# 6	200	10	1.0×10^6
# 7	120	10	0.6×10^6
		Total Volume	47.2×10^6 [b]

Crooked River Arm

Cross-section	Width (ft.)	Depth (ft.)	Volume[a] ($ft.^3$)
# 1	1120	20	11.2×10^6
# 2	1320	10	33.0×10^6
# 3	1840	20	36.8×10^6
# 4	440	15	6.6×10^6
# 5	280	<10 (5)	1.4×10^6
# 6	160	<10 (5)	0.8×10^6
# 7	100	<10 (5)	0.5×10^6
		Total Volume	90.3×10^6

a. volume calculations are for triangularly shaped sediment bodies based on the original topographic configuration of the pre-reservoir terrain.
b. total volume equals 1.34×10^6 cubic meters for Bear Creek and 2.56×10^6 cubic meters for the Crooked River.

Secondly, the hydrologic events for the study period and the years previous did not compare closely. The water year 64-65 runoff was comparable to a Tr = 100, while water year 72-73 was deficient by record amounts.

By assuming Water Year 1972 (Tr=5) as an "average" year, the extimated sediment load indicate that the minimum siltation of the reservoir per year is 103,014 tons or about 129 pounds/acre of watershed. The actual "average year" figure is expected to be more than double this, and much higher in some years.