AN ABSTRACT OF THE THESIS OF

Clair Ellwood Silvernale for the degree of Master of Science

in Soil Science presented on March 18, 1976

Title: TURBIDITY IN PRINEVILLE RESERVOIR AS RELATED TO SOILS AND HYDROLOGY

Abstract approved: Redacted for Privacy

Moyle E. Harward

Persistent levels of high turbidity in the outflow from the Prineville Reservoir led to development of relationships between watershed soils, land use, and resource management and water quality in the Upper Crooked River, Central Oregon.

Seven stations, strategically located for measurement of runoff volume and water sample collection, were established late in 1972. Six stations were on tributaries to the Crooked River; the seventh was on the main stream above the Prineville Reservoir.

During runoff events, suspended sediment samples were obtained on each tributary above the confluence with the Crooked River. Greater stream sediment loads were associated with tributary watersheds under shrub-grass-juniper cover that have steeply rolling, dissected terrain with common rock outcrops. Those watersheds also have dominantly medium-textured, moderately deep

soils. Steeper gradients are associated with these watersheds.

Streams contributing high sediment loads were not necessarily those found to cause the long-term turbidity. This phenomenon was usually associated with those watersheds having a preponderance of soft, tuffaceous sedimentary rock.

The results indicate major runoff events carry the greatest sediment loads to the reservoir and cause considerable turbidity. However, some turbidity-causing material is transported during smaller events as well. Freshets on watersheds with erodible soils cause turbidity during the convective storm season. Turbidity values in streams decreased between storm and runoff events, especially on forested watersheds. Sensitive watersheds (Camp Creek, Tom Vawn and Eagle Creek), with easily eroded soils, and specific reaches of the main channel, supply disproportionate amounts of material, causing long-term turbidity.

X-ray diffraction analyses of suspended sediments, and the clay fraction of soil samples showed a predominance of smectites. Significant amounts of amorphous material were associated with the smectites in samples capable of creating long-term turbidity in the Prineville Reservoir.

Field reconnissance of watershed land use and management indicated situations where domestic animal grazing, timber harvest and associated road building, and fire prevention practices which may unduly contribute to erosion and turbidity problems. Primary consideration of soil-hydrology relationships in land use planning and management is needed to reduce the severe erosion observed on certain tributaries. Particular attention should be directed toward minimizing erosion on soil with characteristics associated with long-term turbidity.

Reservoir management and control should include recreational boating regulations to reduce shoreline turbulence. Limitations on boat draft, engine size, and total use will aid in reducing summertime shoreline turbidity.

Recommended conservation and stabilization practices include:

1. Riparian fencing with controlled access for protection of stream bank soils, channel, and vegetation from external forces;
2. Retention of felled junipers, and continued felling, to extend soil moisture for germination and growth of grass;
3. Selective stream channel clearing to reduce debris-caused dams;
4. More awareness of soil-hydrology interrelationships by management agencies and private owners to better protect against turbidity-causing practices; and

5. Range management designed to maintain and improve grass cover and range condition overall.

Turbidity in Prineville Reservoir as Related to Soils and Hydrology

by

Clair Ellwood Silvernale

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1976

APPROVED:

Redacted for Privacy

Professor of Soil Science
in charge of major

Redacted for Privacy

Head of Department of Soil Science

Redacted for Privacy

Dean of Graduate School

Date thesis is presented March 18, 1976

Typed by A & S Bookkeeping/Typing for Clair Ellwood Silvernale

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. M. E. Harward for his guidance, advice, and assistance, antecedent to and concommittant with the preparation of this thesis. Special thanks are extended to Dr. G. H. Simonson for his valuable contributions, and Dr. Joel Norgren for the many stimulating discussions that were to this dissertation as leavening is to bread.

Finally the author wishes to express his deepest heartfelt thanks to his wife Sonce. Her encouragement, patience and understanding have given me the support necessary to pursue the requirements for this degree.

The study was carried out as part of Oregon Agriculture Experiment Station Project 38--Sources and Nature of Turbidity in Selected Oregon Reservoirs.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table		Page

LIST OF FIGURES

LIST OF PLATES

TURBIDITY IN PRINEVILLE RESERVOIR AS RELATED TO SOILS AND HYDROLOGY

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 has been under study by the Oregon State Wildlife Commission. Concern over water quality in the Prineville Reservoir and its downstream discharges 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 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

---

[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 study.

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) 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 itself 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 the stream above and below the reservoir and had similar turbidity levels, indicating the watershed as the dominant source. The watershed soils are known to have generous amounts of smectite present and are badly eroded in places.

PURPOSE, SCOPE AND OBJECTIVES

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

Because clay tends to remain in suspension 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. Evaluation of sediment transport, turbidity, and clay mineralogy of the soils in the Crooked River drainage basin contributing to the turbidity was within the scope of the study.

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 management with respect to erosion and turbidity.

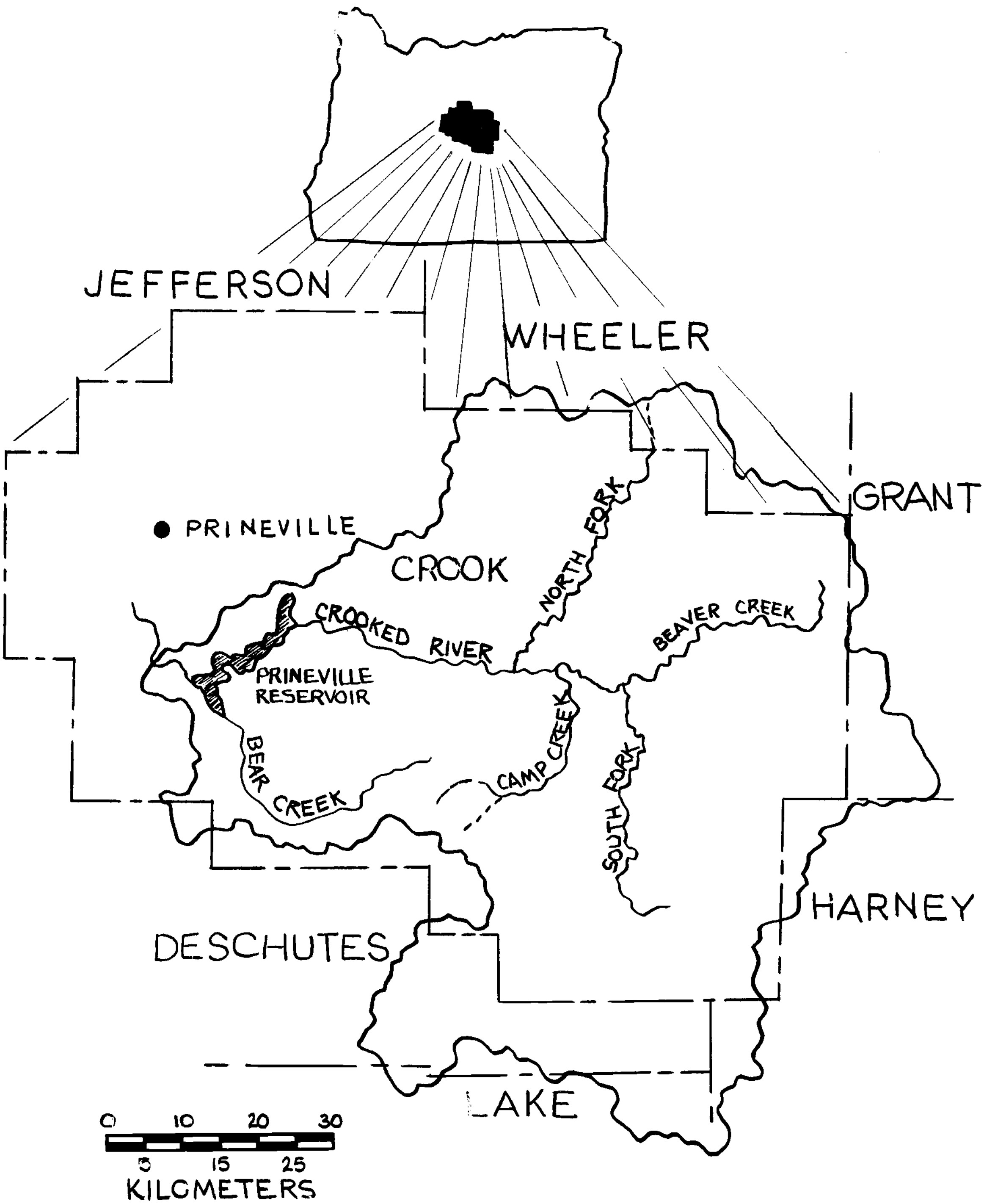


Figure 1. Geographic location of study area showing the major tributaries of the upper Crooked River Basin and the Prineville Reservoir.

DESCRIPTION OF THE STUDY AREA

The Prineville Reservoir is in the Upper Crooked River subbasin of the Deschutes River Basin. This subbasin encompasses about 631,323 hectares. 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 1.92 km. The major portion of the study area occurs below 1219 meters. In association with elevation differences, there are variations in total precipitation, form of precipitation, temperature, and vegetation. At lower elevations, the major part of the yearly precipitation is rain; at the higher elevations the major part is snow. This pattern is reflected in the bi-modal hydrograph of runoff for the basin. 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 (Walker *et al.*, 1967).

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 1). 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 Percentage That Each Major Tributary[a/] is to the Total Area of the Upper Crooked River Drainage Basin.

Major Tributary	Area		Percent of total
	km^2	hectare	
Bear Creek	541	54,065	8.7
Beaver Creek	1,300	131,346	20.6
Camp Creek	448	44,917	7.1
North Fork	827	83,021	13.1
South Fork	2,085	208,434	33.0
	5,201	521,783	82.8[b/]

Total watershed area 6,314 km^2 (631,416 hectares)

[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.

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, 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 A). 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 sub-basins occur in the Maury Mountain range and appear to be contributing considerable sedimentation to the reservoir. For these reasons 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 were 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 the upper extremities of the reservoir were survey staked in the fall of 1972 to determine the bank erosion along this portion of the river.

Cross sections of the stream channel at each sampling location were determined and reference stakes placed 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 accepted 0.6 depth measurements as determined by current meters (Schwab, G. E., *et al.*, 1971).

Laboratory Analysis

Water Samples

Suspended Sediments. Turbidity of the water sample suspensions was measured using a HACH Turbidimeter Model 2100A. The degree of turbidity was recorded in Formazin Turbidity Units (FTU). Problems were encountered when suspensions had high turbidities in excess of 1,000 FTU. Registered readings were frequently in the 200-400 FTU range and their reliability was uncertain. Samples that exceeded 100 FTU were routinely diluted and checked against the original reading. This routine increased the reliability of recorded values.

Often, knowledge of the actual concentration of suspended sediment is desired. FTU readings were correlated with gravimetrically determined suspended solids (Silvernale et al., 1976). The correlation is offered 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). Conductivity was determined on a 25 ml aliquot using a conductivity bridge. The results are reported as micromhos per square centimeter (μmhos/cm^2). The pH of the water was determined 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 1N NaCl. Separate portions of the recovered clay were saturated with Mg and K using 1<u>N</u> chloride salts and washed 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, solvation 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 for organic matter removal. Since the soils were 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 pipette analysis.

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^{o}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 was used for washing to prevent hydrolysis of the saturating ion. After this wash, ammonium acetate was used to replace the previously attached sodium. The supernatant containing the replaced sodium was recovered by centrifugation (Richards, 1954). Cation exchange capacity (CEC) was determined by measuring the displaced sodium on an 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 used because it recovered 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 screen after drying to determine 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 an estimate of 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).

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, sources 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.

Sediment deposits were also measured in the reservoir to estimate the siltation that has taken place since the inception of the reservoir.

Sediment Load to the Reservoir

Theoretically the amount of sediment contributed to the reservoir could be determined by continuous measurement of sediment transport at the points where the Crooked River and Bear Creek discharge into the main reservoir body. Limited funds, time, and personnel precluded such exhaustive work and, therefore, was beyond the scope of the study. Consequently, the major tributaries were monitored during periods of high runoff for the runoff seasons of 1972 and 1973, with emphasis on the peak events during these periods.

The data for runoff periods during winter 1972 and 1973 on Crooked River and Bear Creek are presented in Silvernale *et al.*, (1976).

Tributary Sediment Loads

Turbid waters from other tributaries to the Crooked River were likewise sampled at peak flow. These sample stations were used to monitor the contribution of smaller tributaries to the overall sediment load carried to the reservoir.

RESULTS: MAJOR WATERSHEDS

North Fork

Most of the North Fork 830.2 km^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, now Crater Lake, in the Cascades of Oregon. 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 predominantly amorphous material in the clay fraction, with only a suggestion of smectite type clays.

Committee Creek soils are represented by watershed soil samples CE1A 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 have small runoff, 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.

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 event, 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.

Once water is concentrated in a pumiceous soil, transport is easily achieved. Because infiltration capacities are usually very high, the probability of water concentrating and forming channels is not normally of concern. However, where distrubance may cause water movement in channels to be impeded, or water bars are not provided during road construction, concentration of runoff causes rapid erosion.

Nature of Sediments

Sediment transport versus stream discharge for North Fork, Camp Creek, and Bear Creek (Figure 2) 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 the sediment load which the North Fork contributes is considerable. 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 5,550m^3. 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

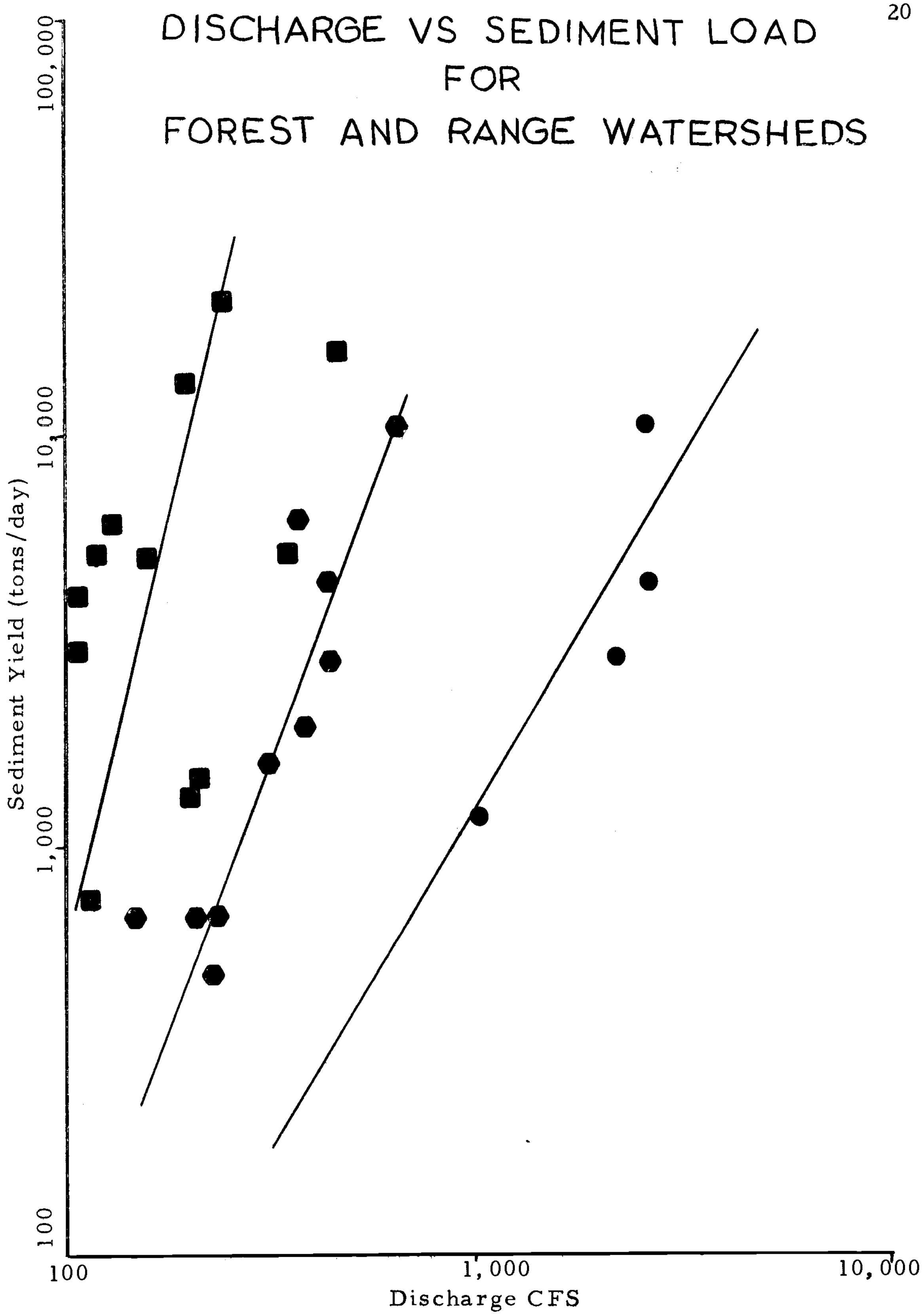


Figure 2. Sediment yield versus discharge for the Bear Creek, Camp Creek, and North Fork watersheds during the major runoff events of Water Year 1971-1972.

downstream. 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.

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.

Sediments coming from North Fork reflect, in part, their pumiceous origin. They are relatively coarse grained and their x-ray diffraction patterns suggest a relatively high proportion of amorphous material (Appendix B).

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 rest 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 (Table 2, February 19, 1972) 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 to the sample

Table 2. North Fork Suspended Sediment Characteristics; Quantities Produced and Associated Water Chemistry for Runoff Events in 1972 and 1973.

Sample Date	Sample No.	PPM Ca	PPM Na	PPM Mg	K	FTU	Conductance (μmhos)	pH	Particle Size (%<50μ)[d]
01/22/72	901	8.0	4.2	2.4	T[a]	35.0	202	7.0	ND[e]
01/23/72	902	9.0	3.3	2.1	T	4.4	202	6.8	ND
02/19/72	903	12.0	4.5	2.4	0.08	150.0	155	7.1	98
02/21/72	904	10.0	3.6	2.4	0.38	19.0	171	7.0	54
03/13/72	905	2.8[b]	8.4	0.9	1.06	95.0	236	7.0	64
03/14/72	906	8.0	2.4	0.9	0.02	30.0	239	6.8	88
03/15/72	907	10.0	2.7	2.7	0.32	25.0	239	7.0	ND
04/07/72	908	12.0	2.1	1.5	T	6.2	-	-	ND
09/20/72	909[c]	27.0	10.8	5.4	1.38	9.5	-	-	71
01/19/73	910[c]	14.0	3.0	2.1	0.08	7.2	341	7.5	

[a]Trace (less than 0.02 ppm). [b]Strontium not used as an anticomplexing agent; therefore Calcium measured is that excess not tied up as complex. [c]Low flow characterization sample. [d]1 micron (μ) is 1/1000 of a millimeter, therefore this value is equivalent to the percent less than 0.05 millimeters. [e]Not determined; insufficient concentration to obtain particle size information.

point. Based on stream gradients of fifty-six feet per mile and velocities of 3 to 10 feet per second[2/] it is readily apparent that materials of this particle size will be carried beyond the sampling point.

Materials of this size (<50μ) would be easily transported from the North Fork down the Crooked River to the reservoir. The finer portions of these materials could remain in suspension in the reservoir. This would 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. 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 observer, but suspension does not persist in the reservoir. The 144 hour (hr) long-term turbidity of such soil material in reservoir water was usually far below that detectable to the naked eye (Silvernale et al., 1976).

[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.

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. Conductivities range from 155 to 341 μmhos/cm. 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 2).

South Fork

The South Fork Drainage area encompases some 2,085 km^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 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, comparison of runoff data with that of the same period for other basins, shows that South Fork ranks third in total runoff for the period considered.

Beaver Creek, North Fork, and Camp Creek watersheds decrease in order of size. However, the discharge of the North Fork and Beaver Creek watersheds, usually exceeded that of the South Fork. This trend held throughout the water year. The discharge per unit area (cfs/km^2) for the storm period 3-13-72 to 3-15-72 was 4.5 and 8.9 for Beaver Creek and North Fork, respectively, compared to only 1.9 for the South Fork.

Factors which explain this apparent anomaly include in addition to presence of internally drained sub-basins of the watershed, 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 20-25 cm 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 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, convective storms are not frequent to the lava plains of the watershed.

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. The turbidity values of the stream passing the sampling point were low (Table 3), and most of the sediments were of small particle size.

Usually more than 90% is less than fifty microns ($< 50\mu$) in diameter. Material of this size (silt and clay) is readily carried to the reservoir. The low FTU suggests that the material in suspension and being transported, even though predominantly clay size, has little

Table 3. South Fork Suspended Sediment Characteristics; Quantities Produced and Associated Water Chemistry for Runoff Events in 1972 and 1973.

Sample Number	Sample Date	Instantaneous Sediment Load (ton/day)	Turbidity (FTU)	Percent of Sediment Sample (<50μ)	Secchi Disc.[a]	meq/liter Na	meq/liter Ca	Na/Ca Ratio
1101	01/22/72	149	40	ND[b]	ND[b]	0.78	0.95	0.82
1102	01/23/72	ND[b]	17	ND[b]	14	1.83	0.75	2.44
1103	02/20/72	108	27	34	12	0.91	0.45	2.0
1104	03/13/72	1517	50	93	5	0.83	0.70	1.19
1107	03/14/72	2690	30	92	7	0.87	0.85	1.0
1108	03/15/72	1038	25	93	12	1.61	1.05	1.51
1109	04/07/72	7	13	91	4-5[c]	1.35	1.55	0.87
1112	09/20/72	ND	4	ND	ND	2.52	1.10	2.32
1110	04/27/72	ND	8	92	ND	ND	ND	ND
1113	01/19/73	625	9	81	ND	2.70	1.05	2.65

[a] Inches below the surface of the stream.

[b] ND--not determined.

[c] Feet below the surface of the stream.

potential to cause long term turbidity (Table 3). This is further supported by the depths to which the Secchi Disc can be seen beneath the surface[3/].

Clay Mineralogy

X-ray diffraction of the sediments show that the clay size fraction has small quantities of 2:1 type clay minerals (Appendix B). It appears for the most part that the sediments are amorphous to x-rays and high in non-crystalline components. This indicates that the tuffaceous sediments reported by Walker *et al.*, for this area are not noticeably contributing to the material in suspension; tuffaceous sediments usually have well defined x-ray patterns.

The source of the non-crystalline material is thought to be weathered from recent volcanic tephra.

Water Chemistry

Water originating from the South Fork watershed generally has a sodium to calcium ratio (Na/Ca) greater than one and occasionally exceeds two (Table 3). Conductivity measurements and pH generally reflect the presence of excess sodium to calcium. Conductivity

---

[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 comparing streams of different turbidities.

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 (Richards, 1954). 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. When these waters and their dissolved solids arrive at the reservoir the concentration, because diluted[4/], could act as a dispersing agent.

Beaver Creek

Beaver Creek drains some 1300 km^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 occupies the easternmost portion of the study area and is the second largest watershed.

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 forestlands. Because their headwaters are within the high elevation forestlands, they receive spring runoff due to snowmelt.

[4/] Sodium in concentrations of 2.2 meq per liter is used in laboratories as a dispersing agent for some clay systems.

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 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.

The major runoff event normally occurs in March 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 35-43 cm 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 forest areas is irrigable valley and basin lands that have moderately deep soils used for alfalfa and small grain crops (Norgren et al., 1969). It is well documented that vegetation stabilizes stream banks (Hudson, 1972; U.S.D.A. 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 simialr 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 4). Samples 201 and 210 were allowed to equilibrate for 72 hours at room temperature and their turbidity recorded. It was found that the water samples did not remain noticeably turbid. The turbidity values recorded were 9 and 5 FTU respectively, which are well below turbidity levels for this basin (Department of Environmental Quality Water Quality Standard, 1971). This indicates that sediments originating from the Beaver Creek drainage would not noticeably contribute to turbidity in the reservoir.

The sediment loads reaching the Crooked River from Beaver Creek are small when compared to the Camp Creek and Bear Creek watersheds (Tables 5 and 7), 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.

Table 4. Beaver Creek Suspended Sediment Characteristics; Quantities Produced and Associated Water Chemistry for Runoff Events in 1972 and 1973.

Laboratory Number	Sample Date	Instantaneous Sediment (tons/day)	Turbidity (FTU)	Secchi Disc. (inches)	Elemental Concentration meq/liter				Conductance (μmhos/cm^2)	pH
					Ca	Na	Mg	K		
201	01/22/72				0.70	0.26	0.25	0.02	128	6.9
202	01/23/72	523	43 (9)[a]	8	0.85	0.39	0.30	0.02	169	7.2
203	02/20/72	626	67	8	1.20	0.30	0.25	0.04	139	7.1
204	03/13/72	10,533	160	2	0.80	0.30	0.25	0.02	155	7.0
205	03/14/72	5,846	40	5	0.80	0.33	0.30	0.02	118	7.3
206	03/15/72	2,765	42	8	1.20	0.34	0.32	0.02	112	7.3
207	04/07/72	ND	10	18	1.40	0.47	0.48	0.01	115	7.9
208[c]	09/20/72	5	34	ND[b]	1.85	1.50	0.98	0.04	124	8.4
209	01/19/73	ND	ND	ND	2.55	0.43	0.32	0.01	147	7.4
210	01/19/73	103	18 (5)[a]	ND	0.95	0.34	0.33	0.02	102	7.2

[a] FTU after standing undisturbed for 72 hrs.

[b] ND--not determined.

[c] Low-flow characterization sample.

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 B) 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 for amorphous material. In view of the low FTU values for the Beaver Creek sample (Table 4) no laboratory analysis for amorphous material was made.

Water Chemistry

The average sodium to calcuim ratio (Na/Ca) for Beaver Creek is generally 0.34, except during low flow, such as that for sample 208 (Table 4). 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.

Conductance values are low and range from 102 μmhos/cm^2 to 169 μmhos/cm^2 (average 132.8 μmhos/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 (Richards, 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 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 at the confluence with the Crooked River to 1,816 m at Arrow Wood Point in the Maury Mountains. A predominance of the runoff comes from these mountains and the Logan Butte region (elevation about 1,585 m). 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 6 meters 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 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 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 establishment 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].

Nature of Sediment

Sediment concentrations originating from Camp Creek are high (Table 5) 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.

One apparent fact from the data 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, and cause turbidity in the reservoir.

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 B) 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 particle 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,

---

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

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 (Plate 1). Smectite 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 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 16 ha). Silt and plant debris covered a portion of the access road to a depth of about 10 centimeters. 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

Table 5. Camp Creek Suspended Sediment Characteristics; Quantities and Associated Water Chemistry for Runoff Events in 1972 and 1973.

Laboratory Number	Sample Date	Instantaneous Sediment Concentration (tons/day)	Turbidity (FTU)	% < 50 μ[a]	Elemental Concentration meq/liter					Conductance μ mhos/cm^2	pH
					Ca	Na	Mg	K	Na/Ca		
301	01/23/72	483	400	ND[b]	ND	ND	ND	ND	ND	56.6	7.3
302	01/22/72	4323	350	ND	1.15	1.00	0.30	0.03	0.87	69.8	7.4
306	02/19/72	682	380	ND	1.40	0.78	0.32	0.02	0.86	77.5	7.5
307	02/20/72	1953	390	ND	1.05	0.78	0.30	0.02	0.74	80.6	7.2
320	03/06/72	1666	320	96	0.70	0.65	0.22	0.04	0.93	77.5	7.6
325	03/07/72	697	340	97	0.90	0.56	0.22	0.04	0.62	77.5	7.5
326	03/13/72	2798	320	97	0.65	0.36	0.06	0.03	0.55	77.5	7.7
331	03/14/72	654	300	93	1.00	0.70	0.27	0.04	0.70	77.5	7.7
332	03/15/72	495	180	66	1.10	0.70	0.33	0.05	0.64	71.3	7.6
334	09/20/72	2	4	ND	1.85	2.87	0.84	0.14	1.55	ND	8.6
335	11/26/72	ND	66	71	1.85	2.26	0.81	0.11	1.22	46.5	7.2
336	01/19/73	39	31	84	1.40	1.96	0.61	0.06	1.40	69.8	7.9
337[c]	05/28/73	ND	130	84	0.60[d]	2.83	0.72	0.07	4.72	54.2	8.2

[a] Percentage of material passing a 300 mesh sieve.

[b] ND, not determined.

[c] Sample taken from Severance Reservoir on Camp Creek.

[d] 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.

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 thus higher readings result.

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 dissolution to take place and more entrainment of the ions being measured. The increase in low-flow sodium to calcium ratio (ave. 1.39) values indicates 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 5). This probably was the result of flushing and leaching of the salts precipitated when the water receded in the summer to low flow levels.

Conductance values are quite low for the runoff waters, suggesting a low level of total salts in solution. The relatively low sodium

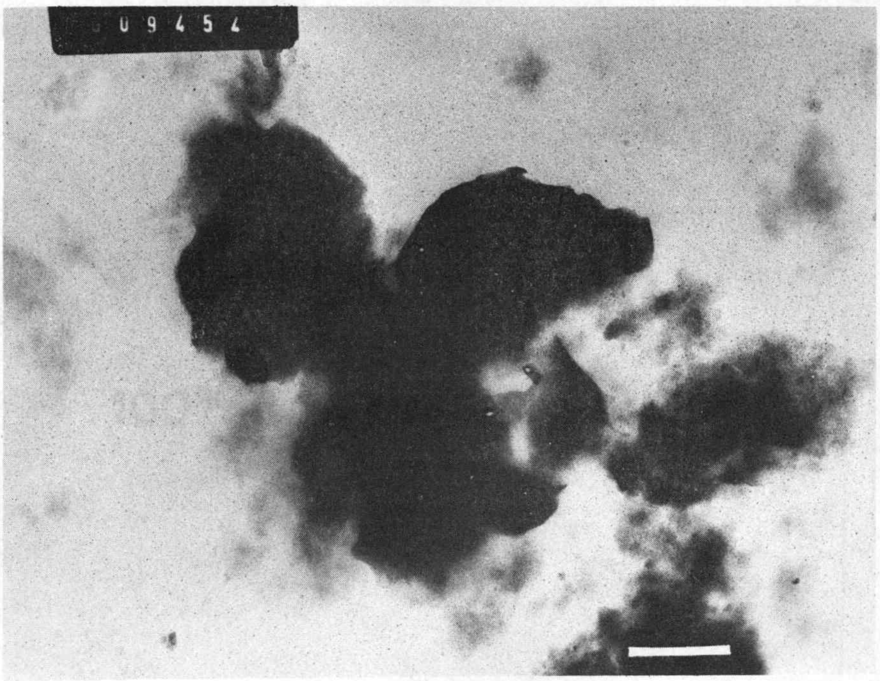


Plate 1 Electron micrograph showing 2:1 clay minerals coated by amorphous material for suspended sediment sample from Camp Creek. White bar lower right represents one micron (1μ).

to calcium ratio indicates that sodium salts 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 remained turbid for weeks. Other samples from this watershed were observed to remain turbid for even longer periods while waiting laboratory analysis. These samples had been refrigerated at 34^{o} - 38^{o} for several months.

Conant Creek

Conant Creek drains 42.1 km^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. Most of the

Table 6. Conant Creek Suspended Sediment Characteristics; Quantities Produced and Associated Water Chemistry for Runoff Events in 1972 and 1973.

Laboratory Number	Sample Date	Turbidity (FTU)	Instantaneous Sediment Concentration (tons/day)	% <50μ[a]	Elemental Concentration (meq/liter)				pH
					Ca	Na	Mg	K	
401	01/22/72	250	74	90	1.75	1.39	1.08	0.08	7.8
405	02/19/72	175	33	44	1.95	1.09	0.96	0.08	7.8
406	02/20/72	250	65	ND[b]	2.55	0.74	1.27	0.09	7.8
407	03/15/72	275	33	70	2.70	1.09	1.55	0.09	7.8
408	04/27/72	150	ND	ND	2.85	0.78	1.51	0.06	7.7
409[c]	09/20/72	ND	ND	ND	3.15	0.74	1.90	0.08	8.2

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

[b] ND--not determined.

[c] Low-flow chemical characterization sample.

watershed is privately owned and is used as pasture - rangeland and for dryland wheat and rye.

In the early 1970's, 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 in some areas. Because of soil and erosion characteristics, the lower reach commonly has vertical walls while the upper reach of the channel has banks near 1:1. Poorly constructed and ill-placed roads were noted to be gullied and rutted. Construction and engineering techniques appeared 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 active, 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 during high runoff events. Turbidity values up to 275 FTU's were recorded (Table 6). 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.

A short distance below the sampling station, a decrease in stream gradient and velocity causes the coarser material (> 2mm) to be deposited. Estimated sediment volume deposited near the sampling station after the spring runoff was 2392 m^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 75.7 hectoliters per minute 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 6).

Clay Mineralogy

The <50μ fraction of suspended sediment contains montmorillonite as the major constituent (Appendix B), with a minor occurence of zeolite. The diffraction patterns depict a well crystallized montmorillonite.

A broad increase in background at the diffraction angle of 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 calcium/liter and 1.02 meq sodium/liter. 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 7.5 pH units, while conductivity values have an average reading of 40 μmhos/cm^2. Halogen salts, expecially those of sodium, give rise to higher conductivity readings if present in sufficient amounts.

Bear Creek

Bear Creek drains 541 km^2 and occupies the most southwestern portion of the Upper Crooked River Basin (Figure 1). 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 boundry. Elevations range from reservoir full pool level at 990 meters to west Maury Mountain with an elevation of 1,846 meters. Nearly all of Bear Creek is range, both public and private, except for about 10 km^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. Little Bear Creek accumulates runoff from the sparsely vegetated highlands on the southwest end of the Maurys. Much of the valley lands, from the Sheep Rock portion of the drainage to the confluence with the main stream, are in crop production.

Bear Creek's stream gradient profile is noticeably parabolic, becoming very steep near the Rodman Rim rimrock country. The gentler gradient throughout much of its reach has resulted in a well defined stream channel. In some portions severe downcutting has resulted in 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. Recognizable stream aggradation is occurring in areas directly affected by the changes. Other areas are in need of improved management programs and some programs are now in implimentation stages by state, federal, and local agencies. Recent reports 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

Table 7. Bear Creek Suspended Sediment Characteristics; Quantities Produced and Associated Water Chemistry for Runoff Events in 1972 and 1973.

Laboratory Number	Sample Date	Instantaneous Sediment Load (tons/day)	Turbidity (FTU)	%<50μ	Elemental Concentration (meq/liter) Ca	Na	Mg	K	pH
100[a]	01/22/72	5390[a]	484[a]	97[a]	1.80[a]	0.71[a]	0.66[a]	0.03[a]	7.5[a]
111	01/23/72	768	225	86	2.25	1.00	1.10	0.03	7.5
112	02/20/72	672	226	ND[b]	2.10	0.35	0.98	0.03	7.4
114	03/13/72	16632	7500	60	1.40	0.04	0.60	0.03	7.6
115	03/14/72	5088	145	72	2.00	0.04	0.70	0.03	7.5
116	03/16/72	1368	225	77	1.45	0.04	0.62	0.03	7.0
117	03/20/72	744	180	43	2.30	0.13	0.82	0.03	7.4
118	04/18/72	ND	49	74	1.25	0.26	0.98	0.02	8.0
119	12/17/72	3	17	85	1.25	0.30	0.70	0.01	7.8
120A[c]	12/18/72	9	26	90	3.34	1.56	1.25	0.06	8.2
120B[c]	12/18/72	10	33	89	2.35	1.52	1.32	0.02	7.6
121	12/22/72	22	83	87	2.35	1.26	1.40	0.03	7.7
122	12/26/72	9	9	73	2.70	1.65	1.52	0.03	7.9
123	01/15/73	10	46	86	2.45	1.48	1.38	0.03	7.6
124	01/26/73	11	31	91	2.80	1.48	1.52	0.03	7.8
125	01/20/73	6	24	74	2.80	1.52	1.58	0.03	7.8
126	02/28/73	16	145	83	1.35	1.43	1.02	0.05	7.1
127	03/02/73	13	50	ND	-	-	-	-	-
128	03/05/73	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.

the main Bear Creek drainage is composed of Eocene and Oligocene andesite flows, breccias, and sedimentary rock (Walker *et al.*, 1967). The main stream has etched its channel in the older John Day Formation and the Quaternary alluvial deposits.

Bear Creek Buttes are volcanic landforms composed of basalts and andesitic agglomerates that have been modified by 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 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.

Nature of Sediments

Sediment loads from Bear Creek are exceedingly high for the related discharge rates (Figure 2). About 25-40% of the sediment being transported during periods of high runoff is greater than the fifty-micron particle size (Table 7). This indicates the stream's competence for large sediment loads at small discharge volumes and suggests that the bed load is of major importance.

Sediment transport of material in the less than 50μ size fraction is commonly about 78 kgm/ha/day and as much as 290 kgm/ha/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. This latter figure would more nearly represent the interim sediment discharge for the watershed, excluding peak discharge periods. 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 noted throughout the sampled tributaries to the Crooked River and was the result of the unusually low rainfall for water year 1972-1973.

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 montmorillonite, generally well crystalized, with a 7.2Å kaolinite peak about 20% the height of the montmorillonite peak. 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 these 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.

Analysis by TEM on the material being transported indicated a small proportion of 2:1 clays, but a larger amount of organic material present. There was evidence of algal bodies present. Algae are usually dormant during the colder months and therefore their presence would reflect poor storage prior to receipt of samples. Other TEM micrographs from the 1972 runoff were suggestive of fine particles of kaolinite in suspension along 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 low when compared to the other watersheds. This suggests that the water coming from the Bear Creek watershed is lower in sodium and higher in calcium (Table 7) than that in the reservoir and other streams analyzed. Calcium tends to act as a flocculating agent of materials causing turbidity. The effect is really fortuitous because, if one considers the sediment transported by Bear Creek and its associated clay mineralogy, the potential for continued turbidity in the reservoir would be correspondingly large. However, a short response time and high intensity short duration rains reduce the effect of the calcium present in the soils on the watershed. This effect explains why sediment transporting runoff from summer freshets apparently give rise to more turbidity in the reservoir.

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.

<u>Eagle Creek</u>

Eagle Creek drains approximately 25.9 km^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 and the 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 orginates 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 <u>et al.</u>, 1969) lining the channel proper are visibly disturbed and exposed to erosional processes within the watershed. These exposed red soils are considered suspect for the reddish discolorations. The origin of green discolorations were more elusive but 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 smaller watershed. Discharge rates were usually 5-6 cfs and the water turbidity values ranged up to 290 FTU (Table 8).

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 and size are both important, as discussed in the soil analysis section of this report.

Clay mineral analysis of the suspended sediments reveals the presence of 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 B) 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

Table 8. 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	0.40	0.65	0.05	0.03
	602	01/23/72	150	95	6.8	161	0.45	1.1	0.08	0.02
	603	02/19/72	250	83	6.9	163	0.55	1.2	0.02	0.04
	604	12/17/72	96	85	7.6	147	0.50	0.87	0.18	0.03
	605	12/18/72	215 (87)[a]	93	7.2	170	0.60	0.80	0.18	0.03
Lost	801	01/22/72	290		6.9	148	0.45	0.09	0.12	0.03
	802	01/23/72	200		7.2	141	0.55	0.09	0.15	0.03
	803	12/18/72	330		7.1	81	0.60	0.74	0.18	0.06
	804	12/17/72	420 (44)[a]		7.0	133	1.20	0.78	0.18	0.06
Newsome	144	12/17/72	11	73	7.5	45	2.45	1.17	1.05	0.01
	145	12/18/72	115	78	7.7	42	2.55	1.17	1.12	0.02
Drake	142	12/17/72	74	78	ND[b]	64	1.25	0.22	0.40	0.03
	143	12/18/72	64 (18)[a]	98	7.0	71	1.60	0.52	0.48	0.04
Tom Vawn	147	12/18/72	1120	98	7.6	53	1.30	1.22	0.32	0.04
Horse Heaven	97	01/22/72	48	65	7.1	110	1.45	0.61	0.38	0.04
	98	01/23/72	56	54	7.0	124	1.25	0.56	0.33	0.04
	99	02/19/72	200	73	7.1	124	1.20	0.46	0.26	0.04
	100	02/20/72	125	79	6.6	171	0.85	0.65	0.18	0.04
Wickiup	133	01/23/72	35	52	7.4	99	1.05	0.04	0.40	0.01
	134	02/19/72	880	65	7.2	122	2.05	0.36	0.40	0.01
Pine Stub	127	02/19/72	280	100	7.5	119	0.50	0.40	0.12	0.02

[a] Samples allowed to stand undisturbed for 72 hours to determine residual turbidity.

[b] ND--not determined.

to calcium ratio was 1.8. This ratio suggests that relative amounts of sodium may be sufficient 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 8) further supports this hypothesis. Values of conductivity ranging to 171 μmhos/cm^2 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 stream then flows beneath Highway 380 at the junction of Teeters Road. The sample station for the drainage was a large retangular concrete culvert at Highway 380. The drainage area encompasses 112.6 km^2, about one-third of which is forested, high-elevation, public lands. The high elevation portions of the watershed are geologically composed of Picture Gorge Basalts (Swanson, 1969). As noted for North Fork, these basalts 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). Red clayey soils known as Day-Ridgeway undifferentiated are formed from these formations (Norgren et al., 1969).

Stream sediments were sampled and analyzed for their contribution to siltation 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 after 72 hours settling time the samples remained turbid. Sample 804 illustrates this tendency toward continued turbidity (Table 8). 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 B) is a 7.2Å peak, which corresponds to a 1:1 clay mineral of the Kaolin Group 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.

<u>Newsome Creek</u>

Sherwood, Gibson, and Hammer Creeks are tributaries to Newsome. The 77.7 km^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 ashy soils of the north aspect have subdued the erosional processes that have given rise to high sediment transport in other watersheds of similar geology.

<u>Comments on Sediments</u>. Chemical and physical analysis of the suspended sediments indicate low concentrations and low turbidity values (Table 8). 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 allowed to concentrate on them. The erosion takes place rapidly and cuts deeply.

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 readings average 7.5 units.

Drake Creek

Wildcat and Shotgun Creeks are tributaries of Drake Creek. Essentially one-half of the 42.4 km^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 are classed as active (Swanson, 1969). The watershed of Shotgun Creek contains exposed Clarno Formation (Swanson, 1969), but its influence usually is not noted because the runoff 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 8). 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. The geology and soils of the Tom Vawn watershed are similar to those of the Camp Creek basin and the sediments have physical and chemical properties that are analogous (Table 8).

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 streams have short response times and 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 both in the channel and 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 8). Approximately one-half of each of the suspended sediment samples collected consisted of coarse sediments that may cause aggradation of the Crooked River channel but are not likely 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 probable sources of the color for this 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 section of the report, the portion of the Crooked River to be considered begins at the Beaver Creek sampling station (T17S, R23E. Sect. 7; Bench mark 1, 110. 5 m) and terminates immediately below the Prineville Dam. The Upper Crooked River, with a drainage basin of approximately 5, 776 km^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 in some areas below the town of Post, Oregon, is the old channel. Also visible are berm remnants used to contain and direct the water during repair. Reconnaissance in the

Table 9. Suspended Sediment Characterization and Quantification for the Crooked River--Water Year 1972.

Laboratory Number	Sample Date	Turbidity (FTU)	PPM	Instantaneous Load Suspended Sediment (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	15568	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.

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 again evident 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 meters of once stable and agriculturally productive riparian land were eroded and transported downstream toward the reservoir.

Because of the requirements that a sampling 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. The bridge spans the Crooked River 9.7 km upstream from the uppermost extremity of the reservoir. The bridge affords the necessary accessibility 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 9) reflect the tremendous potential that the Crooked River has for sediment transport. Sustained discharge rates of 203, 880 m^3/hr and sediment loads of 3,629 tons (metric)/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 9, samples 501-504) in January 1972, an average 146 tons (metric)/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 t that the usual sediment transport rate is more nearly in the range of 315-360 tons (metric)/hr and is estimated to double and possibly even triple during extreme events. A doubling was suspected to occur during the March 1972 spring runoff, and interpretation of several years discharge data indicates that event to have had about a five-year return frequency.

Of the suspended sediment passing the sampling station, 82% is less than 50 microns. 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 B). 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 somewhat poorly crystallized phases. 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 altitude 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 by Silvernale et al.(1976).

A survey conducted on streambank erosion reported that 64.4 km of the Crooked River (about the total length studied) is considered to be moderately eroded. This rating of 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 has occured, the water has removed 1910 m^2

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

and 37,677 m^2 over 91.4 m and 125 m channel bank meander segments, respectively. The figures are equivalent to volumes of 5,098 m^3 and 11,175 m^3 at the sites. These figures and other information, provide evidence of river migration and flood plain erosion. Because they represent only two meanders, they are obviously only small fractions of the total. Figures of this magnitude are considered low estimates of the erosion occurring. This is because of the difficulties encountered in measurement of sediment loads. Similar evidence has been recognized as valid in other regions too (Bondurant, 1970). 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.

Water Chemistry. The sodium to calcium ratio for the Crooked River is 0.75 meq/liter respectively. These figures reflect the dilution-averaging effect 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 10).

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 watersheds has a tendency toward neutrality. During low flows pH values increase to 8.3 units, which reflects the substantial increase in sodium to calcium ratio of 1.45. This trend was noted in about every watershed studied and is discussed in the section on Camp Creek.

Prineville Reservoir

The Prineville Reservoir has a total length of 23.3 km, a capacity of 19,112 ha-m and, when filled to pool elevation of 985.5 meters, has an area of 125.5 ha. The authorized use is flood control. Recreation and irrigation are two of the important benefits of the dam, constructed by the Bureau of Reclamation between 1958 and 1962, becoming operational in late 1962.

Shoreline Characteristics. Around the perimeter of the reservoir there 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.

Table 10. Chemical Analysis of Suspended Sediment-Water Samples From the Crooked River, 1972-73.

Laboratory Number	Elemental Concentration Ca	Na (meq/liter)	Mg	K	Conductance (μmhos/cm)	pH
1972 Runoff Year						
501	0.50	0.36	0.20	0.04	139.4	6.7
502	0.55	0.36	0.15	0.04	151.9	6.8
503	0.80	1.20	0.20	0.04	133.3	6.9
504	0.85	0.59	0.22	0.04	136.4	7.1
505	0.85	0.46	0.21	0.04	108.5	7.1
506	0.95	0.59	0.31	0.01	103.8	7.0
507	1.05	0.56	0.27	0.01	108.5	7.1
508	0.85	0.83	0.26	0.04	124.0	7.0
509	1.05	0.52	0.26	0.04	105.4	6.9
510	0.90	0.57	0.27	0.05	117.8	7.6
512	0.65	0.34	0.22	0.03	156.5	7.1
513	0.50	0.30	0.22	0.03	148.8	7.1
514	0.75	0.33	0.26	0.02	ND[b]	7.5
515[a]	1.75	2.54	1.14	0.12	ND	8.3
1973 Runoff Year						
516	0.75	0.53	0.36	0.05	99.2	7.4
517	0.85	0.55	0.35	0.04	155	7.5
518	1.45	0.72	0.40	0.06	124	7.4
519	1.40	1.21	0.68	0.08	57.3	7.1
520	0.30	0.48	0.30	0.04	108.5	7.5
521	0.32	0.56	0.35	0.05	108.5	7.7
522	0.26	0.35	0.20	0.03	325.5	7.1

[a]Low-flow characterization sample--September 17, 1972.

[b]ND--not determined.

In areas where protection 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 mechanizm 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 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 seldom 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 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 not significantly affected by erosion and appears stablized, 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. 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 61 m long and 15 m wide area studied, an estimated 1435.5 m^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 Mackenthun *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 the dam site graph (Figure 4). The temperature distribution shown is typical of temperate lakes and reservoirs that have sufficient depths for this phenomenon to occur.

The upper region 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 with obvious thermoclines, epilimnions, and hypolimnions present when graphed show the resemblance of the Prineville Reservoir profile to a hypothetical profile (Silvernale et al., 1976). Between data collection periods the reservoir was undergoing draw-down for irrigation 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 cyclic nature of the reservoir. 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, points worthy of note are: (a) an increase in turbidity below the thermocline (Figures 4 and 5), (b) a general lessening of turbidity near the dam (Figure 3), (c) decreasing turbidity in the profile with increasing thermocline depth (Figures 4 and 5), (d) a slight increase in surface turbidity just before algal bloom, and (e) the turbidity profile below the surface essentially remains more nearly linear even after the reservoir achieves a near uniform temperature profile (Figure 5).

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 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 4). 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) as a result of the sampling station's proximity to the penstock of the dam, a plume of clearer water may exist.

A general decrease in turbidity with increasing depth above the thermocline is thought to be a result of warmer, less dense and less turbid water. This is due to the reduced viscosity of the water and a continual exchange of oxygen caused in part by the blowing wind.

The increase in surface turbidity just prior to 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 where it literally covers the surface. With increased depth the algae become highly dispersed and almost imperceptible to laboratory instrumentation.

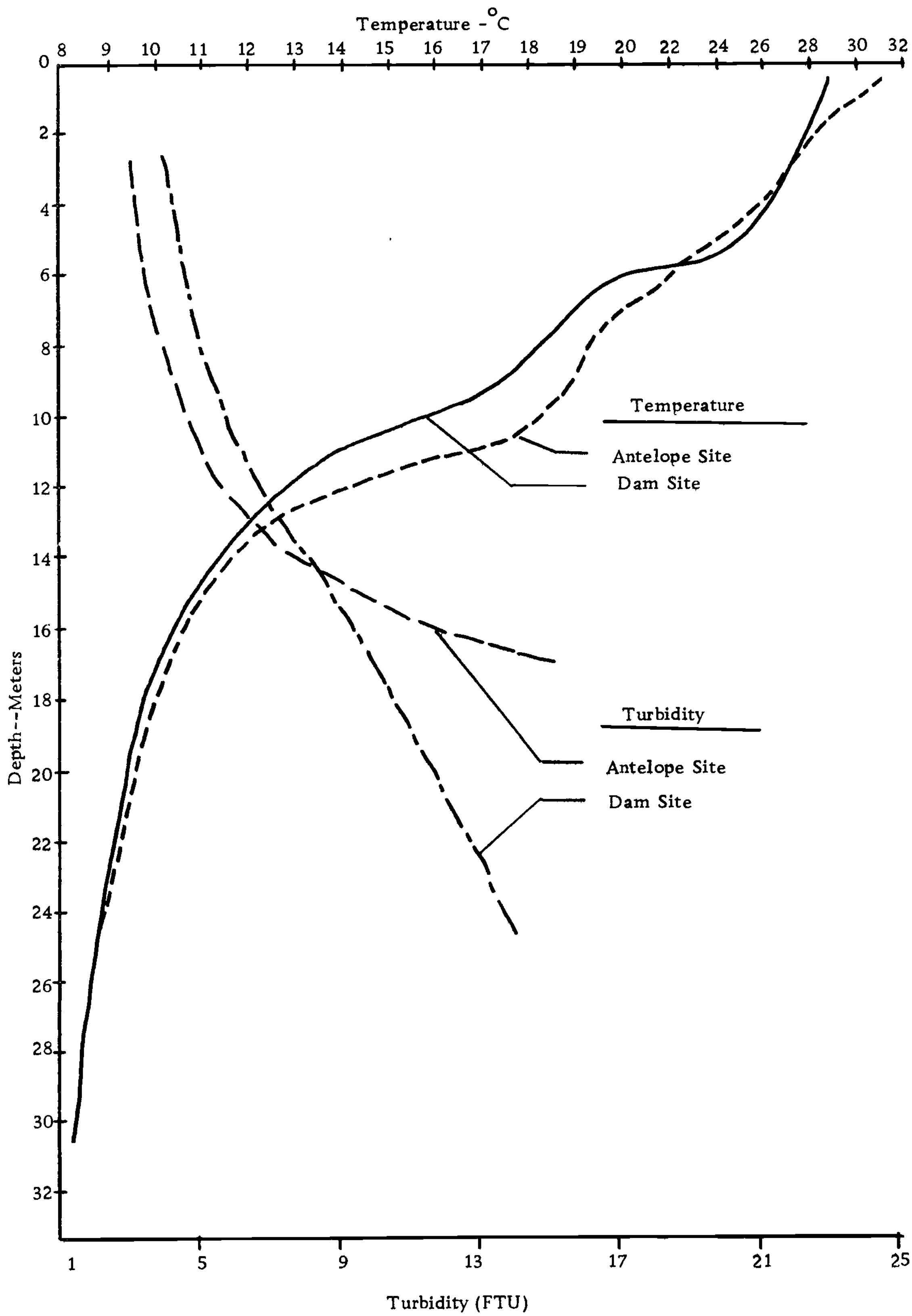


Figure 3. Prineville Reservoir Temperature Profile--August 8, 1972.

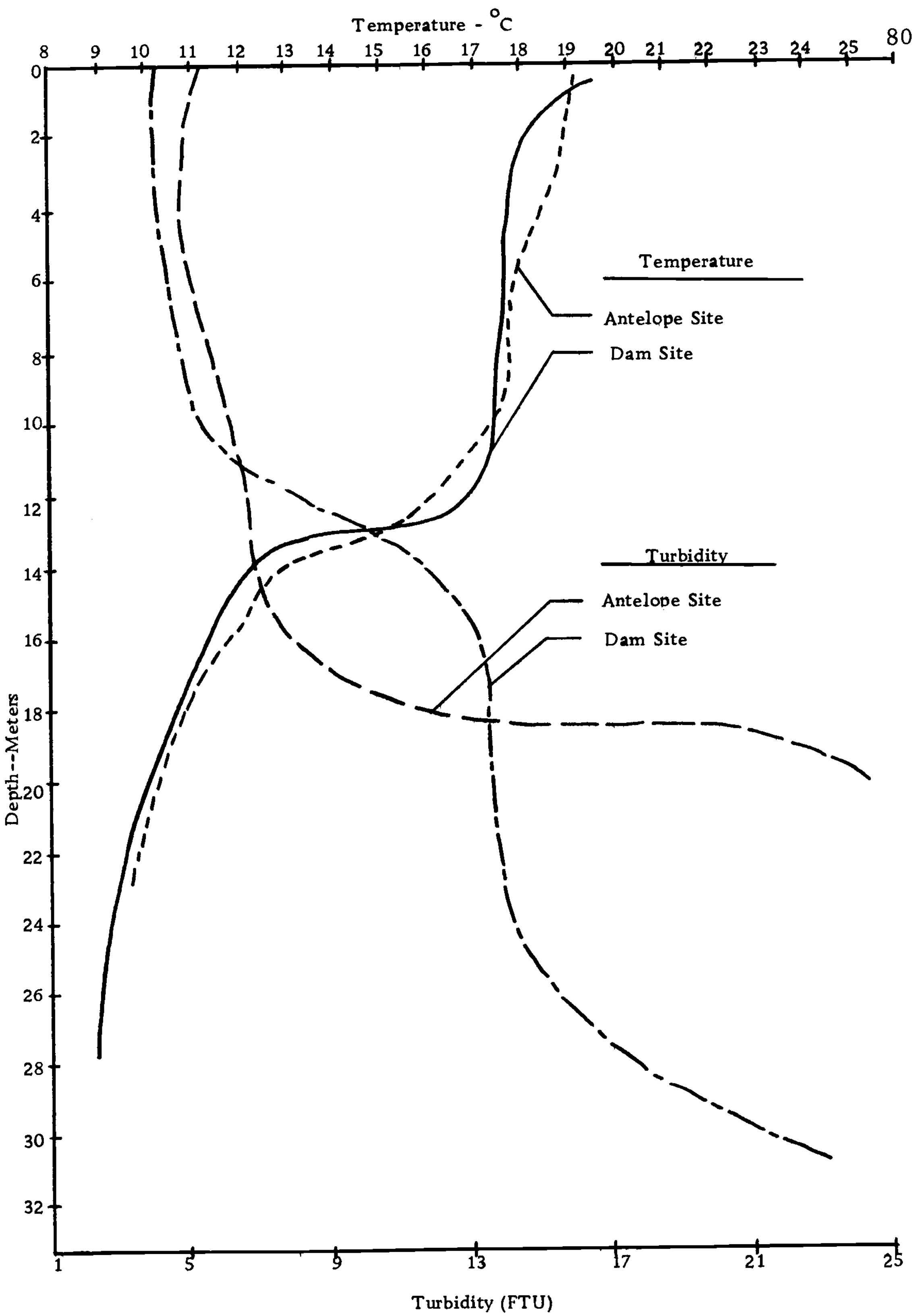


Figure 4. Prineville Reservoir Temperature Profile--September 13 and 15, 1972.

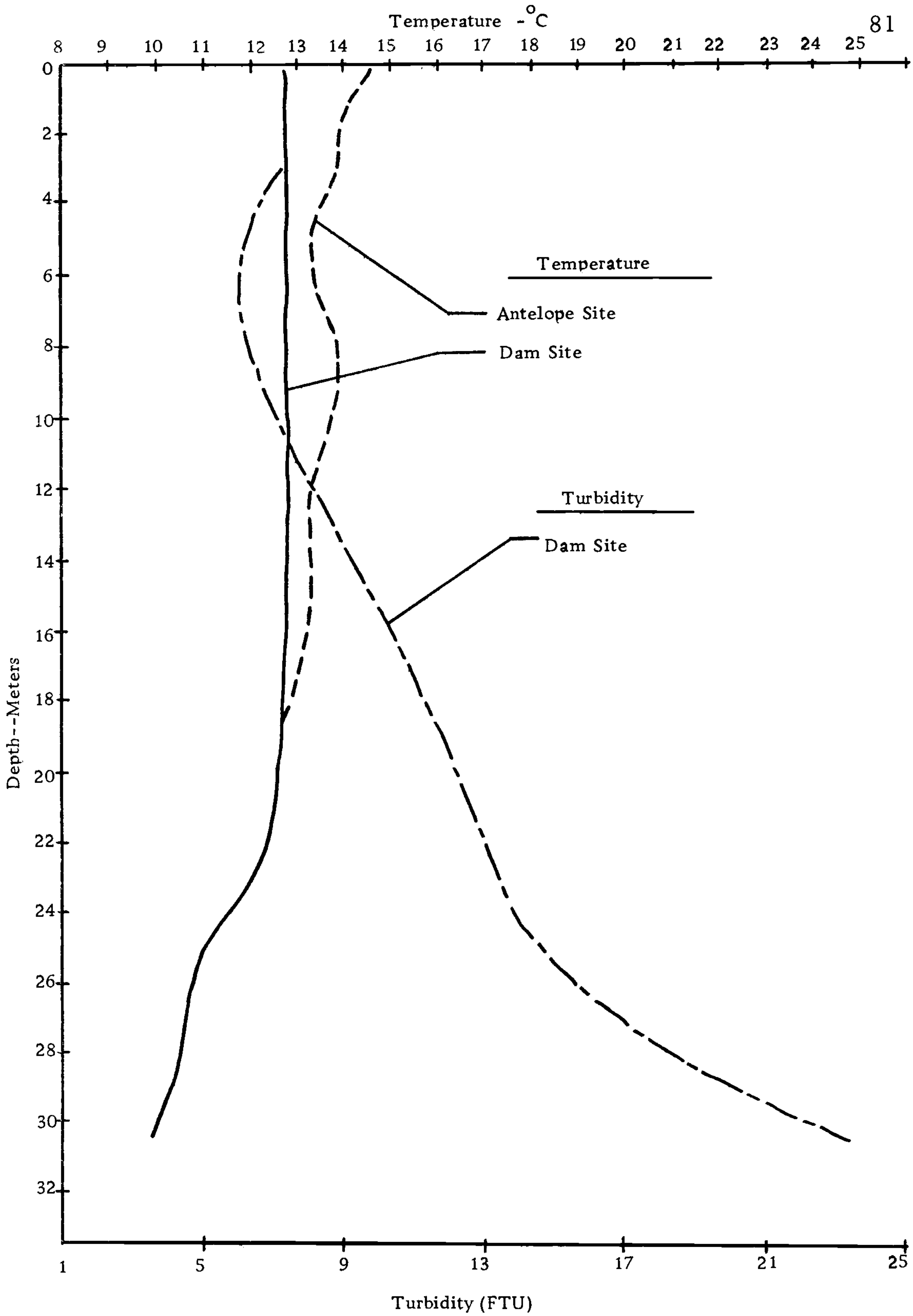


Figure 5. Prineville Reservoir Temperature Profile--October 20, 1972.

Even though the reservoir achieves a near uniform temperature profile in October, 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 discernible and several meters deeper.

Clay Mineralogy. Material suspended in the reservoir was subjected to study using transmission electron microscopy. Results indicate that the surface 6 m (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 (Jasper Point) (Appendix B). 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 in TEM micrographs is interpreted to be amorphous material. Also in Appendix B is a diffraction pattern for the suspended sediments obtained from the turbid waters at the reservoir's edge on on the Bear Creek Arm. The pattern shows the influence of the kaolinite bearing soft-red tuffaceous shoreline material characteristic of this arm.

Water samples obtained from below the thermocline studied by TEM (Plate 2) 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

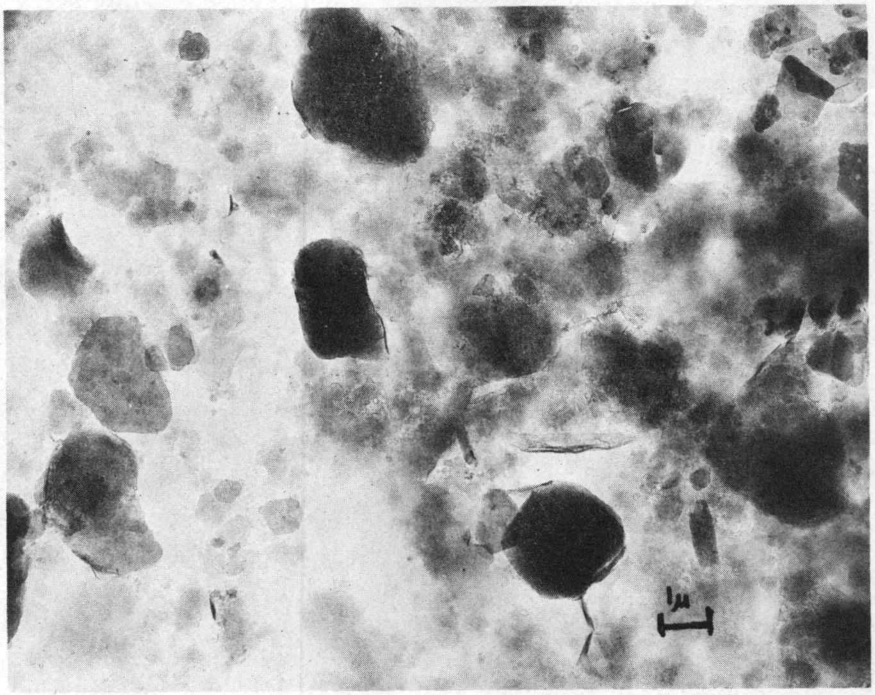


Plate 2: TEM of water sample obtained below the thermocline of Prineville Reservoir, June 21, 1972.

in concentration is reflected in the Temperature-Turbidity Profile graphs by increased turbidity below the thermocline.

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.

Reservoir samples ranged from 27% to 43% amorphous clays. These percentages are of interest because 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 respective 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 11).

The Crooked River is intermediate in amorphous materials between Camp and Bear Creeks. The two reservoir samples appear to be in the same order of magnitude.

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

Table 11. Amorphous Material in Suspended Sediments as Estimated by Dissolution Treatments.

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.

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 978.5 m). 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/] 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

---

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

the volumes extrapolated. Summation of the individual cross-sections and channel section volumes yields the total volume for the tributary arm of concern.

Inundated portions of the reseroir were not measured because sophisticated underwater measuring equipment was not available.

Sediment Volumes. The sediment deposition estimated to have occurred totals 38.9×10^6 m^3; this figure constitutes 2% of the total volume of the reservoir. However, it must be remembered that the true value is likely a few percent greater.

The figures for sedimentation of the reservoir average about 623,700 tons (metric)/year. Using Sediment transport data collected Silvernale, *et al.*, (1976) calculated an average of 47,635 tons (metric)/year being transported to the reservoir. Although this seems in great disparity, there are at least two reasons that will help explain the conflict; (1) the lack of continuous measurement and (2) record low precipitation for Water Year 73.

First, the data used to calculate the yearly contribution were derived during periods of peak runoff and then not continuously throughout those events. 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 volumes in the reservoir, see Silvernale *et al.*, 1976.

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 73 was deficient by record amounts.

By assuming Water Year 1972 (TR=5) as an "average" year, the estimated sediment load indicates that the minimum siltation of the reservoir per year is 93,454 metric tons or about 144 kg/ha of watershed.

PRINEVILLE RESERVOIR WATERSHED SOILS STUDY

Purpose, Scope, Method

The intent of this part of the study was to investigate the relationship of the clay mineralogy of watershed soils to turbidity in the reservoir and to determine which soils in the watersheds would be considered major point sources. Information pertaining to the soils of the Crooked River Watershed was of the reconnaissance survey level (Norgren *et al.*, 1969). Neither time nor funding allowed for a more complete soil survey of the 6475 km^2 watershed. Field observations after the 1972 runoff season revealed areas most prone to erosion and disturbance.

Soils were sampled to meet the objectives stated in the introductory portion of this thesis. Site location and descriptive field data are presented along with complete profile descriptions for most of the soils sampled (Appendix A). The soil sample sites were chosen to compare characteristics and predict behavior of what appeared to be the more troublesome soils with the more stable soils.

Soils - General

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

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, Gribble, 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 deep. Most prominant of the associations used to categorize soils formed from these materials are the Anatone-Klicker-Hall Ranch and the Hankton-Hankins-Klicker and their component soils. Other major component soil series are Boardtree, Whistler and Tolo. In this thesis these series and others are characterized for their contribution to turbidity.

A soils-landscape map of Crook County showing additional associations, with component series indicated in the legend, is presented by Silvernale et al., (1976). Taxonomic classification of the soil series noted is given in that publication. The map and legend are preliminary data, developed as part of the Oregon ERTS investigation (Simonson et al., 1975).

The major land use is rangeland at the lower elevations. The major land use at higher elevations is 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.

Preliminary Laboratory Work

All soil samples were subjected to analyses for particle size distribution, exchangeable cations, cation-exchange-capacity, pH, and conductivity. Analyses were made to determine the soil's dispersibility in distilled water and similar analyses were performed using water collected from the reservoir on November 25, 1972.[9/] Those samples that remained in suspension both in distilled water and reservoir water were selected for further analysis and interpretation. In addition to those soils showing long term dispersion, samples considered representative of the remaining soils were also selected. These samples were then subjected to the same analyses as the readily dispersed soils so that differences in chemical-physical properties could be observed.

Selected Soils

The first five soil samples in Table 12 were subjected to preliminary analysis and found to exhibit high turbidity in both distilled and reservoir water and are, therefore, critical to the reservoir turbidity. (Data on the remaining soils are presented for review and comparison in Appendix H of Soil and Watershed Characteristics in

---

[9/] Chemical analysis of this water is presented in the water chemistry section for Prineville Reservoir, Silvernale et al., 1976.

Table 12. Soil Samples Capable of Extended Suspension in Distilled and Reservoir Water.

Critical Soils--Turbidity Range-High

General Location	Sample Identification	Probable Soil Series	Turbidity (FTU) in Distilled Water 4 hr.	Turbidity (FTU) in Distilled Water 144 hr.	Turbidity (FTU) in Reservoir Water 4 hr.	Turbidity (FTU) in Reservoir Water 144 hr.
Camp Creek-Channel	CP2B[a]	Powder	750	360	365	125
Crooked River	CR1C	Saprolyte	1000	450	1325	475
Crooked River	CR1E	Saprolyte	1350	600	1000	180
Eagle Creek	EE2B	Day (Y)[b]	315	120	155	31
Faught Creek	FT1C	Hankins	200	75	175	31
Arrowwood Point	AW1A	Anatone	25	3	15	4
Arrowwood Point	AW1C	Anatone	42	5	19	6
Roba Creek	RB1A	Roba	57	10	30	2
Camp Creek	CP1A	Powder	380	370	325	8
Maury Mountains	MY5C	Hankton	100	37	72	18
Conant Creek	CT3A	Courtrock	54	16	24	4
Sheep Rock Creek	SP1A	Day (Y)	100	33	46	5
Sheep Rock Creek	SP1B	Day (Y)	61	14	ND[c]	ND
Sheep Rock Creek	SP2B	Day (R)	200	62	65	8
Eagle Creek	EE2A	Day (Y)	315	120	59	8
Reservoir Bank	R1C		285	260	38	10

[a] The last letter is related to depth and profile position and is not necessarily a horizon designation.

[b] The (Y) and (R) indicates the perceived soil color.

[c] ND--not determined.

Relation to Turbidity of the Prineville Reservoir, Silvernale et al., 1976). These five soils and 11 others capable of yielding a range of turbidities were analyzed for amorphous material and clay mineralogy.

It is apparent from the data that most soils are more dispersible in distilled water than in the reservoir water (Table 12). Some soils exhibited very high turbidity in distilled water but failed to cause continued turbidity in the reservoir water and were excluded from further analysis. The combination of soil and water resulted in a less turbid suspension at the end of the dispersion time than the reservoir water alone. These phenomena are attributed to chemical interactions within the suspension. Samples resembling the Rarey and Courtrock soil series were in this group. The calcium carbonate within the profile (Appendix A) is thought to have acted as a flocculant, causing the suspended materials in the reservoir water to coalesce and precipitate after prolonged suspension.

In addition to the soils having calcium carbonate present, the reservoir water had dissolved salts. The combination seems to have enhanced the flocculation phenomenon in certain instances.

Those soils selected in addition to the five contributing to long-term turbidity are included in Table 12. These soils represent differences in at least one of three measurable parameters: turbidity, clay mineralogy, and weathering. Two of these parameters, clay minerals and weathering result from basic differences in climate, parent material (geology), organic matter (flora and fauna), topography (relief), and time. Possible soil series relationships are suggested. The Day series produces high turbidity. This suggests a basic difference in the five soil-forming factors or variants of the same soil series.

Soil samples representative of a wide range of turbidity between distilled water and reservoir water are the Powder saline variant (CP1A) and the Day soil series, (EE2A). These two samples are from the surface horizons of the soil profiles studied. In distilled water, both exhibited 4-hour turbidity readings greater than 300 FTU. However, their reservoir water showings were dramatically different (225 vs 65 FTU) for the 4 hour reading but were found to be equal for the 144-hour reading. A time lag due to reaction rate difference would be expected.

Samples AW1A, AW1C of the Anatone series and RB1A of the Roba series were chosen to be representative of the soils with a preponderence of non-crystalline clays. Their x-ray diffraction patterns suggested that very little crystalline clay was present, however, AW1C had more crystalline clay than AW1A--its surface counterpart. The increase in crystalline clay content in AW1C is an expected result of weathering processes in soils and is indicative of pedogenesis, assuming no ash or colluvial surface deposition.

The SP sample series is representative of those soils with reasonably well developed clay mineralogies (Day clay). Their x-ray diffraction patterns exhibit well defined peaks representative of such clay minerals as montmorillonite and kaolinite.

Weathering differences were observed in sample R1C when compared to the soil samples. This sample is of the soft, red, saprolytic tuffaceous rock material observed to occur on the shoreline perimeter of the reservoir. Characteristically, these materials have a predominance of 1:1 clay. The 1:1 clays generally are the result of a weathering sequence that begins with vitreous volcanic material and terminates in kaolinite (Loughnan, 1969).

Such a weathering sequence is favored by the warmer, more humid climate that existed during the geologic period when the red beds were formed (Baldwin, 1969). A cooler, more arid climatic regime, under which weathering processes are slower, now prevails.

Additional weathering differences were shown by the Powder - saline variant surface sample (CP1A) and Hankton series lower solum (MY5C). They were found to contain montmorillonite as the predominate clay, plus some zeolites. The seemingly inconsistent presence of zeolites in a surface horizon (CP1A) is not inexplicable when one considers the history of the Camp Creek riparian soils of which the CP samples are representative. The soils for the most part have formed from Recent alluvial deposits derived by subarieal erosion including gullying. These deposits would have incorporated the zeolites coming from the raw bedrock exposures and subsolum gullying. Under the prevailing climate of wet cool winters and hot dry summers, zeolites could be expected to remain unweathered in these young soils.

Not all of the 11 soils were selected for comparison on the basis of one parameter. Some represented differences in two or more characteristics, such as samples SP1A and CT3A. These samples and one or two others indicated that kaolinite was present in the samples along with montmorillonite. However, the peak intensity of kaolinite tends to dominate or at least equal the smectite. This suggests another source of the kaolinite noted in the electron micrographs previously mentioned for the reservoir profile. A closer source of kaolinite is the red tuff situated around the shoreline and represented by the "R" sample series and the diffraction patterns for R1C. The predominance of kaolinite has been discussed. In addition, these samples were observed to be capable of remaining in suspension in distilled water giving high turbidities, but not in reservoir water.

The x-ray diffraction patterns for the Day series samples SP1A, SP1B, SP2B, were obtained from soil with red clayey subsoils and red or yellow surface soils, located on the Lost Creek watershed. Sample R1C, which exhibits the same mineralogy, is from the red tuffs found around the shoreline of the reservoir. The soils obviously have formed from similar tuff exposures and their kaolinite mineralogy is inherited from the parent rock.

Soils Prone Toward Turbidity

Soils obtained from the watersheds of Camp Creek, Eagle Creek, and Faught Creek have been shown to be most able to cause turbidity in reservoir waters. They were found to exhibit 144-hour turbidity readings considered to be objectionable (Table 12). One series of samples (CR1A thru CR1F) collected from the Crooked River channel bank are highly saprolitic red, brown, yellow and green tuffaceous material and are not considered soil but regolith. However, their exposure, erodibility, and physical nature warranted sampling and analysis because it was observed during runoff that this deposit added significantly to the turbidity of the waters contacting the material. The site is located on the south bank of the Crooked River in SW 1/4 SW 1/4 SE 1/4, Sec. 34, T16S R20E.

Riparian soils situated on the Camp Creek watershed were noted to be more easily detached and transported than the other soils on the watershed. This does not, however, mean that the other soils of the watershed are not capable of contributing to reservoir turbidity. To the contrary, they are as potentially capable of causing turbidity as are the riparian soils, but are being eroded more slowly.

Evidence of this is obvious from the frost action that occurs on the watershed. The surface few inches of soil are readily detachable and easily succumb to sheet erosion. Low concentrations of organic matter associated with low aggregate stability enhance their detachability. Frost erosion was observed on soils in the Cabin Creek drainage on the Maury Mountains' south side.

The riparian soils on the Camp Creek watershed are easily eroded, as evidenced by gullies and small active spur channels. These erosional features are deepened and widened by each spring freshet and runoff event. Bank sloughing along the main channel contributes several cubic meters of riparian soils to add to the sediment transport and turbidity of each event. On one occasion, sloughing of an estimated 64.2 m^3 of channel bank soils practically dammed off the stream on the middle fork of Camp Creek. These soils have a tremendous potential for turbidity once dispersed. One Camp Creek soil dispersed in distilled water for 432 hours was found to exhibit a sustaining turbidity of 320 FTU, with relatively little indication of settling or clarification. Fortunately, reservoir water is chemically able to reduce turbidity of this magnitude, as indicated by CP2B (Table 12). Although the tendency for extreme turbidity is reduced, the amount of reduction does not approach acceptable limits.

Soil Chemistry

The chemistry of the soils studied reflect the varied conditions from which they were derived. In general, those exhibiting a C. E. C. of more than 50 meq/100 g., conductivities of more than 200 μmhos and pH values greater than 7.5 units, exhibit long-term turbidity in both distilled and reservoir water. The amount of sodium present appears to be a factor. Those soils exhibiting long-term turbidity have sodium concentrations far in excess of the calcium concentrations, and usually greatly exceed the sodium concentrations in other soils to which turbidity was not attributable.

Those soils found to have the highest long-term turbidity producing potential generally had high exchangeable sodium. Those soils that had high conductivities are generally the ones that had calcium carbonate accumulation in their profile.

The pH of most soils examined generally grouped around neutrality. However, the soils more prone to cause turbidity tended to have more alkaline pH values, most likely attributable to the Na concentration.

Amorphous Material

Both control soils and those capable of causing turbidity were analyzed for amorphous material by the acid-ammonium-oxalate-KOH weight-loss method outlined in the methods and materials section. The results (Table 13) are listed from highest amorphous material concentration to lowest, with corresponding clay percentages, turbidity after 144 hours suspension in reservoir water, and presence of crystalline montmorillinite and kaolinite clays.

Generally those soils that are more able to contribute to long-term turbidity have between 30 and 60% amorphous material. The highest turbidity occurs in those soils with only montmorillinite and amorphous material. Partial exceptions are the Hankins and Day, FT1C, and EE2B, respectively, which are borderline to being considered turbid. Evaluating the reason for this, consideration is given to relative peak intensities on x-ray diffraction patterns, i.e. peak intensity of montmorillinite divided by peak intensity of kaolinite. When this is done it is found that the FT1C and EE2B samples have relative peak intensity ratios of 0.14 and 0.25 respectively. These low ratios are interpreted to be a small proportion of kaolinite to montmorillinite, and suggests that kaolinite may affect turbidity by reducing the 2:1 clays influence in the presence of amorphous material.

When the soils are evaluated considering the different combinations of factors i.e., % clay versus FTU, % amorphous versus & clay, etc., the best indicator of turbidity potential is amorphous material versus type of clays present. When graphed (Figure 6),

Table 13. Relationship of Amorphous and Crystalline Clays to Turbidity.

Sample Identification	Percent Amorphous[a]	Percent Clay	Turbidity[b] (FTU)	Crystalline Clay[c] Mont.	Crystalline Clay[c] Kaol.
RB1B	83	13	6	0	+
AW1A	75	16	4	0	+
EE2A	70	83	8	+	+
* EE2B	65	80	31	+	+
CT3A	65	20	4	+	+
MY5C	64	25	18	+	+
AW1C	63	12	6	+	+
SP2B	60	57	8	+	+
* CR1E	59	73	180	+	0
* CR1C	46	89	475	+	0
* FT1C	46	54	31	+	+
* CP2B	44	29	125	+	0
SP1A	44	53	5	+	+
SP1B	36	52	12	+	+
CP1A	31	36	8	+	0
R1C	25	23	10	+	+

[a]Percent amorphous means percent of total clay. Percent clay is of total soil.

[b]144 hours after dispersion in reservoir water.

[c]After amorphous dissolution treatment.

[d]X-ray diffraction patterns for all soils presented in Appendix F.

*Most turbid when dispersed in reservoir water.

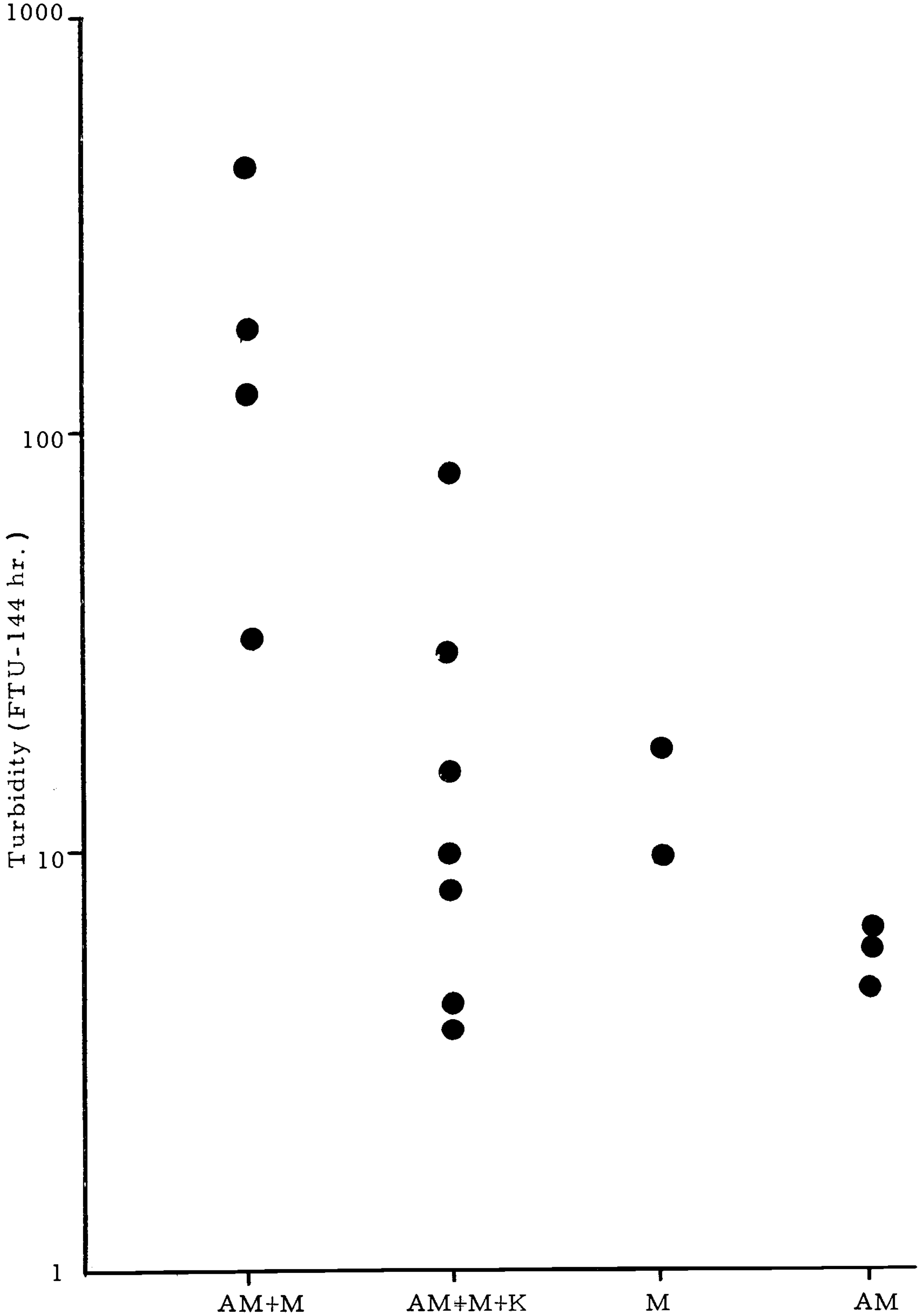
it appears a relationship exists between the amount of amorphous material present, the type of clay, and the various proportions of montmorillinite versus kaolinite. There is also an indication that the percentage of clay (which includes the amorphous material) may be involved. The relationship presented graphically is arrived at by x-ray diffraction pattern analysis and is interpreted as follows:

a) Soils with only amorphous material present contribute little to the long-term turbidity in the reservoir. These soils do not exceed 20% clay as determined by the pipette method.

b) Soils with montmorillinite present with very low concentrations of amorphous material (if any) add slightly to the effect of turbidity, but generally do not cause high turbidity readings after long-term suspension.

c) Soils containing amorphous material, montmorillinite and kaolinite together react similarly to those soils with only montmorillinite, but as the relative qualitative amount of kaolinite increases, the turbidity decreases.

d) Soils containing significant amounts of montmorillinite with 30 to 60% amorphous material in the clay fraction and no indication of kaolinite are capable of long-term turbidity. This combination far exceeds the other



Clay type-montmorillinite (M), kaolinite (K), and amorphous material (AM).

Figure 6. Turbidity Versus Clay Type and Amorphous Material

clay-amorphous material combination's ability to cause long-term turbidity.

Summary of Soils

Those soils found capable of extended turbidity in distilled water, and particularly reservoir waters, are expected to be of the Powder saline variant from the Camp Creek drainage basin and at least one non-soil (sparolitic bedrock) point source on the Crooked River.

Soils of the Day series on the Eagle Creek watershed were found to be borderline in their ability to cause turbidity, as was the Hankins series from Faught Creek. The other soils examined were able to cause turbidity of varying degrees, but did not approach the values exhibited by those five soils.

Soils within the Crooked River study area possessing amorphous material from 30 to 60% of the clay fraction, coexisting with only the 2:1 clay mineral montmorillinite, are considered to be the most likely to produce Fourbidity[10/] at levels considered extreme in this study.

[10/] It is proposed that the coined word Fourbidity (Formazin Units - 144 hour turbidity) be defined as the turbidity in excess of 30 FTU after settling undisturbed for six days under a constant 20°C. temperature. A further proposal is that for environmental concerns the 144 hr-turbidity (Fourbidity) be the basis for determining degredation of water quality of a long-term nature. This should not be confused with turbid waters that could be a result of natural occurences or man's activities that cause transient turbidity.

CONCLUSIONS

Sediment and turbidity measurements indicate that most of the sediment received by the reservoir is added during runoff from low elevation January rains and heavier mid-March snowmelt. Some streams supply disproportionate amounts of sediment with resulting turbidity. Sediment loads and turbidity decreased in all streams between periods of high runoff. However, Camp Creek was turbid through much of the irrigation season.

Previous observers have recognized the erodible nature of the soils and some have alluded to the deterioration of individual watersheds. This study concurs with those earlier sources and has derived the following conclusions based on the data obtained.

Watershed

Through the quantification of sediment transport and sediment deposition, laboratory analyses of runoff waters, sediments and watershed soils, comparison of management practices and hydrologic considerations, it is the conclusion of this study that Camp Creek, Eagle Creek, and a small segment of the Crooked River's main channel are major contributors to the Fourbidity in the Prineville Reservoir.

Bear Creek carries the greatest sediment load per volume of flow. However, this does not mean that Bear Creek provides more sediment than does the Crooked River; this is hydrologically improbable. Hydrograph analysis showed that the Crooked River far exceeds Bear Creek in both volume and flow duration. Measurements of sediment deposition and sediment transport support this conclusion. Based on these observations and analyses of turbidity-causing potential of suspended sediments, Bear Creek does not appear to be a substantial contributor to Fourbidity in the reservoir.

Factors affecting sediment transport on forested watersheds are debris dams which cause rerouting of streams with associated deep erosion and resultant high sediment transport. Debris dams may also clog culverts and cause road washouts.

Similar in effect to culvert damage are the downcutting and erosion caused on roads that have insufficient or nonexistent waterbars. In general, roads with ill-placed, unmaintained, and/or undersized culverts and waterbars were the rule, rather than the exception, over much of the study area.

Watershed Soils

Based on observation of individual watersheds, soils with the potential necessary to cause Fourbidity are not as predominant on Bear Creek and apparently do not contribute every year or during every runoff, as is the case with Camp Creek and Eagle Creek.

Soils high in silts or ash are most susceptible to erosion and transport. Such soils on uplands are dominately forested and include the Rarey, Boardtree, Whistler, Hankton, and Ginser series. Soils forming over the soft tuffaceous material or those riparian soils on alluvium from the raw sediments are most likely to create Fourbidity in the reservoir. These soils are of the Powder-Courtrock and Simas-Tub-Soft Sedimentary Bedrock Associations.

Those soils that occur in the Simas-Tub-Soft Sedimentary Rock Association or geologic formations exhibiting soft tuffaceous material and a clay mineralogy that has only the clay montmorillonite and between 30 and 60% amorphous material in the clay fraction causes Fourbidity in reservoir waters.

Reservoir

Soils like the Day clay add significant shoreline turbidity as a result of wave and wake action. The occurrence of very small kaolinite particles in turbid waters above the thermocline suggest these soils contribute to continuing turbidity through the summer recreation season.

Soil lost from shoreline areas since the inception of the reservoir, and continuing shoreline erosion appears to reflect reservoir flucuations and recreational use. However, documentation and data were not conclusive. The continued unchecked use of "pumice beaches" on the reservoir perimeter is causing the excessive loss of these beaching areas.

RECOMMENDATIONS

Watershed

1. Develop management plans for the more critical watersheds that provide:

   a. Better control of domestic animal use.

   b. Protection for the more sensitive and fragile riparian soils.

   c. Fencing of critical channel reaches as started on Camp Creek and allowing for controlled access points within the fenced area.

   d. Clearing of man-caused forest debris from stream channels after management change.

   e. Maintenance and sizing of culverts to accept greater run-off volumes.

   f. The revegetation of these watersheds by soil-holding grasses.

   g. The removal of juniper and other unwanted species that compete with grass for soil moisture.

   h. Assistance and guidance to private land owners for improvement of their lands and practices.

   i. Educational programs that advise and inform agency contractors, land users, and managers of soil conservation techniques.

j. Rip-rapping of sediment or turbidity-producing point sources such as occur on the Crooked River.

k. More supervision follow-up and enforcement of regulations.

l. Levels of grazing, forestry, and recreation use compatible with watershed protection.

2. Observe and monitor each watershed before, during and after implementation of management change.

3. Implement management practices at optimum times.

4. Evaluate range management programs on all watersheds with respect to:

   a. Soil and hydrologic conditions and needed conservation measures.

   b. Rotation timing and duration as it relates to a. above.

   c. Cost-benefit analysis comparing maximum AUM's now and future AUM's resulting from sound conservation and range management.

Watershed Soils

1. Use soil maps to locate those soils shown to exhibit high erodibility and those able to cause turbidity.

2. Evaluate each management practice with respect to soils present before implementation or continuation of practices that can cause erosion.

3. Instruct resource people how to recognize the problem soil types.

4. Implement conservation measures on each area recognized to contain critical soil types.

5. Practice and enforce soil conservation on all projects.

Reservoir

1. Evaluate the implied relationship of recreational boating, and boat size and their contribution to continual turbidity within the reservoir.

2. Evaluation of algal, chemical, density, thermic, and physical parameters relative to the reservoir.

3. Evaluate the potential for addition of chemical additives to promote flocculation in the reservoir. Manganese has shown promise in some studies.

4. Rip-rap the more sensitive exposed clayey soils that occur on the shoreline in the proximity of the Prineville Dam.

BIBLIOGRAPHY

Baldwin, E. M. 1967. Geology of Oregon. 2nd ed. Univ. of Oregon, Eugene. 165 p.

Baver, L. D. 1949. Soil Physics. McGraw-Hill - New York.

Beasley, R. P. 1971. Erosion and Sediment Pollution Control. Iowa State Univ. Press. 320 p.

Bondurant, D. C. 1970. Basic Sedimentation Problems. In Sediment Transport in Rivers and Reservoirs. U. S. Army Corps of Engineers. The Hydrologic Engineering Center. Davis, Calif.

Brown, C. E. and T. P. Thayer. 1966. Geologic Map of the Canyon City Quadrangle Northeastern Oregon; Misc. Geologic Investigations Map I-447. Washington, D. C.

Chu, T. Y. and D. T. Davidson. 1953. Simplified Air-jet Dispersion Apparatus for Mechanical Analysis of Soils. Hwy. Res. Bd. Proc., 35:245-140.

Dept. of Environmental Quality. 1971. Water Quality Standards. Oregon Admin. Rules. Chap. 340.

Dingus, D. D. 1973. The Nature and Properties of Amorphous Colloids Formed from Mazama Tephra. Ph. D. Thesis, Corvallis, Oregon State Univ. 95 numbered leaves.

Dudas, M. J. and M. E. Harward. 1971. Effect of Dissolution Treatment on Standard and Soil Clay. Soil Sci. Soc. Amer. Proc., 35:134-140.

Harward, M. E. and C. T. Youngberg. 1969. Soils from Mazama Ash in Oregon: Identification, Distribution and Properties. Pedology and Quanternary Reasearch Symposium. Univ. of Alberta, Edmonton. 218 p.

Hewlett, J. D. and W. L. Nutter. 1969. An Outline of Forest Hydrology. Univ. Georgia, Athens. 137 p.

Higgins, G. R. and J. M. Colonell. 1973. Hydrologic Factors in the Determination of Watershed Yields. Univ. of Mass. at Amherst. Pub. No. 20.

Hudson, N. 1971. Soil Conservation. Cornell Univ. Press. Ithaca, New York. 320 p.

Kilmer, V. J. and L. T. Alexander. 1949. Methods for Making Mechanical Analysis of Soil. Soil Sci. 68:15-24.

Leet, D. L. and S. Judson. 1965. Physical Geology. 3rd ed., Prentice Hall, Inc., New Jersey. 502 p.

Lidstrom, J. W. 1972. A New Model for the Formation of Crater Lake Caldera, Oregon. Ph. D. Thesis. Corvallis, Oregon State Univ. 85 numbered leaves.

Loughnan, F. C. 1969. Chemical Weathering of the Silicate Minerals. Amer. Elsevier Publishing Co., Inc., New York. 154 p.

Mackenthun, K. M., W. M. Ingram and R. Porges. 1964. Limnological Aspects of Recreational Lakes. U.S.H.E.W., Public Health Service Div. of Water Supply and Poll. Control. 176 p.

McGriff, E. C. 1972. The Effects of Urbanization on Water Quality. J. Environmental Quality, Vol. 1:1-86 p.

Morisawa, M. 1968. Streams: Their Dynamics and Morphology. McGraw Hill Book Company, New York. 175 p.

Mortimer, C. H. 1969. Agricultural Drainage and Eutrophication. In Eutrophication: Causes, Consequences, Corrections, G. A. Rohlich (ed). National Academy of Sciences, Washington, D. C.

NASA U-2 Imagery. 1972. Environmental Remote Sensing Laboratory. Oregon State University, Corvallis, Oregon.

Norgren, J. A., G. H. Simonson, B. R. Thomas, M. G. Lindsay, B. B. Lovell, and D. W. Anderson. 1969. General Soil Map Report with Irrigable Areas Deschutes Drainage Basin. Oregon's Long-Range Requirements for Water. Appendix I-5. State Water Resources Board. 116 p.

Norris, L. A. and D. G. Moore. 1970. The Entry and Fate of Forest Chemicals in Streams. In Forest Land Uses and Stream Environment, Proc. Oregon State Univ., Corvallis, Oregon.

Richards, L. A., ed. 1954. Diagnosis and Improvements of Saline and Alkali Soils, U. S. Salinity Lab. USDA Handbook No. 60.

Russell, I. C. 1905. Preliminary Report on the Geology and Water Resources of Central Oregon. U.S.G.S. Bull. 252:62-63.

Russell, I. C. 1902. Geology and Water Resources of the Snake River Plains of Idaho. U.S.G.S. Bull. 199:145-146.

Schwab, G. O., R. K. Frevert, K. K. Barnes, and T. W. Edminister. 1971. Elementary Soil and Water Engineering. 2nd ed. John Wiley and Sons. New York. 316 p.

Silvernale, C. E., G. H. Simonson and M. E. Harward. 1976. Soil and Watershed Characteristics in Relation to Turbidity of the Prineville Reservoir, Oregon Agricultural Experiment Station Special Report #453, Feb. 1976.

Simonson et al., 1974. Comparative Evaluation of ERTS-1 Imagery for Resource Inventory in Land Use Planning. Final Report to NASA. 311 p.

Streambank Erosion in Oregon. 1973. State Soil and Water Conservation Commission. A Report to the Fifty-Seventh Legislative Assembly.

Thomas, B. J. 1970. Sedimentation Activities in the North Pacific Division. In Sediment Transport in Rivers and Reservoirs. U. S. Army Corps of Engineers. The Hydrologic Engineering Center, Davis, Calif.

U. S. Dept. of Agriculture. Science and Saving Water and Soil. Bull. 324.

U. S. Dept. of the Interior. 1957. Bureau of Reclamation. Crooked River Project--Oregon: Topography, Prineville Dam and Reservoir Site. No. 113-119-181. Salem, Oregon. Source: Mr. LaSelle E. Coles. Ochoco Irrigation District Manager. Prineville, Oregon. 1972.

U. S. Geological Survey. Computation of Fluvial-Sediment Discharge. Techniques of Water-Resources Investigation of the U.S.G.S., Book 3, Chap. C-3.

Walker, G. W., N. V. Peterson, and R. C. Greene. 1967. Reconnaissance Geologic Map of the East Half of the Crescent Quadrangle Lake, Deschutes, and Crook Counties, Oregon. Map I-493, U.S.G.S.

Youngberg, C. T., M. E. Harward, G. H. Simonson, D. Rai, P. C. Klingeman, D. W. Larson, H. K. Phinney, and J. R. Bell. 1971. Hills Creek Reservoir Turbidity Study. Water Resources Research Inst., Oregon State Univ., Corvallis, Oregon.

APPENDICES

APPENDIX A

SOIL PROFILE DESCRIPTIONS

Profile AW1
September 13, 1973

Profile is of the Anatone soil series. The profile represents the soils characteristic to the higher elevation basalt plateaus of the North Fork and the southeast end of the Maury mountains. These soils appear stable with regard to erosional processes.

01	5-0 cm--Leaves, pine needles, grass and twigs.
A11	0-5 cm--Dark brown (7.5YR 3/2) moist gravelly silt loam; weak to moderate fine granular structure; very friable, slightly sticky, plastic; abundant fine roots; charcoal fragments; 5% by volume of 1 cm coarse fragments; slightly acid (pH 6.4); diffuse smooth boundary.
A12	5-15 cm--Dark brown (7.5YR 3/2) gravelly loam, brown (10YR 5/3) dry; moderate fine granular structure; slightly hard, slightly sticky, plastic; abundant medium roots; charcoal fragments; common very fine tubular and interstitial pores; greater than 35% by volume coarse fragments; neutral (pH 7.0); gradual wavy boundary.
B1	15-30 cm--Dark brown (7.5YR 3/2) gravelly clay loam, brown (7.5YR 3/4) dry; strong medium subangular blocky structure; slightly hard, firm, slightly sticky, very plastic; common fine to medium and few coarse roots; many fine pores; neutral (pH 7.0); clear wavy boundary.
B2	30-48 cm--Dark reddish brown (5YR 3/3) gravelly clay loam, brown (7.5YR 5/2) dry; strong medium to coarse subangular blocky structure; firm, slightly sticky, very plastic; very few fine roots; greater than 35% coarse fragments; neutral (pH 7.0).
R	48+ cm hard lava flow.

Remarks: Underlying rock type is a red, fine-grained dense lava.

Location: Arrow Wood Point, site #1, SE1/4 NW1/4, Sec. 8, T18S, R21E.

Setting: The vegetation is Ponderosa pine and pine grass. The visible human influence is logging but there is no evidence of erosion.

Drainage and Permeability: Well-drained with the profile dry to 48 cm; moderate permeability.

Stoniness: Class 0.

Description of Area: The site is located on a broad ridge top above steep, deeply dissected hills. The aspect is east and slope range is 0 to 2%. The elevation is approximately 1.5 km.

Profile CR2
May 26, 1973

Profile is fine textured variant of the Powder series. This site is subject to erosion during most high runoff events. This soil is similar to most flood plain soils between the North Fork and the upper end of the Prineville Reservoir.

Ap 0-18 cm--Very dark grayish brown (10YR 3/2) silt loam; strong subangular blocky, parting to very fine granular structure; firm, slightly sticky, plastic; few fine roots; common fine interstitial pores; moderately alkaline (pH 8.3); clear smooth boundary.

B1 18-25 cm--Very dark brown (10YR 2/2) clay loam; strong medium subangular blocky, parting to fine granular structure; hard, sticky, plastic; common fine roots; many fine interstitial pores; moderately alkaline (pH 8.2); clear wavy boundary.

B2 25-58 cm--Very dark grayish brown (10YR 3/2) silty clay; weak medium prismatic, parting to subangular blocky structure; hard, very sticky, very plastic; common fine roots; many fine tubular and interstitial pores; mildly to moderately alkaline (pH 7.3 to 8.0); diffuse wavy boundary.

IIC1 58-68 cm--Very dark grayish brown (10YR 3/2) gravelly silt loam; moderate medium subangular blocky structure; hard, sticky, plastic; few fine roots; common fine interstitial pores; greater than 15% 0.05 cm coarse fragments; moderately alkaline (pH 8.4); clear wavy boundary.

IIC2 68-152 cm--Dark brown (10YR 4/3) fine sandy loam; single-grained structures; mildly to moderately alkaline (pH 7.4 to 8.0).

Remarks: The parent material is mixed alluvium.

Location: Crooked River, site #2, milepost 24 on State Highway 380, Bonny View Ranch (near Post, Oregon), SW1/4SW1/4NE1/4, Sec. 19, T 16S, R19E.

Setting: The site is located in the cutbank of the river and the land between it and the highway is in cultivated grass. Human influence seems limited to the cultivation. There is no evidence of erosion.

Drainage and permeability: Well-drained, with moderate permeability.

Description of Area: The site is situated in the flood plain of the river and the slope is 0 to 3%.

Profile CT2
May 26, 1973

Profile resembles the Courtrock series and represents the soils characteristic to the upper Conant Creek drainage. These are the major tilled soils of the watershed. They are easily eroded by precipitation when vegetative cover is absent.

A11 0-13 cm--Dark brown (10YR 3/3) sandy loam; moderate fine granular structure; loose, very friable, nonsticky, nonplastic; abundant fine roots; many fine interstitial pores; neutral (pH 6.8); clear boundary.

A12 13-30 cm--Very dark grayish brown (10YR 3/2) fine sandy loam; weak very fine granular structure; firm, slightly sticky, slightly plastic; abundant fine and few coarse roots; very few fine interstitial pores; 0.2 cm coarse fragments; weak cementation with secondary carbonate; mildly to moderately alkaline (pH 7.4 to 8.0); gradual wavy boundary.

AC 30-43 cm--Dark brown (10YR 3/3) fine sandy loam; strong very fine granular structure; very friable, sticky, plastic; common coarse roots; many fine interstitial pores; 1% by volume of 0.02 cm coarse fragments; weak carbonate cementation; mildly to moderately alkaline (pH 7.4 to 8.0); gradual wavy boundary.

C1cam 43-61 cm--Dark brown (10YR 4/3) sandy loam; weak very fine granular structure; firm, nonsticky, nonplastic; few fine roots; 1% by volume 0.2 cm coarse fragments; moderate carbonate cementation; mildly to moderately alkaline (pH 7.4 to 8.0).

C2cam 61-152 cm--Light yellowish brown (10YR 6/4) strong carbonate cementation; moderately alkaline (pH 8.4).

Remarks: The parent material is alluvium and the rock source is probably tuffaceous.

Location: Conant Creek Basin watershed, site #2, 3.5 km above the Bolletto Ranch, Sec. 33, T16S, R18E.

Setting: The site is vegetated by juniper, rabbit brush, greasewood, blue-bunch wheatgrass, lupine, and bitterbush. Grazing is in evidence. Erosion in the form of sheet, rill, and wash is present. Frost action is also visible.

Drainage and Permeability: The profile was dry from 0-4 cm and moist below. Drainage ranges from moderately well to well-drained. Permeability is moderate to rapid above the cemented horizons.

Stoniness: Class 0.

Description of Area: The surrounding area is rolling to steeply sloping uplands and the site is located on a convex foot slope with a northeast aspect. Slope is 11%. Altitude is approximately 1.2 km.

Profile CT3
September 16, 1973

Profile is of the Courtrock series. Seasonal runoff events cause this soil to be eroded and transported in copious amounts.

A1 0-10 cm--Very dark grayish brown (10YR 3/2) silt loam, grayish brown (10YR 5/2) dry; weak very fine granular structure; loose, slightly sticky, slightly plastic; abundant fine roots; few medium tubular and many fine vesicular pores; 5% of up to 0.5 cm coarse fragments; weakly effervescent; gradual smooth boundary.

AC1 10-61 cm--Very dark grayish brown (10YR 3/2) loam, grayish brown (10YR 5/2) dry; weak fine subangular blocky structure; slightly hard, nonsticky, slightly plastic; abundant very fine, fine and medium roots; few medium tubular pores; 5% of up to 0.5 cm coarse fragments; weakly effervescent; diffuse smooth boundary.

AC2 61-304 cm--Dark brown (10YR 3/3) sandy loam, light gray (10YR 7/1) dry; weak fine to medium subangular blocky structure; slightly hard, nonsticky, non-plastic; common fine tubular pores; less than 5% of up to 0.5 cm coarse fragments; strong effervescence.

C1ca 304-330 cm--Coarse sand interspersed with bands of fine silt and sandy loam subsoil; strong effervescence.

Remarks: The parent material is well-sorted mixed alluvium.

Location: Conant Creek channel, site #3, near sample station just below confluence of Lucky and Conant Creeks. Sec. 23, T16S, R18E.

Setting: Entrenched floodplain of Conant Creek. Sagebrush, willow, juniper, bluebunch wheatgrass, fescue and assorted forbs dominate the vegetation. Human influence consists of overgrazing. Erosion is evident as demonstrated by the deeply carved channel banks.

Drainage and Permeability: Well-drained (approximately 3 meters) and the water table is deep; rapid permeability.

Stoniness: Class 0.

Description of Area: The site is located in a stream cut bank in a deeply incised drainage. The surrounding area is rolling uplands and aspect is southeast. Slope at site is 0 to 3%. Elevation is 1.1 km.

Profile CW1
September 14, 1973

Profile is an ashy variant of the Hall Ranch soil series and is characteristic of those soils on lower slopes and adjacent to Cow Creek. When disturbed, these soils are eroded easily and are slow to stabilize.

01 2.5-0 cm--Duff and undecomposed needles.

A11 0-5 cm--Very dark grayish brown (10YR 3/2) loam, dark gray (10YR 4/1) dry; single-grained to moderate fine granular structure; loose, slightly sticky, slightly plastic; abundant very fine roots; 2% by volume of 1 cm coarse fragments; neutral (pH 6.7); abrupt smooth boundary.

A12 5-20 cm--Very dark brown (10YR 2.5/2) loam, dark gray (10YR 4/1) dry; massive to granular structure; slightly hard, slightly sticky, slightly plastic; abundant fine roots; common tubular pores; 1 cm charcoal fragments; 2% by volume 1 cm coarse fragments; neutral (pH 7.0); clear smooth boundary.

B 30-76 cm--Very dark grayish grown (10YR 3/2) loam, dark grayish brown (10YR 4/2) dry; massive to granular and single grained structure; common coarse roots; very fine tubular pores; micelia present; slightly acid (pH 6.4).

R 76+ cm--Fractured basalt bedrock.

Remarks: Parent material is colluvium from volcanic ash and basalt.

Location: Cow Creek watershed, site #1, stream bank cut just off Forest Service road 1752, 30 paces south of section marker, NE 1/4, NE 1/4, NE 1/4, Sec 9 T18S, R18E.

Setting: Vegetation is Ponderosa pine and pine grass. Human influence is related to logging operations and cattle grazing. The stream channel erosion has been excessive in the past and is now slowly healing, though not completely stopped.

Drainage and Permeability: Well-drained and a dry profile. Water table is deep. Moderately rapid permeability.

Stoniness: Class 0.

Description of Area: The site is located in a stream bank in a ravine at the bottom of a concave side slope in hilly uplands. Aspect is southeast and slope is 28%. Elevation is about 1.5 km.

Profile DE1
September 14, 1973

Profile somewhat resembles Simas series, but is in deep unconsolidated silty material. The soil is not extensive but does receive considerable disturbance from domestic range animals. Accelerated erosion is apparent.

A1 0-10 cm--Dark brown (10YR 3/3) silty clay loam, grayish brown (10YR 5/2) dry; strong fine subangular blocky structure; hard, sticky, very plastic; common fine roots; many fine tubular pores; 5 to 10% by volume of 1 to 8 cm coarse fragments; clear smooth boundary.

B21 10-20 cm--Dark brown (10YR 4/3) silty clay, brown (10YR 5/3) dry; strong fine subangular blocky structure; hard, very sticky, very plastic; common fine roots; many fine tubular pores; clear smooth boundary.

B22 20-25 cm--Dark brown (10YR 4/3) silty clay loam, light yellowish brown (10YR 6/4) dry; strong medium subangular blocky, parting to platy structure; hard, very sticky, very plastic; common fine roots; many fine tubular pores; gradual wavy boundary.

B3-Cca 25-152 cm--Dark brown to dark yellowish brown (10YR 3/3.5) silt loam; strong fine subangular blocky structure grading to massive; very hard, slightly sticky, slightly plastic; few fine roots; many fine tubular pores; bands of carbonate interspersed throughout this horizon, exhibiting mild effervescence.

Remarks: Parent material is loess or fine colluvium.

Location: Drake Creek watershed, site #1, roadcut on Forest Service road 1728, NW 1/4, NW 1/4, SE 1/4, Sec. 9, T17S, R20E.

Setting: Major components of the vegetation are sagebrush, rabbit brush, juniper, willow, Ponderosa pine, and bluebunch wheatgrass. Human influence is mainly grazing. The evidence of erosion is severe on the road cut, showing heavy gullying. Sheet erosion is evident on the surface.

Drainage and Permeability: Well-drained with a dry profile. The water table is deep. Permeability is moderately slow.

Stoniness: Class 1.

Description of Area: The site is located in steep, deeply dissected, rolling uplands on a convex side slope with a northeast aspect. The slope is 21%. Estimated elevation is 1.5 km.

Profile DE1-1
September 13, 1973

Profile resembles the Hankins series with a stony surface but is skeletal. It is underlain by a deep deposit of old landslide material. The parent material is from basalt or tuff.

01	2.5-0 cm--Duff
A11	0-8 cm--Very dark brown (10YR 2/2) silt loam; ashy; strong fine granular structure; soft, nonsticky, plastic; abundant fine roots; very fine tubular and interstitial pores; 10% 1.0 cm coarse fragments; neutral (pH 6.8); clear wavy boundary.
A12	8-30 cm--Very dark brown (10YR 2/2) gravelly silt loam; mixed with ash; moderate medium subangular blocky structure; hard, slightly sticky, plastic; few fine and medium roots; common fine tubular pores; 20-30% 0.2 to 2.0 cm coarse fragments; neutral (pH 6.8); clear smooth boundary.
B1	30-48 cm--Very dark grayish brown (10YR 3/2) clay loam; strong fine subangular blocky structure; slightly hard, sticky, plastic; few coarse and common fine roots; many very fine tubular pores; 50% 0.4 to 10 cm coarse fragments; neutral (pH 7.0); clear smooth boundary.
IIB21t	48-79 cm--Very dark grayish brown (10YR 3/2) gravelly clay; dark yellowish brown (10YR 3/4) clay films; strong medium subangular blocky structure; hard, sticky, plastic; few fine roots; few very fine tubular pores; 50% greater than 2 cm coarse fragments; neutral (pH 6.8); diffuse smooth boundary.
IIB3t	79-152 cm--Strong brown (7.5YR 5/6) very gravelly clay; dark brown (7.5YR 3/4) clay films; firm, hard, sticky, plastic; 50% weathered basalt gravels.

Location: Drake Creek watershed, site #1, roadcut 0.4 km west of the posted Forest Service road 1887F on FS road 1887. Section 9, T18S, R20E.

Setting: Ponderosa pine, pine grass, and juniper are the main components of the vegetation and the area has been logged. There is no evidence of erosion.

Drainage and Permeability: Well-drained with a dry profile and a deep water table. Permeability is slow.

Stoniness: Class 3.

Description of Area: The site is located on a convex side slope in an area of steeply sloping, rolling uplands. The slope is 15% and the aspect is north-east. Estimated elevation is 1.5 km.

Profile EE1
September 15, 1973

Profile is of the Tub series. Soil is subject to erosion when disturbed. Frost action causes the surface to erupt and be subject to transport on steeper slopes.

A1 0-8 cm--Very dark brown (10YR 2/2) gravelly silt loam, grayish brown (10YR 5/2) dry; weak fine subangular blocky structure; soft, slightly sticky, slightly plastic; common fine roots; many fine tubular pores; 30% 1.0 to 10.0 cm coarse fragments; neutral (pH 6.9); clear smooth boundary.

A12 8-13 cm--Very dark grayish brown (10YR 3/2) heavy clay loam, dark gray (10YR 4/1) dry; moderate to strong fine subangular blocky with a "platy" pocket; hard, very sticky, slightly plastic; few fine roots; common fine interstitial pores; 10% 1.0 to 10.0 cm coarse fragments; neutral (pH 6.7); clear wavy boundary.

B1 13-30 cm--Very dark brown (10YR 2/2) light clay loam, gray (10YR 5/1) dry; strong fine and medium subangular blocky; very hard, slightly sticky, very plastic; very few fine roots; many very fine tubular pores; 10% 5.0 to 10.0 cm coarse fragments; neutral (pH 6.8); clear smooth boundary.

B2t 30-51 cm--Dark brown (10YR 3/3) gravelly clay, dark brown (10YR 4/3) dry; strong medium subangular blocky structure; excessively hard, sticky, very plastic; interstitial cracks with thick clay films on the surfaces; very few fine roots; very few very fine tubular pores; neutral (pH 6.7); clear smooth boundary.

IIC 51-152 cm--Yellowish brown (10YR 5/4) gravelly clay, light gray to pale yellow (2.5YR 7/3) dry; massive structure; moderate effervescence; mildly alkaline (pH 7.7).

Remarks: The parent material is from tuff and the type of underlying rock is tuff.

Location: Eagle Creek watershed, site #1, roadcut on west side of State Highway 380 on milepost 13.5. Sec. 1-2, T16S, R17E.

Setting: Sage, bunch grass, juniper, and rabbit brush form the main components of the vegetation. Grazing is the major human influence. There is evidence of severe sheet and rill erosion plus frost action.

Drainage and Permeability: Well-drained with the profile moist from 0-30 cm and dry below. The water table is deep. Permeability is slow.

Stoniness: Class 2.

Description of Area: The site is located in rolling uplands on a convex side slope with a southeast aspect. Slope is 11%. Elevation is 1.12 km.

Profile FT1
May 17, 1973

Profile is very fine variant of the Hankins series occurring at high elevations on south, south west, and west slopes on the south side of the Maury Mountains. Indications on the landscape suggest mass movement may be associated with this soil.

01 0-2.5 cm--Undecomposed litter.

A1 2.5-23 cm--Dark reddish brown (5YR 3/3) silt loam; subangular blocky parting to granular structure; loose, friable slightly sticky, nonplastic; common fine and few medium roots; common medium tubular pores; 10% by volume of 2 to 5 cm coarse fragments; neutral (pH 6.6); clear smooth boundary.

IIB2t 23-41 cm--Dark reddish brown (2.5YR 3/4) silty clay; strong medium subangular blocky structure; firm, very sticky, very plastic; many clay films on peds; very few coarse roots; few fine interstitial pores; neutral (pH 6.8); gradual smooth boundary.

IIB3t 41-152 cm--Dark reddish brown (2.5YR 3/4) silty clay; massive to weak medium subangular blocky parting to fine granular structure; very sticky, very plastic; few medium and coarse roots; few very fine interstitial pores; very fine concretions of less than 1 mm.

Remarks: The parent material is ash over tuff colluvium forming a readily detachable surface. The rock type is tuff.

Location: Faught Creek watershed, site #1, in roadcut on Forest Service road 1887,NE1/4, SW1/4, Sec. 12 T18S, R19E.

Setting: Ponderosa pine is the major vegetation and logging the obvious human influence.

Drainage and Permeability: Well-drained. Profile moist from 0-41 cm. Below 41 cm profile was very wet. There was no water table visible, and permeability is slow.

Stoniness: Class 0.

Description of Area: The site is located on a convex side slope of about 1.2 ha below an upland plateau. The aspect is west and slope is 20%. Elevation is about 1.6 km.

Profile MY3a
September 16, 1973

Profile is a cold variant of the Hack series. Profile was studied because of its apparent geologic instability. It is not extensive within the watershed.

A1 0-25 cm--Very dark grayish brown (10YR 3/2) loam; ashy; fine granular structure; loose; many very fine roots; many interstitial pores; 10% 0.5 to 1.0 cm coarse fragments.

IIB 25-91 cm--Dark brown (7.5 YR 4/4) gravelly loam; weak fine subangular blocky structure; friable; common fine and coarse roots; many tubular pores; 10% 1.0 to 2.0 cm coarse fragments; 1 cm charcoal chips; 20% cobbles.

IIC 91+ cm--Cobbly loam; weak medium subangular blocky structure.

Location: Maury Mountains, site #3a, 0.16 km west of section marker, center E 1/2, SE1/4, Sec. 23, T17S, R20E.

Setting: The vegetation is fir. There is no visible evidence of erosion but there may be inherent slope instability, indicated by bowed tree trunks.

Description of Area: The site is located on a convex foot slope of about 2 ha in extent on a slope of 15% at 1.4 km on north slope.

Profile MY1
September 13, 1973

Profile is of the Boardtree soil series and is characteristic of the soils found in the headwaters of Maury Creek. Soils are susceptible to disturbances caused by range animals and logging.

A1 0-15 cm--Very dark grayish brown (10YR 3/2) gravelly silty loam, grayish brown (10YR 5/2) dry; weak fine granular structure; loose, nonsticky, slightly plastic; abundant very fine roots; many fine pores; 10 to 20% by volume of 0.5 cm coarse fragments; neutral (pH 6.6); clear wavy boundary.

B21 15-66 cm--Very dark grayish brown (10YR 3/2) loam, grayish brown (10YR 5/2) dry; massive structure; hard, nonsticky, slightly plastic; common fine roots; many fine tubular and vesicular pores; charcoal chips; neutral (pH 6.8); gradual irregular boundary.

IIB22 66-112 cm--Dark brown (7.5YR 4/2) clay; strong medium and coarse angular blocky structure; very firm, slightly sticky, very plastic; common medium roots; neutral (pH 7.0).

IIC 112+ cm--Dark brown (10YR 4/3) clay; strong medium angular blocky structure.

Remarks: Parent material is coarse ash material over clayey colluvium.

Location: Maury Creek watershed, site #1, roadcut on the northwest slope below CCC Spring, center of S 1/2, NE1/4, NW1/2, Sec. 31, T17S, R21E.

Setting: The vegetation is juniper, Ponderosa pine, and pine grass. The human influence is logging and grazing. The evidence of erosion is slight.

Drainage and Permeability: Well-drained profile is dry. Permeability is moderately rapid above the discontinuity and slow below.

Stoniness: Class 0.

Description of Area: The site is located in a convex side slope on a ridge flanking Maury Creek. The surroundings are rolling uplands, deeply dissected by drainages. The aspect is west and slope is 14%.

Profile MY3
September 16, 1973

Profile is a thin variant of Boardtree series. Typical of profiles found on the Maury Creek within the Forest Service boundary. The soil is easily eroded when surface cover is removed. Riparian locations where domestic animals congregate leave soils bare, pulverized and primed for transport.

A1 0-8 cm--Very dark grayish brown (10YR 3/2) loam, dark brown to brown (10YR 4.5/3) dry; ashy; moderate very fine granular structure; loose, nonsticky, slightly plastic; abundant fine roots; less than 1% 1.0 to 4.0 cm coarse fragments; neutral (pH 6.8); clear smooth boundary.

A3 8-20 cm--Dark yellowish brown (10YR 3/4) loam, brown (10YR 5/3) dry; ashy; moderate fine subangular blocky structure; soft, nonsticky, slightly plastic; abundant fine roots; few fine tubular pores; 1% 1.0 to 4.0 cm coarse fragments; neutral (pH 6.6); clear smooth boundary.

B2 20-36 cm--Dark yellowish brown (10YR 4/4) sandy loam, light yellowish brown (10YR 6/4) dry; ashy; moderate fine subangular blocky parting to granular structure; slightly hard, nonsticky, nonplastic; few fine roots; common fine tubular pores; 5% 1.0 to 4.0 cm coarse fragments; tonguing with very dark grayish brown (10YR 3/2) clay loam, strong fine subangular blocky structure; neutral (pH 6.6); wavy gradual boundary.

IIAb 36-56 cm--Very dark grayish brown (10YR 3/2) silty clay; strong fine subangular blocky structure; firm, sticky, plastic; few fine and coarse roots; many fine tubular pores; neutral (pH 6.8); clear smooth boundary.

IIBb 56 cm--Dark yellowish brown (10YR 3/4) gravelly clay; fine subangular blocky structure; plastic, sticky; interstitial pores; 35% stones; neutral (pH 6.7).

Remarks: (F. S. mapping unit 72). Parent material appears to be ash and underlying rock type is vesicular basalt.

Location: Maury Creek watershed, site #3, 0.16 km east of section market, center SE1/4, NE1/4 SW1/4, Sec. 23-24, T16S, R20E.

Setting: Ponderosa pine, Douglas fir, rabbit brush, thistle and bunchgrass make up the principal vegetation and both logging and grazing constitute the human influence. Evidence of erosion is slight.

Drainage and Permeability: Well-drained with a deep water table. The profile was dry from 0-20 cm. and moist from 20 to 56 cm. Permeability below the discontinuity is slow.

Stoniness: Class 0.

Description of Area: The site is located on a small bench below a broad ridge top. The aspect is north and the slope is 6%.

Profile MY4
May 27, 1973

Profile resembles the proposed Rarey series. The soil is readily eroded and carried to stream channels when roads, skid trails and animal trails cause water to be concentrated.

A — 0-8 cm--Very dark grayish brown (10YR 3/2) loam; very fine granular structure; very friable, slightly sticky, nonplastic; many fine roots; common fine interstitial pores; 15% 1 cm coarse fragments; neutral (pH 6.8); clear, smooth boundary.

AC — 8-74 cm--Very dark grayish brown (10YR 3/2) loam; weak medium subangular blocky structure; very friable, slightly sticky, nonplastic; few fine tubular pores; 15% 1 cm. coarse fragments; 15% charcoal fragments; neutral (pH 6.8); gradual, wavy boundary.

IIB — 74+ cm--Dark brown (10YR 3/3) silty clay loam; strong medium subangular blocky structure; firm; very sticky, very plastic; few fine roots; few very fine tubular pores; 30% 1.5 cm. coarse fragments; neutral (pH 6.8).

Remarks: This is a weakly developed soil that presents great difficulty in distinguishing between A and AC. There are clay skins in evidence in the IIB and there are micelia present. There is also a stone line and root hairs between the AC and the IIB. Parent material is volcanic ash and the rock is basalt.

Location: Maury Creek watershed, site#4, SE1/4, SW 1/2, NW 1/4, Sec. 30,. T17S, R21E at CCC Spring on Forest Service Road 1727.

Setting: Ponderosa pine and Douglas fir are the principal vegetation and the site has been logged. There is frost action evident and erosion is slight to moderate.

Drainage and Permeability: Well-drained with medium runoff; moderate permeability.

Stoniness: 1%.

Description of Area: The site is located on a convex side slope of about 0.8 ha on a northwest aspect with a slope of 38%. The elevation is 1.4 km.

Profile MY5
September 13, 1973

Profile is similar to Hankton soil series. The soil is fairly extensive and found on many of the north ridges of the Maurys.

01 2.5-0 cm--Forest litter, undecomposed needles, twigs.

A1 0-15 cm--Very dark brown (10YR 2/2) silt loam, dark gray (10YR 4/1) dry; weak very fine granular structure; slightly hard, firm, sticky, slightly plastic; abundant very fine roots; 20% by volume of 1 to 3 cm. coarse fragments; neutral (pH 6.6); abrupt smooth boundary.

B2 15-51 cm--Very dark brown (10YR 2/2) gravelly clay, very dark gray (10YR 3/1) dry; strong coarse subangular blocky structure with many large prismatic blocks, 6-10" in length; excessively firm, very sticky, very plastic; few very fine, fine and coarse roots; few fine interstitial pores in cracks between ped faces; 20 to 30% by volume of 5 cm coarse fragments; neutral (pH 6.8); gradual wavy boundary.

B3 51-76 cm--Dark grayish brown (10YR 4/2) gravelly clay; strong coarse subangular blocky structure with many prismatic blocks 6-10" in length; excessively firm; few coarse roots; interstitial pores in cracks; neutral (pH 6.8).

Remarks: The boundary at 15 cm probably forms an impermeable layer and causes the lower part of the profile to be wetter most of the year.

Location: Maury Creek watershed, site #5, NE 1/4, NE 1/4, NW 1/4 Sec. 1, T18S, R20E, on road connecting Forest Service Road 1727 and 1732. The section marker for T17S R20E, Sec. 36 is approximately 61 meters north of the site.

Setting: Vegetation is Ponderosa pine, pine grass, rabbit brush, juniper, and sage. Human influence consists of logging. Evidence of erosion is sheet.

Drainage and Permeability: Moderately well drained. The profile was dry to 15 cm, moist thereafter; slow permeability.

Stoniness: Class 2.

Description of Area: The site was located on a ridge extending to the Maury Creek drainage in a convex side slope with west aspect and slope of 3%. Elevation is 1.5 km.

Profile MY6
September 13, 1973

Profile is a cold variant of the Ruckles soil series and is representative of those soils found in the Indian Creek drainage on Forest Service Road 1887. The surfaces are easily eroded and respond unfavorably to disturbances such as frost action, skid trains, and poor management practices.

O1 2.5-0 cm--Forest litter.

A1 0-15 cm--Dark gray (10YR 4/1) and very dark grayish brown (10YR 3/2) gravelly silt loam; weak very fine granular structure; loose, nonsticky, slightly plastic; abundant fine roots; many very fine vesicular pores; 5% 0.5 cm coarse fragments; neutral (pH 7.2); abrupt smooth boundary.

A12 15-30 cm--Black (10YR 2/1) gravelly silt loam; weak fine subangular blocky structure; hard, slightly sticky, slightly plastic; common fine to medium roots; few fine tubular and interstitial pores; about 40% 1-30 cm coarse fragments; neutral (pH 6.8); clear smooth boundary.

IIB2t 30-51 cm--Very dark grayish brown (10YR 3/2) clay with interior of the peds of a dark grayish brown (2.5YR 4/2); strong fine angular blocky structure; extremely firm, very sticky, very plastic; few medium roots; cracks; more than 5% larger than 10 cm coarse fragments; neutral (pH 7.0); clear smooth boundary.

IIC-R 51+ cm--Light olive gray (5YR 6/2) (or greener) bedrock; massive structure; few medium roots; few cracks; greater than 5% larger than 10 cm coarse fragments; neutral (pH 6.8).

Remarks: The surface layers of the profile appear to be mixed ash. The A horizon is readily detached and has good infiltration.

Location: Maury Mountains, site #6, Sec. 9, T18S R20E, in the Indian Creek drainage system on Forest Service Road 1887.

Setting: Ponderosa pine, sage, juniper, and Idaho fescue are the principal vegetation with no evidence of human influence. The surface appears to be susceptible to erosion, as evidenced by a slight degree of bunch grass pedestaling.

Drainage and Permeability: Well-drained. The profile was dry within four inches of the surface and moist below that depth. Permeability is slow.

Stoniness: Class 3.

Description of Area: The site is located on a fairly level bench of 8.1 ha on a convex side slope. The slope is 14% and aspect is southwest. Elevation is about 1.5 km.

Profile NE1
September 14, 1973

Profile resembles the Elmore series. It is of limited extent on the lower Newsome Creek watershed. When disturbed, the soil becomes easily tranported. Activities of heavy equipment and domestic animals are readily discernible, leaving indications of its erosiveness.

A1 0-8 cm--Very dark brown (10YR 2/2) very stony silt loam, dark gray (10YR 4/1) dry; weak fine subangular blocky parting to granular structure; soft, sticky, slightly plastic; abundant fine roots; common fine tubular pores; 5% by volume of 0.2 to 2.0 cm coarse fragments; stones cover about 20% of surface; neutral (pH 6.6); clear smooth boundary.

B2t 8-46 cm--Very dark brown (10YR 2/2) gravelly clay loam, grayish brown (10YR 5/2) dry; moderate fine to medium subangular blocky structure; hard, sticky, plastic; common fine roots; common fine tubular pores; 5 to 10% by volume of 1 to 2 cm coarse fragments; neutral (pH 6.8); smooth diffuse boundary.

B3 46-122 cm--Dark grayish brown (10YR 4/2) gravelly loam, grayish brown to brown (10YR 5/2.5) dry; strong fine subangular blocky structure; hard sticky, plastic; common medium roots; common fine tubular pores; 5 to 10% by volume of 1 to 2 cm coarse fragments; neutral (pH 6.8).

C 122+ cm--Tuff.

Remarks: Parent material is believed to be dacitic basalt.

Location: Newsome Creek watershed, site #1, 0.8 km above fork leading to Sherwood Saddle on Forest Service Road 1646 and 3.2 km north of the Forest Service boundary. NE 1/4, SW 1/4, NE 1/4, Sec. 24 T17S, R18E.

Setting: Juniper and badly overgrazed bluebunch wheatgrass are all the evident vegetation. Human influence is grazing and close proximity to a ranch house. Erosion is heavy sheet and rill.

Drainage and Permeability: Well-drained, dry profile, of moderate permeability.

Stoniness: Class 4.

Description of Area: The profile is located in a road cut on a convex side slope adjacent to a stream channel. The aspect is south and slope is 14%. Elevation is about 1.2 km.

Profile NE2
May 28, 1973

Profile is from the Hankins series. The soil is extensive in the Newsome Creek uplands on north aspects. Disturbed soil is easily transported where water concentrates.

A 0-13 cm--Very dark brown (10YR 2/2) gravelly sandy loam; weak medium granular structure; loose, slightly sticky, slightly plastic; common fine roots; common fine interstitial pores; clear smooth boundary.

B1 13-20 cm--Dark brown (10YR 3/3) and very dark grayish brown (10YR 3/2) sandy clay; weak medium platy structure; firm, slightly sticky, plastic; common fine roots; common fine interstitial pores; 10% greater than 0.02 cm coarse fragments; many charcoal fragments; clear wavy boundary.

IIB21t 20-38 cm--Dark brown (10YR 3/3) heavy clay loam; strong medium subangular blocky structure; firm, slightly sticky, plastic; few very fine roots; few fine interstitial pores; 60% of up to cobble size coarse fragments; well-preserved charcoal fragments; stone-line at boundary.

IIB22t 38-58 cm--Dark brown (10YR 3/3) heavy clay loam; strong medium subangular blocky structure; many thick clay films; few fine roots; few fine interstitial pores; 40% of greater than 7.5 cm coarse fragments.

IIIC 58+ cm--Dusky red (2.5YR 3/2) gravelly clay, dark brown (7.5YR 3/2) dry; variegated peds, unconsolidated.

Remarks: The IIIC horizon has been postulated to contain zeolites and is probably of the John Day geologic formation. Parent material is highly weathered basalt colluvium.

Location: Newsome Saddle watershed, site #2, NW1/4 SW1/4, Sec. 34, T17S, R18E Forest Service Road 1731.

Setting: Ponderosa pine, squirrel-tail, rabbit brush, and bluebunch wheatgrass form the predominant vegetation and human influence has consisted of logging, thinning, scarification, and burning. The evidence of erosion is both sheet and rill compounded by frost action.

Drainage and Permeability: Well-drained, profile moist from 0 to 46 cm, wet below that. Water table appears to be deep, permeability is slow.

Stoniness: Class 1.

Description of Area: The site is located in mountainous uplands in a concave side slope of northwest aspect. Slope is 11 to 15% and elevation is approximately 1.6 km.

Profile SP2
September 15, 1973

Profile resembles the Day series and the soil is a gravelly phase. Characteristically this soil type contributes to turbidity in the Lost Creek drainage in most runoff events.

A1 0-5 cm--Reddish brown (5YR 5/3) gravelly loam, reddish brown (5YR 5/3) dry; moderate very fine subangular blocky structure; hard, slightly sticky, plastic; common fine roots; many fine vesicular pores; 30% by volume of 1 cm. coarse fragments; neutral (pH 6.8); clear, smooth boundary.

AB1 5-15 cm--Reddish brown (5YR 4/3) gravelly silty clay, reddish brown (5YR 5/4) dry; strong fine subangular blocky structure; slightly sticky, very plastic; few fine roots; few fine tubular and interstitial pores; 30% by volume of 1 cm. coarse fragments; neutral (pH 6.8); clear smooth boundary.

AC1 15-25 cm--Yellowish red (5YR 4/6) gravelly silty clay, reddish brown (5YR 4/4) dry; weak medium prismatic structure; slightly sticky, very plastic, very few medium roots; few fine tubular pores; 30% by volume of 1 cm coarse fragments; neutral (pH 7.2); clear smooth boundary.

AC2 25-51 cm--Reddish brown (5YR 4/4) gravelly clay, reddish brown (5YR 4/3) dry; moderate coarse blocky structure; sticky, plastic; very few fine roots; 30% by volume 10 cm. coarse fragments exhibiting strong effervescence; moderately alkaline (pH 8.4); clear smooth boundary.

C 51-102 cm--Reddish brown (5YR 4/4) very gravelly clay; 30% by volume of 10 cm coarse fragments exhibiting a strong effervescence; moderately alkaline (pH 8.4).

Remarks: The parent material is alluvium and the type of rock is mixed.

Location: Sheep Rock watershed, site #2, on tributary to Sheep Rock Creek (east side of drainage), 1.9 km north of barn on road, NW 1/4, SW 1/4, Sec. 30, T16S, R21E.

Setting: Sagebrush, bunchgrass, rabbitbrush, and juniper constitute the vegetation. Grazing is the major human influence. There is evidence of sheet and rill erosion and the stream channel is gullied out.

Drainage and Permeability: Well-drained with a dry profile. Water table is deep.

Stoniness: Class 1.

Description of Area: The site is located in rolling uplands on an alluvial fan with a north aspect. The fan is gullied with ephemeral drainages. Slope is 8%. Elevation is 1.1 km.

Profile KM1
September 14, 1973

Rarey (Proposed)

Profile closely resembles the Rarey soil series and is representative of those soils predominating on the Klootchman Creek watershed. They are readily eroded when water is concentrated on them and appear to be easily transported. In riparian sites they frequently are deeply incised.

01	5-0 cm--Forest litter.
A11	0-6 cm--Very dark brown (10YR 2/2) sandy loam, dark brown (7.5YR 4/2) dry; weak fine subangular blocky structure; loose, nonsticky, slightly plastic; abundant very fine roots; 2% by volume of greater than 2 cm coarse fragments; neutral (pH 6.6); clear smooth boundary.
A12	6-15 cm--Very dark brown (10YR 2/2) sandy loam, dark brown (7.5YR 4/2) dry; weak medium subangular blocky structure; firm, nonsticky, slightly plastic; abundant fine and very few medium roots; many fine tubular pores; 2% by volume greater than 2 cm. coarse fragments; neutral (pH 6.8); clear wavy boundary.
B1	15-30 cm--Dark brown (7.5YR 3/2) sandy loam, dark brown (7.5YR 4/2) dry; moderate medium subangular blocky structure; firm, nonsticky, slightly plastic; common coarse roots; many fine tubular pores; less than 5% by volume of greater than 4 cm coarse fragments; neutral (pH 6.8); diffuse wavy boundary.
B2	30-74 cm--Dark brown (7.5YR 3/2) sandy loam, pinkish gray (7.5YR 6/2) dry; moderate medium subangular blocky structure; firm, nonsticky, slightly plastic; common coarse roots; common fine tubular pores; 5% by volume of 1 cm. coarse fragments; neutral (pH 7.0); gradual wavy boundary.
B3	74-102 cm--Dark brown (7.5YR 3/2) loamy sand, pinkish gray (7.5YR 7/2) dry; weak coarse subangular blocky structure; firm, nonsticky, nonplastic; common coarse roots; few fine tubular pores; 5 to 10% by volume of 1 cm coarse fragments; neutral (pH 6.8).
IIBt	102-152 cm--Dark yellowish brown paleosol.
Remarks:	Charcoal fragments of up to 1 cm were abundant throughout the profile from 0 to 74 cm. The parent material is volcanic ash. The rock type is basalt.
Location:	Klootchman Creek watershed, site #1, 0.56 km southeast of Shearing Spring and 69 meters east on Forest Service road 1546H, in the roadcut on Klootchman Creek. NW 1/4, NW 1/4, Sec. 17, T18S, R19E.
Setting:	Dominant vegetation is Ponderosa pine, pine grass, and juniper. Human influence consists of logging and thinning operations. There is evidence of erosion at the site.

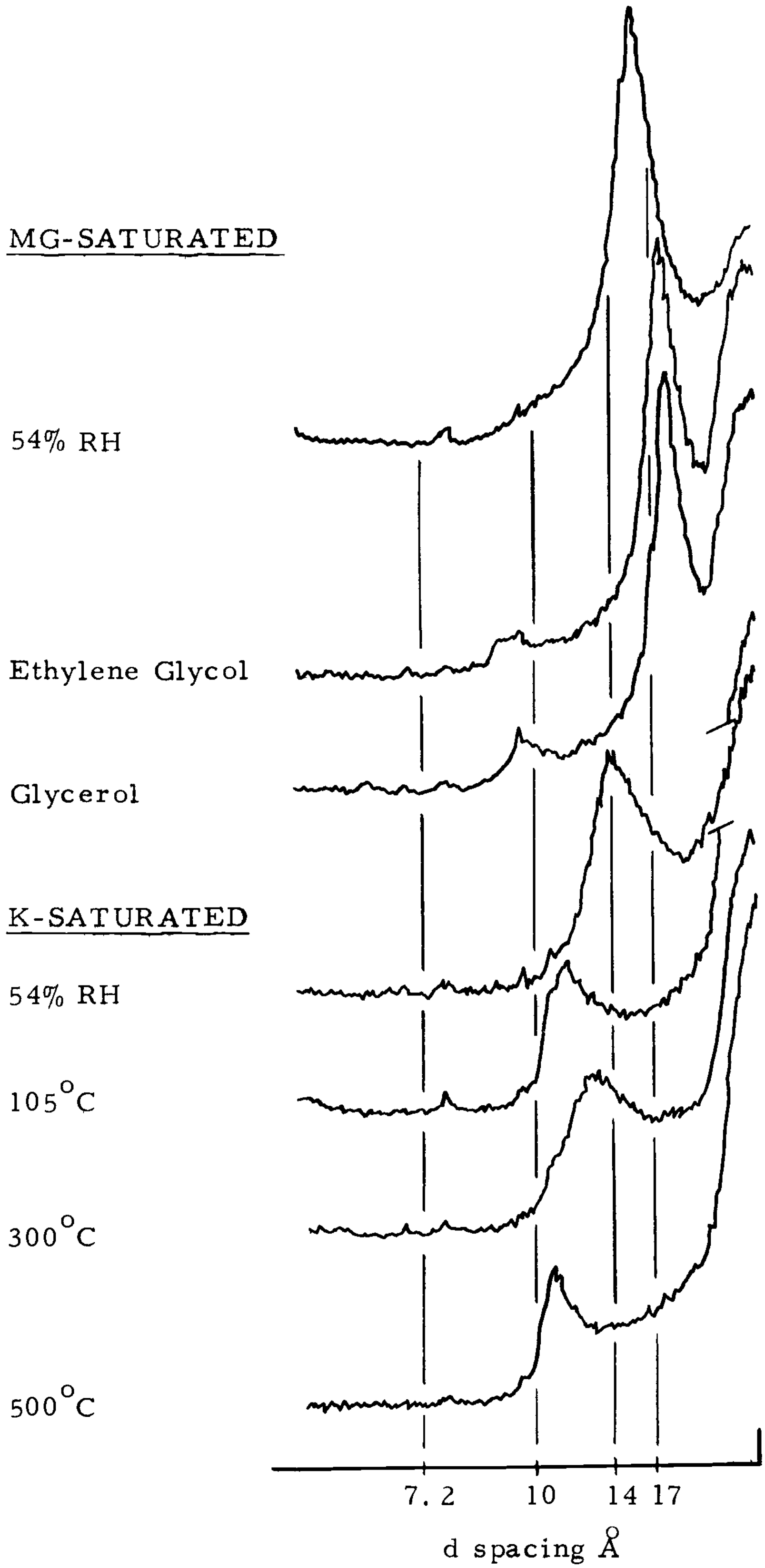
Drainage and Permeability: Well-drained profile dry to 102 cm.; moderate permeability

Stoniness: Class 1.

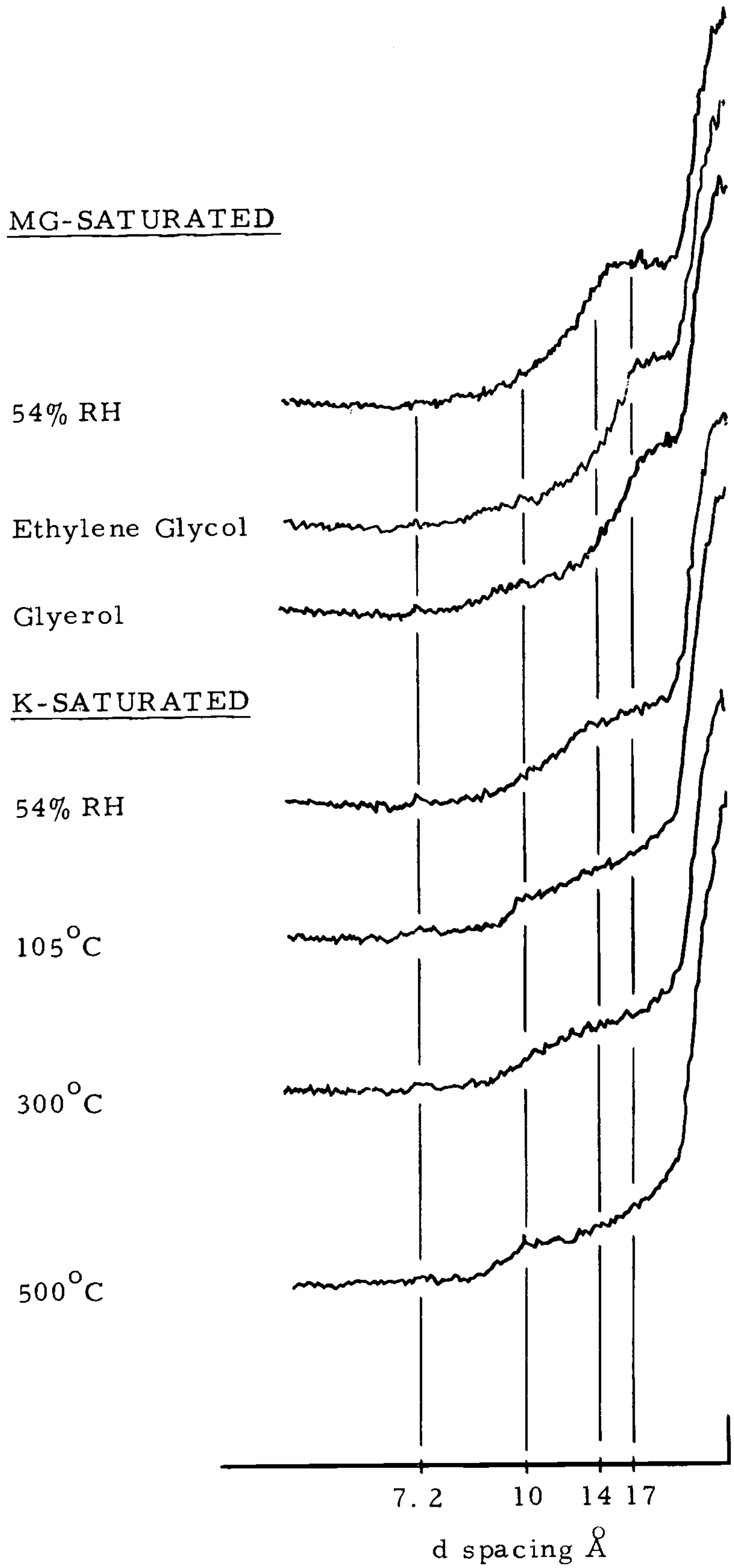
Description of Area: The site is located on a convex side slope in rolling uplands, deeply dissected with drainage ways. The aspect is south and slope is 17%. Elevation is approximately 1.6 km.

APPENDIX B

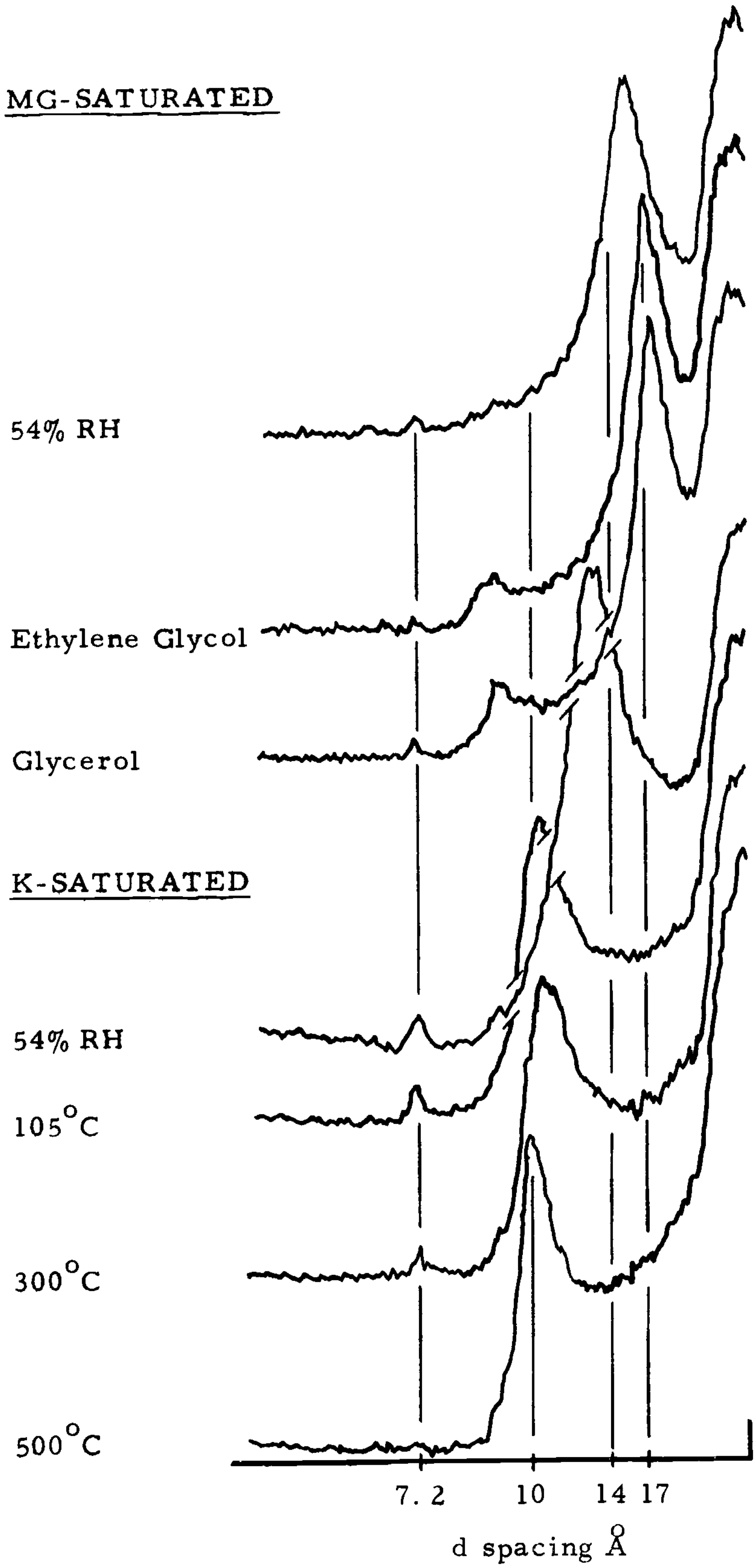
X-RAY DIFFRACTION PATTERNS FOR SOILS CAPABLE OF PRODUCING LONG-TERM TURBIDITY



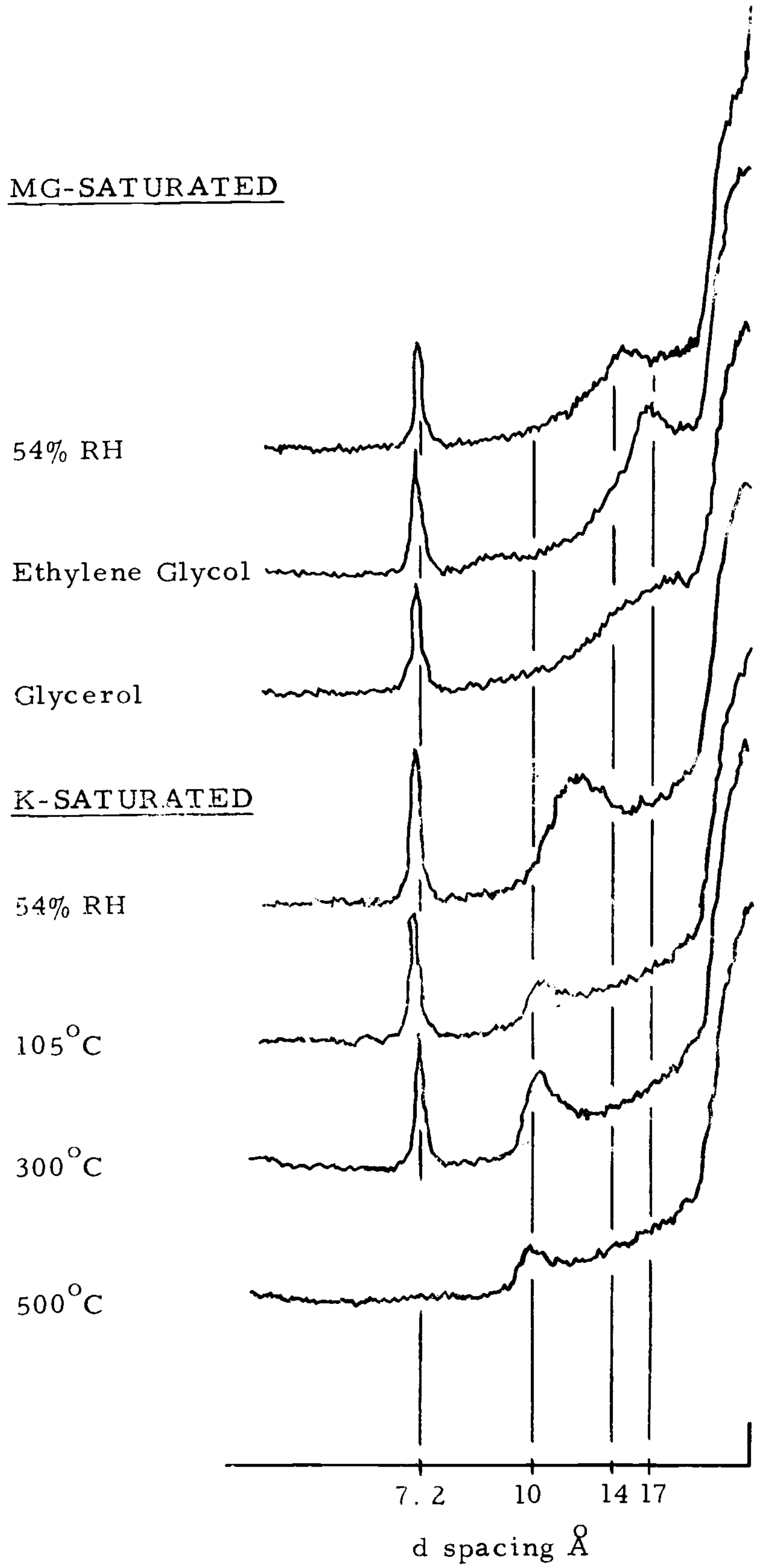
X-ray diffraction pattern for the clay fraction of suspended sediment from the North Fork, February 19, 1972.



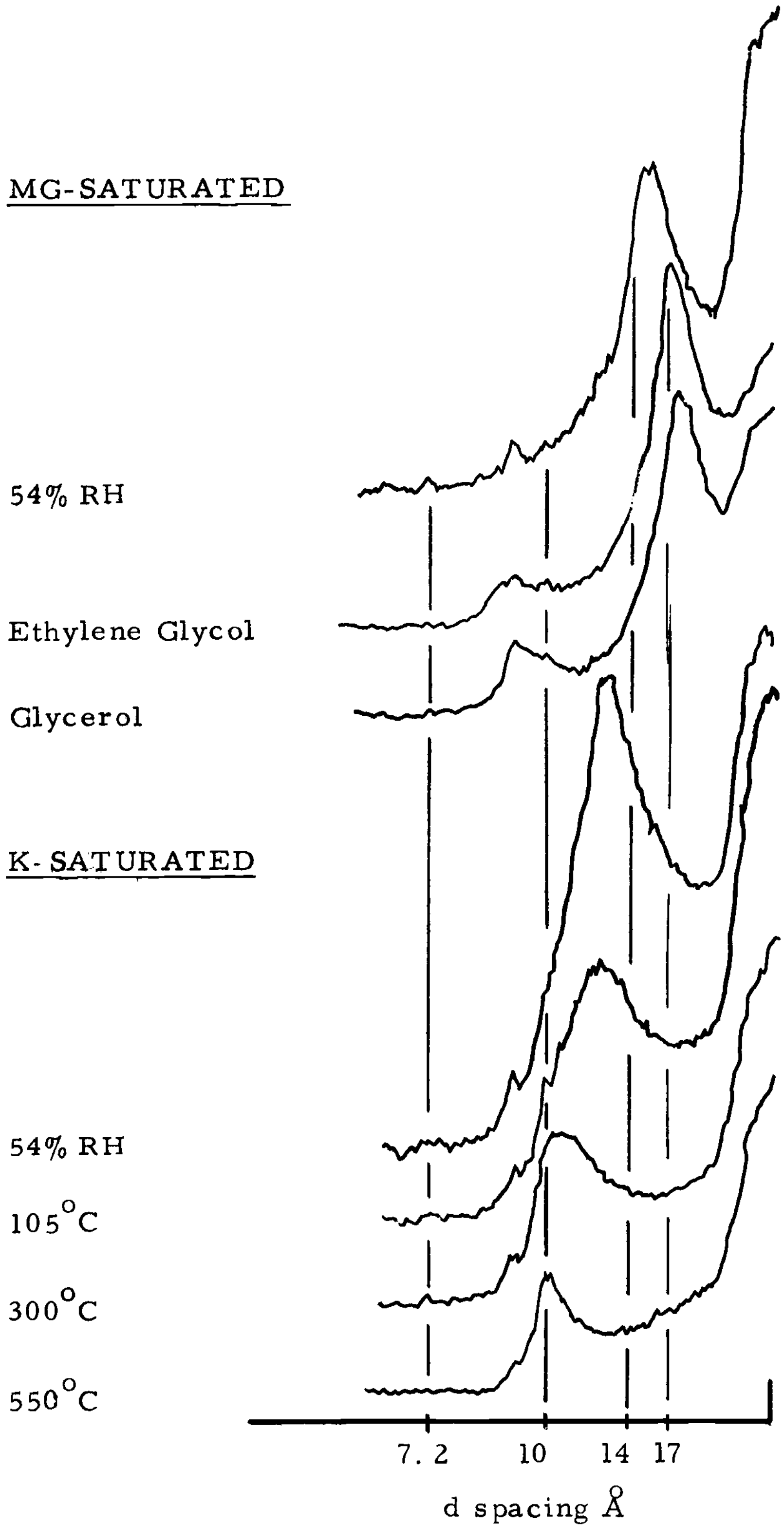
X-ray diffraction pattern for the clay fraction of suspended sediments from the South Fork, February 20 1972.



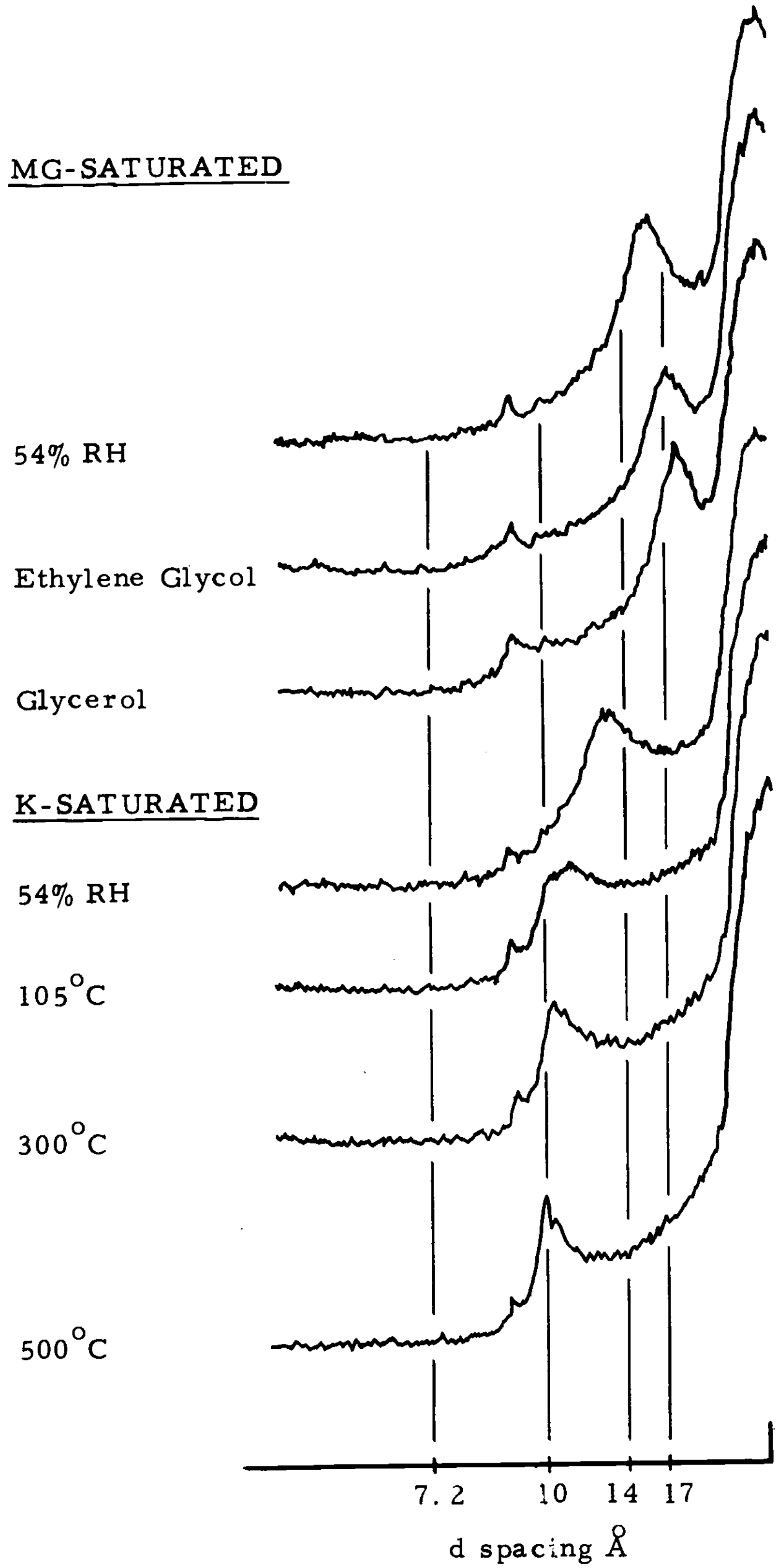
X-ray diffraction pattern for the clay fraction of suspended sediments from Lost Creek; sample # LT-comb.



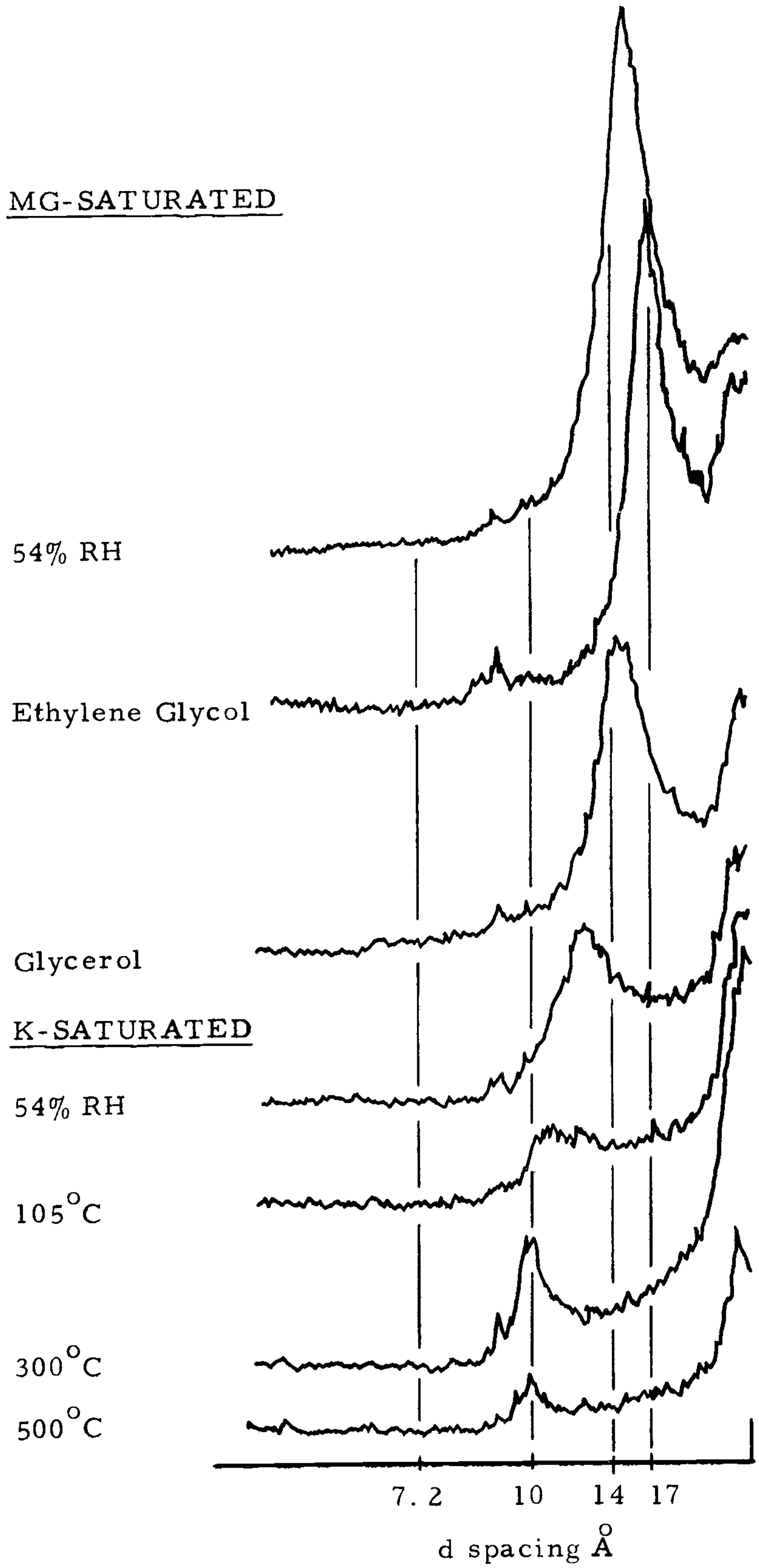
X-ray diffraction pattern for the clay fraction of suspended sediment from the Bear Creek arm of the Prineville Reservoir; August 8, 1972.



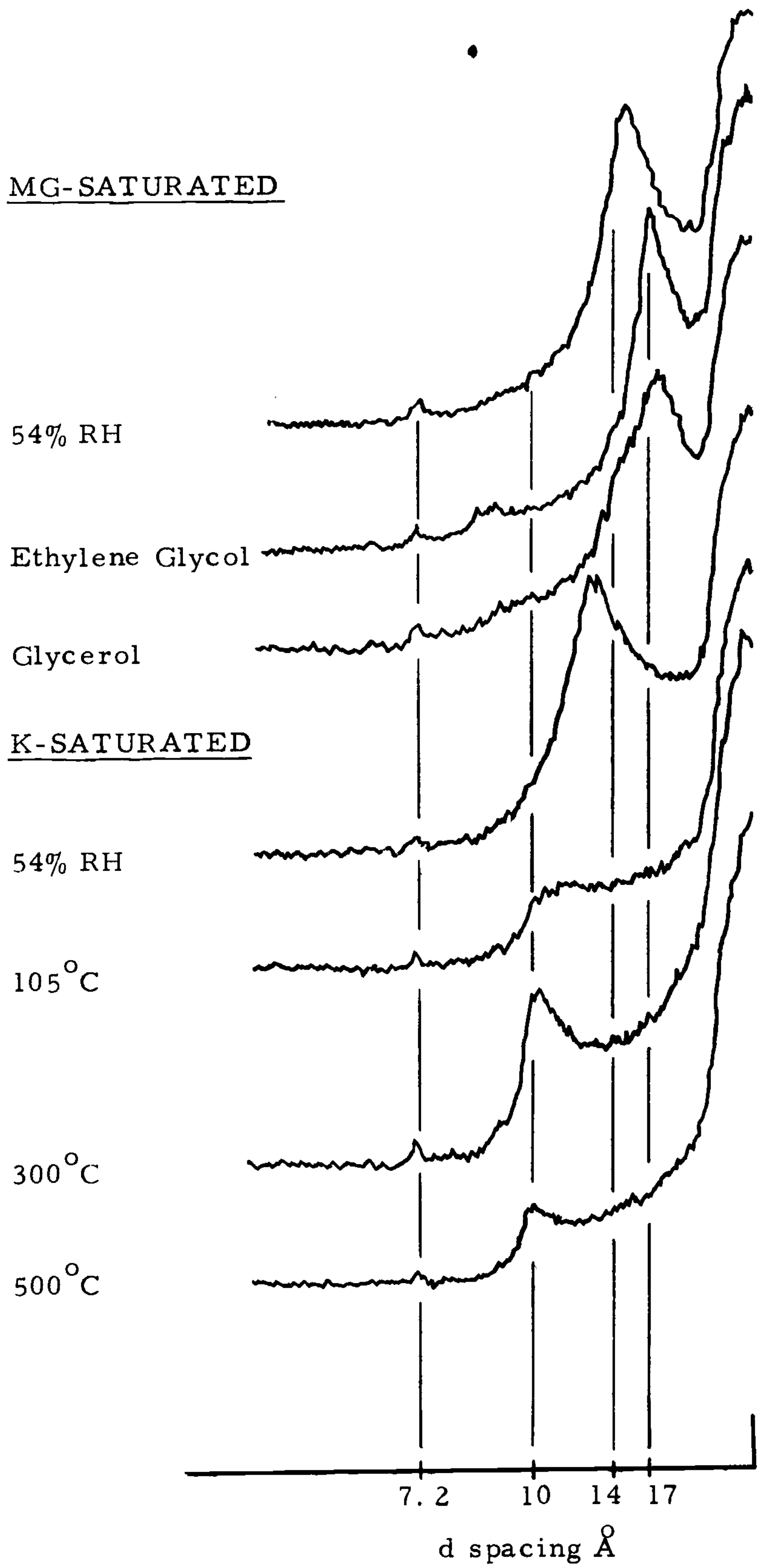
X-ray diffraction pattern of the clay fraction of suspended sediments from the Crooked River, February 20, 1972.



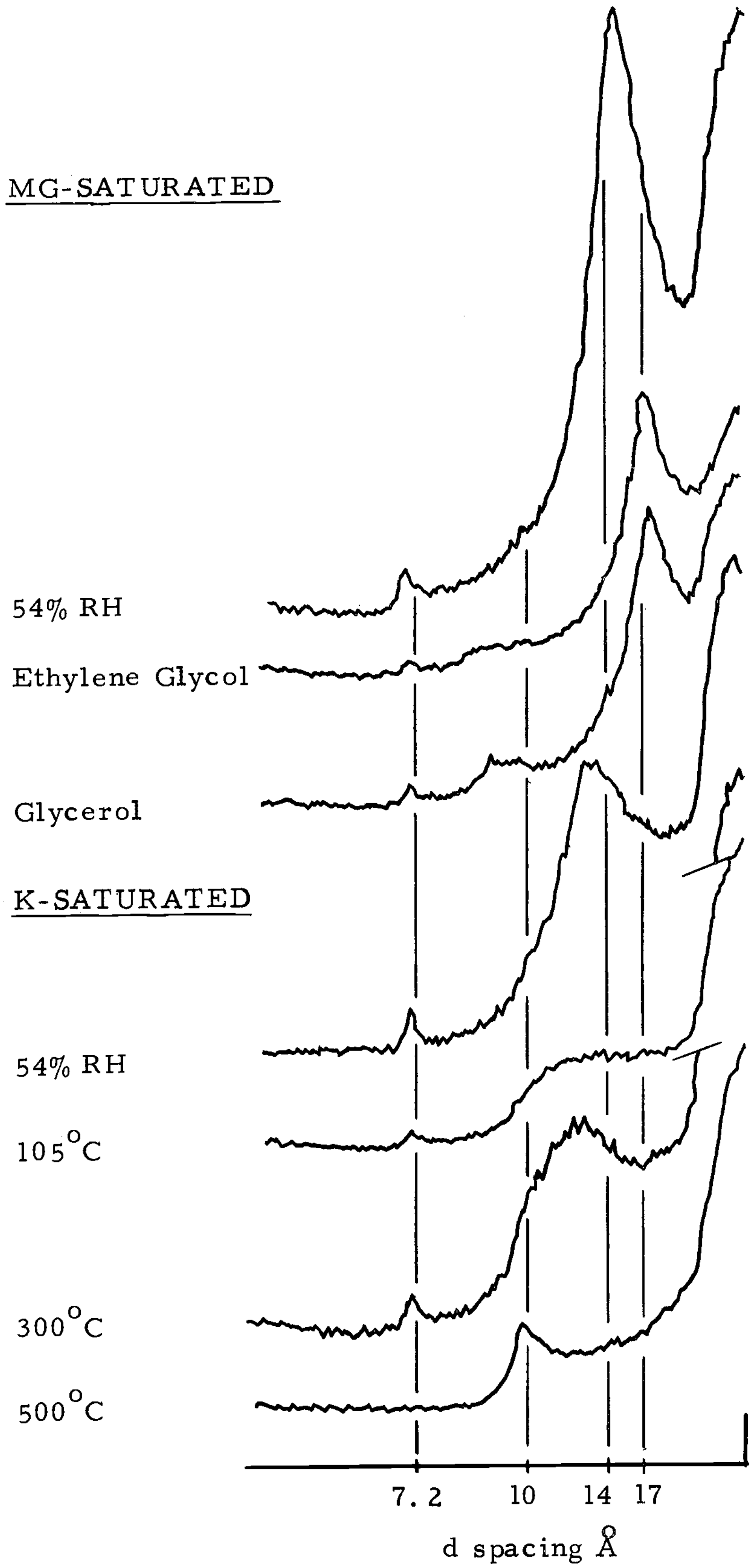
X-ray diffraction pattern for the clay fraction of the suspended sediments from Eagle Creek; sample # 19F1200.



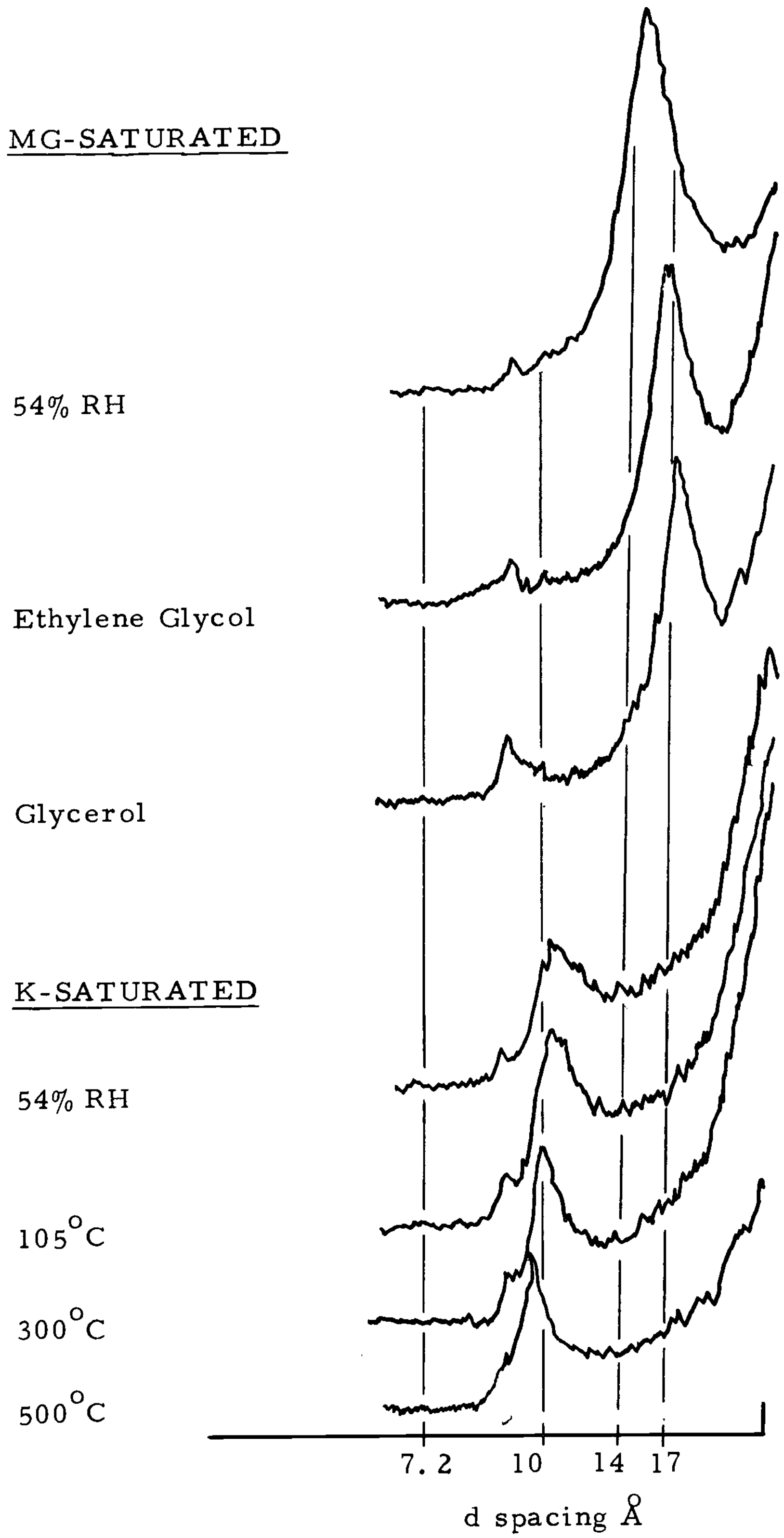
X-ray diffraction pattern for the clay fraction of suspended sediments from Conant Creek, January 22, 1972.



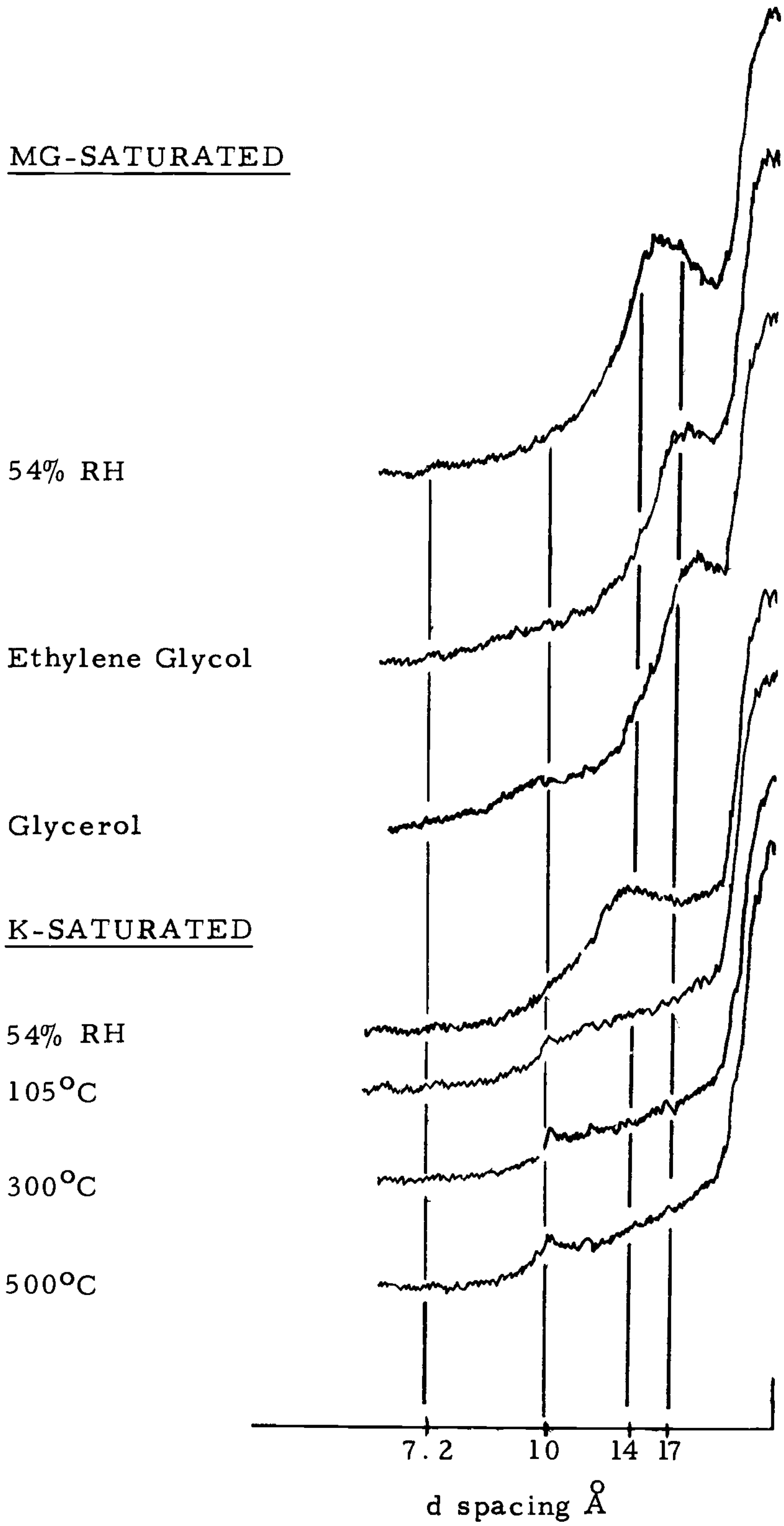
X-ray diffraction pattern for the clay fraction of the suspended sediments near Jasper Point (Antelope site) on the Prineville Reservoir, August 8, 1972.



X-ray diffraction pattern of the clay fraction of the suspended sediments near the Prineville Dam of the Prineville Reservoir; April 22, 1972.



X-ray diffraction patterns of the clay fraction of the suspended sediments from Camp Creek, January 23, 1972.



X-ray diffraction pattern for the clay fraction of suspended sediments from Beaver Creek, January 22, 1972