Sediment Yield Analysis of Reservoir #1, Bull Run Watershed, West Cascade Mountains, Oregon

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THESIS APPROVAL

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ABSTRACT


Title: Sediment Yield Analysis of Reservoir #1, Bull Run Watershed, West Cascade Mountains, Oregon.

Bull Run Watershed was set aside in late the 1800s as the water supply source for the City of Portland. Other than two dams being constructed, Reservoir #1 (1929) and Reservoir #2 (1962), development of the land had been minimal as public access was restricted. In the early 1960s, land management changed with increased road building and timber removal raising concerns about increased sediment discharge into the reservoirs. The objective of this study is to evaluate how much and how fast the sediment has accumulated in Reservoir #1, and to determine if the rate of sediment accumulation has changed over time.

Three methods are utilized: 1) differencing map comparing pre- and post-impoundment sediment conditions, 2) analysis of tree-stumps on reservoir floor, and 3) gravity coring of reservoir sediment. Combining these methods, sediment volume is estimated between 254,000-422,000 cubic meters (332,000-552,000 cubic yards) and the rate of accumulation between 11.5-19.1 tonnes/km²/yr, reflecting a relatively low sediment yield rate.

Two anomalous event-layers were identified in gravity cores collected. These are interpreted to be the 1964 flood and the 1972 North Fork Slide. Using these two
events, sediment yield rate was divided into different historical segments: 15.33 (1930-1965); 43.62 (1965-1972); and 17.00 tonnes/km²/yr (1972-1993). The increase from 1965-1972 is attributed to either residual affects from the 1964 flood and/or changes in land management activities during this time.

The source of the reservoir sediment is primarily from upper tributaries, with 20 percent being attributed to the anomalous events. Smaller amounts of sediment come from the reservoir side walls as lake levels raise and lower.

Suspension and turbidity conditions in the reservoir are affected by the dynamics of the drainage system including seasonal fluctuations. Turbidity remains high at the upper reaches of the reservoir before settling out closer to the dam. Some sediment possibly leaves the reservoir over the spill-way or when water is removed for power production.
SEDIMENT YIELD ANALYSIS OF RESERVOIR #1, BULL RUN WATERSHED, WEST CASCADE MOUNTAINS, OREGON

by

DOANN M. HAMILTON

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
GEOLOGY

Portland State University
1994
ACKNOWLEDGMENTS

This study was requested and funded by the City of Portland, Bureau of Water Works. They provided data, equipment, and personnel to assist on this project. I especially want to thank Doug Bloem the coordinator on this project and Roland Hege, Bureau of Water Works civil engineering surveyor.

There were also many volunteers that made this project possible, and I hope to encourage other undergraduates to get involved for the experience and for the simple fact that some of the graduate projects need the assistance. I especially want to thank Sheryl Zinsli and LeNoi Hayward for time, patience, and good humor along with Daryl Wienke who was my only paid assistant. Other volunteers came from Portland State University diving instructor and assistants: Larry Nelson, Pat Adams, Doug Robinson, and Debi Strong.

An enormous appreciation goes to my advisor Curt D. Peterson who read my quarterly reports and drafts promptly. I appreciate his honest and open communication letting me know his schedule so we could work around it and together. Most of the time he would just stop and put aside his work at a moments notice when I had a question. This promptness helped keep me focused and on schedule by noting problem areas and addressing these issues early.

Finally, I want to thank all of those who fed me and gave me moral support. There are many but mainly: Ken Walsh, Brett Brodersen, Kristi Vockler, and Maureen Soar. Thanks to Louie Edmonds for cutting open the core tubes, Jan Larson for her friendship and cheep rent, and finally Marilyn Jenks my family.

I dedicate this thesis in memory of Elaine Forsgard.
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INTRODUCTION

This study, which examines causes and effects of sedimentation in Bull Run Reservoir #1, was conducted at the request of the City of Portland, Bureau of Water Works. The Bull Run Watershed serves as the primary water source for the City of Portland and several outlying communities.

On June 17, 1892, President Benjamin Harrison signed a proclamation declaring the Bull Run area a National Forest Reserve, which provided federal protection of the water supply from the Bull Run River and allowed the Portland Water Committee (now called the Bureau of Water Works) to acquire land parcels and riparian rights in the reserve. In response to increasing demand for water, two dams were constructed to store winter run-off. Reservoir #1, completed in 1929, holds a capacity of 34 billion liters (9 billion gallons). The capacity was increased to 38 billion liters (10 billion gallons) in 1954 with the installation of gates on the overflow. In 1962, a second dam was completed, just below Reservoir #1, creating Reservoir #2 with a capacity of 26 billion liters (7 billion gallons). Reservoir #2 is usually held close to full, with maximum drawdowns averaging 2.5-3 meters (8-10 feet). To help keep Reservoir #2 full, Reservoir #1 is drawn down during the summer months when water demand increases and rainfall decreases. These drawdowns of Reservoir #1 decrease its volume by an average of one-third. The maximum drawdown occurred in 1987, at 23 meters (75 feet) below full-pool height (319 to 296 meter, 1045 to 970 foot elevation) (City of Portland, 1991).

On April 28, 1904, the United States Congress passed Public Law #206, The Bull Run Trespass Act, which limited public access to the watershed. The restricted
area included the Bull Run Watershed plus several key areas outside the watershed. This restricted area was called the Bull Run Division and is now known as the Bull Run Management Unit. (Figure 1)

To protect this area, the United States Forest Service has been responsible for land management practices. These practices changed during the early 1960s with the passage of Public Law #86-517, The Multiple-Use/Sustained Yield Act, which "acknowledged the need for research and watershed protection, but . . . also called for improved recreational facilities, fishing grounds, and roads and trails. It further clarified the Forest Service logging policy, encouraging a timber management program which would produce revenue while not endangering the health of the forests." (Short, 1983)

These changes permitted increased road construction and timber harvest within the watershed. The historical records on timber harvesting, road construction, reforestation, and fuel treatment conducted within the acres draining into Bull Run Reservoir #1 are shown in Appendix A, Tables A1-A3 and Figures A1-A4. Most of these activities started in 1958 with road construction starting in 1956. Road construction peaked in 1962 and the majority of the timber harvest was conducted during the 1960s and early 1970s. (U.S. Department of Agriculture, Forest Service, 1992)

Figure 2 shows a composite of aerial photographs around Reservoir #1, prior to these changes. Figure 3 shows a composite of the same area, about 15 years later when the increase in roads and timber harvest can be noted.

Concerns grew during the 1960s and 1970s as to whether these changes in land management practices could reduce water quality by increasing sediment discharge into the drainage system. In February 1977, Portland City Council passed Resolution #31832 to be presented to Congress. This resolution recommended that
Figure 1: Bull Run Management Unit enclosing the Bull Run Watershed.  
(Scale 1:220,383)
Figure 2: Composite aerial photographs (1958-1959) around Reservoir #1. In this configuration, only one main road along the north side of the river can be observed. Timber reduction has also not begun. (Scale 1:64,985)
Figure 3: Composite aerial photographs, 1984, around Reservoir #1. Comparing this composite to Figure 2, increased road construction and timber reduction can be noted. (Scale 1:63,360)
the City of Portland be "co-equal with the Forest Service in planning, managing, and monitoring the Reserve" (Short, 1983). On November 23, 1977, President Jimmy Carter signed Public Law #95-200, which ensured participation by the City of Portland in all policy matters that affect the water supply.

The City of Portland, Bureau of Water Works, funded this study to determine the amount of sediment collected within Reservoir #1 from the time of its creation in 1929. The purpose was also to determine the rates and locations of sediment accumulation, and if possible, the source of the sediment. The Bureau of Water Works wanted to determine whether most of the sediment came from the major tributaries and/or from the side walls of the reservoir. The consideration was that the sediment from the upper tributaries could be related to land management practices, while sediment from the side walls could reflect the Bureau of Water Work's practice of raising and lowering lake levels to meet water demand.

The goals of this study are to: 1) establish the distribution patterns of the sediment in the reservoir to help identify sediment sources, 2) calculate sedimentation rates and determine any historical changes in these rates, and 3) to better predict hydrographic conditions leading to anomalous turbidity in Bull Run Reservoir #1.

The objectives used to accomplish these goals include: 1) estimate post-impoundment sediment thickness for the volume of basin fill, 2) calculate the sediment yield rate based on time-stratigraphic markers thereby identifying any historical changes in that rate, and 3) identification of sediment sources and mechanisms of sediment suspension and transport in the reservoir.
STUDY AREA

Bull Run Watershed lies in the Cascade Range of northwest Oregon bounded by latitudes 45° 35' in the north and 45° 25' 30" in the south; and longitude 122° 12' 30" in the west and 121° 47' 30" in the east. The watershed is mapped on portions of several USGS 7 1/2-minute quadrangles: Multnomah Falls, Tanner Butte, and Wahtum Lake to the north; and Bull Run, Brightwood, Hickman Butte, and Bull Run Lake to the south.

The watershed is located in east Multnomah County and northeast Clackamas County. East of the watershed is Mt. Hood, elevation 3,426 meters (11,239 feet). To the north are the Columbia River and the communities of Corbett, Multnomah Falls, Dodson, and Bonneville. To the west are Portland, at approximately 42-69 kilometers (26-43 miles), and Gresham. Sandy, Cherryville, Alder Creek, Brightwood, Wemme, and Zigzag communities lie to the south. (Figure 4)

Access to the watershed is by I-84 to the north and U.S. Highway 26 to the south. The major entrance into the watershed is from the west on U.S. Forest Service road FS10 which extends the entire east-west length of the watershed, exiting at Lolo Pass to the east. This road is accessed via Ten Eyck Road, a county road from Sandy. Entry can also be obtained from Zigzag on FS18, which leads to Lolo Pass; from Brightwood on FS14; or from Larch Mountain on FS20. Major Forest Service roads are blacktopped, with secondary roads graveled.

The watershed drains 277 square kilometers (107 square miles), extending 31 kilometers (19 miles) east to west and 19 kilometers (12 miles) north to south. Bull Run River, the watershed's major river, flows first to the northwest from
Figure 4: Location of study area. Bull Run Watershed is within Bull Run Management Unit.
headwaters at Bull Run Lake (elevation 963 meters, 3160 feet), capacity 15 billion liters (4 billion gallons) (Allen and others, 1973), then turns to the southwest. Bull Run River flows through steep mountains for approximately 32 kilometers (20 miles), then through foothills for approximately 8 kilometers (5 miles). Major tributaries are Blazed Alder, Fir Creek, and North and South Forks of the Bull Run River (Figure 5).

The topography is shaped by glaciation above the 610 to 760 meter (2,000 to 2,500 foot) elevation, volcanic mountain building, and stream erosion and deposition (Beaulieu, 1974). Topographic elevation decreases from east to west. Maximum elevations in the east are Buck Peak at 1448 meters (4751 feet), Hiyu Mountain at 1422 meters (4664 feet), and Preachers Peak at 1389 meters (4556 feet) (Figure 5). The lowest elevation in the west is 152 meters (500 feet) and occurs along the Bull Run River at the Sandy entrance on FS10. Mean elevation of the watershed is approximately 777 meters (2550 feet).

Climate in the watershed is strongly influenced by storms moving eastward from the Pacific Ocean. Due to the orographic effect, moist unstable air changes to rain as the air rises over the Cascade Range. Approximately 70 percent of the watershed's precipitation falls between October and March. Only 10 percent falls during June, July, and August (Stephens, 1964). In an average year, snow starts accumulating in the higher elevations in late October and often remains until mid-June (Stephens, 1964). Precipitation records within the reservoir are listed in Table 1.

The two major vegetation zones within the watershed are the Humid Transition and the Canadian zones. The Humid Transition zone extends up to approximately the 914 meter (3,000 foot) elevation and contains the following conifers: Douglas fir, western hemlock, western red cedar, and grand fir. Red alder
Figure 5: Watershed boundary and major rivers. Locations of several gauge stations of previous studies are marked, along with major peaks. The three major lakes are Bull Run Lake, Bull Run Reservoir #1, and Bull Run Reservoir #2. (Rinella, 1987)
and big leaf maple are the most prevalent hardwood trees. The dominant shrub species include vine maple, salal, red huckleberry, and dull Oregon grape. Herbaceous understory vegetation includes swordferns, oxalis, trillium, and vanilla leaf. (Stephens, 1964)

The Canadian zone extends from the Humid Transition zone to nearly 1830 meters (6,000 feet) and includes the following: mixed stands of Douglas fir, silver fir, noble fir, western hemlock, mountain hemlock, alpine fir, western red cedar, Englemann spruce, lodgepole pine and western white pine. Shrub species include blue huckleberries, rhododendron, rusty Menziessia, vine maple, and Douglas maple. Herbaceous vegetation includes beargrass, bunch berry, vanilla leaf, inside-out flower, Clintonia, and devil’s club. (Stephens, 1964)

Table 1: Precipitation Records
(data obtain from City of Portland, Bureau of Water Works).

<table>
<thead>
<tr>
<th>Station</th>
<th>Elevation</th>
<th>Average Year of Lowest</th>
<th>Largest Year of Lowest</th>
<th>Lowest Year of Lowest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>meters (ft)</td>
<td>cm (in)</td>
<td>yr total</td>
<td>cm (in)</td>
</tr>
<tr>
<td>Headworks</td>
<td>229 (750)</td>
<td>203 (80)</td>
<td>350 (138)</td>
<td>1933</td>
</tr>
<tr>
<td>(1899-1992)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Fork (*)</td>
<td>323 (1060)</td>
<td>340 (134)</td>
<td>444 (175)</td>
<td>1990</td>
</tr>
<tr>
<td>(1980-1992)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blazed Alder Cr</td>
<td>774 (2540)</td>
<td>295 (115)</td>
<td>361 (142)</td>
<td>1990</td>
</tr>
<tr>
<td>(1981-92) (@)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* station #14138900 see Figure 5 @ station #14138800 see Figure 5

The watershed contains three major lakes: Bull Run Lake, Reservoir #1, and Reservoir #2. Bull Run Lake was created in a glacial cirque at the headlands when a prehistoric landslide blocked the drainage path (Sherrod and Pickthorn, 1989). The lake drains naturally through a porous bottom to re-appear approximately 1.6 kilometer (one mile) downstream as a series of large springs approximately 53 meters (175 feet) below the elevation of the lake surface. In 1915, clay was
deposited on the bottom of Bull Run Lake in an attempt to eliminate porous drainage and create the first site for water storage. Also at this time, a small log dam was constructed. With these two alterations, the water-level was increased six meters (twenty feet). (Allen and others, 1973)

Reservoir #1 was created in 1929 with the construction of a concrete gravity arch-dam. The spillway crest was at the 316 meter (1036 foot) elevation, and the foot of the dam at approximately the 265 meter (870 foot) elevation. In 1954, gates were added, raising the spillway crest to the 319 meter (1045 foot) elevation. The reservoir measures approximately 483 meters (0.3 miles) wide by 5.5 kilometers (3.4 miles) long, and holds a capacity of 38 billion liters (10 billion gallons). Construction of a power plant at the base of the dam was completed on December 28, 1981. Power is generated only when water is discharged to refill Reservoir #2. Water is never withdrawn from storage solely for power generation, unless the reservoir is full (City of Portland, 1991).

Reservoir #2 was created by an earthen rock-filled dam with a detached concrete spillway completed in 1962. The spillway crest is at the 262 meter (860 foot) elevation and the foot is at the 229 meter (750 foot) elevation. The reservoir measures approximately 644 meters (0.4 miles) wide by approximately 6.4 kilometers (4 miles) long, and holds a capacity of 26 billion liters (7 billion gallons) (City of Portland, 1991).

This study concentrates on sedimentation in Bull Run Reservoir #1.
REGIONAL GEOLOGY

Bull Run Watershed lies in the northwestern section of Oregon’s Cascade Range. The Cascade Range is divided into the Western Cascades and the High Cascades. The Western Cascades, the older of the two, ranges in age from late-Eocene to Miocene. The High Cascades are associated with Pliocene and Quaternary volcanism of north-south trending composite volcanoes. In this study area, Mt. Hood is the nearest volcano of this type (Wise, 1969).

The underlying geologic unit exposed in the Bull Run Watershed is the Miocene Columbia River Basalt Group (Vogt, 1981) which consists of flood basalts that entered the area from fissures in the east (Tolan and Beeson, 1984). This group is topped unconformably in the west by the upper-Miocene to lower-Pliocene Rhododendron Formation and in the east by Pliocene and Quaternary volcanic rock associated with the High Cascade volcanism (Beaulieu, 1974) (Figure 6). Outside the Watershed, the Columbia River Basalt Group unconformably overlies either the upper-Oligocene to lower-Miocene Stevens Ridge, Fifes Peak, or Eagle Creek formations, depending on the location (Tolan and Beeson, 1984). Each of these formations is associated with ancestral Western Cascades volcanism (Figure 7).

Columbia River Basalt Group

The Columbia River Basalt Group consists of a sequence of subaerial tholeiitic flood basalts that erupted from north-northwest trending fissures in northeastern Oregon, eastern Washington, and western Idaho. These large-volume, low-viscosity flows spread out from the vents toward the west, accumulating on the Columbia Plateau (Tolan and Beeson, 1984). The Columbia River Basalt Group is
<table>
<thead>
<tr>
<th>Period</th>
<th>Epoch</th>
<th>UNIT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Holocene</td>
<td>Surficial Deposits</td>
<td>Surficial deposits: Including landslide debris, terrace gravels, and glacial moraine and outwash</td>
</tr>
<tr>
<td></td>
<td>Pleistocene</td>
<td>Qvic</td>
<td>Quaternary volcanic rock: Includes hornblende andesite volcanic-intrusive complex (Qvic), basalt and andesite flows (Qba), and cinder cones (Qcc).</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Pliocene</td>
<td>Qvic &amp; Qcc</td>
<td>Pliocene volcanic rock unit: Greater than 610 meters (2,000 ft) of basalt andesite flows and fewer basalt flows and pyroclastic breccias and tuffs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Troutdale Form.</td>
<td>Troutdale Formation: Up to 60 meters (200 ft) of fluvial conglomerate, sandstone, and micaceous siltstone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rhododendron Form.</td>
<td>Rhododendron Formation: Up to 180 meters (600 ft) of tuff, lapilli tuff, laharc breccia, and pyroclastic breccia.</td>
</tr>
<tr>
<td>Miocene</td>
<td></td>
<td>Columbia River Basalt</td>
<td>Columbia River Basalt Group: Up to 270 meters (900 ft) of dense, tholeiitic basalt flows and minor pillow basalts, palagonite breccia, and sedimentary interbeds of the Wanapum and Grande Ronde Basalts.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grande Ronde Basalt</td>
<td>Base not exposed.</td>
</tr>
</tbody>
</table>

Figure 6: Stratigraphic units in the Bull Run Watershed (Schulz, 1980).
Figure 7: Stratigraphic section of the region. The basal unit exposed in the Bull Run Watershed is the Columbia River Basalt Group. Dashed lines indicate unconformable boundaries. (modified from Swanson, 1986; and Tolan and Beeson, 1984)
characterized by the thick columnar- and hackly-jointed flows, which are fine-grained, dark gray to black, with a basalt to basaltic andesite composition (Peck and others, 1964).

These flows covered 164,000 square kilometers (63,000 square miles) with an estimated volume of 174,000 cubic kilometers (42,000 cubic miles) (Tolan and others, 1989). Most of these flows exceeded hundreds of cubic kilometers while some exceeded 2,000 cubic kilometers (500 cubic miles) (Tolan and others, 1989). The larger volume flows moved farther west through a topographic low bounded by the present-day Columbia River Gorge to the north and the Clackamas River to the south, spilling out into the present-day Willamette Valley, with several flows reaching the coastal area (Tolan and Beeson, 1984). The Bull Run Watershed is located in this pre-existing low, through which these flows moved.

The Columbia River Basalt Group consists of several formations: Grande Ronde, Wanapum, and Saddle Mountains Basalts; which are made-up of several flows. Figure 8 shows the stratigraphic relationships between these different formations. An asterisk represents the flows that reached western Oregon and Washington (Tolan and Beeson, 1984). The units noted by a dot appear in the Bull Run Watershed (Schulz, 1980).

Grande Ronde Basalt. The Grande Ronde Basalt, at 148,600 cubic kilometers (36,000 cubic miles), comprises 85 percent of the Columbia River Basalt Group by volume (Tolan and others, 1989). The Grande Ronde Basalt consists of fine-grained aphanitic groundmass with rare plagioclase or plagioclase-clinopyroxene microphenocrysts (Swanson and others, 1979). A small amount of olivine is present, representing less than 0.5 percent of the groundmass (Swanson and others, 1979).

The Grande Ronde Basalt is divided into four magneto-stratigraphic units according to the natural remnant magnetism recorded in each flow. These units have
Figure 8: Stratigraphic column of the Columbia River Basalt Group. Asterisks indicate flows that reached western Oregon (Tolan and Beeson, 1984). Dots indicate flows found in the Bull Run Watershed (Vogt, 1981). Dashed lines indicates local erosional unconformities. (modified from Tolan and others, 1989)
been numbered R1, N1, R2, and N2 with R1 being the oldest (Tolan and Beeson, 1984). The Grande Ronde Basalt is also divided informally into "high-Mg" and "low-Mg" according to the composition of magnesium oxide (Tolan and Beeson, 1984). Only N2 and R2 occur in the Bull Run Watershed (Vogt, 1981).

**Vantage Member of Ellensburg Formation.** Separating the Grande Ronde and Wanapum Basalts is the Vantage Member, a highly variable sedimentary interbed unit of the Ellensburg Formation (Swanson and others, 1979). This paleosol/sedimentary unit represents a hiatus of at least several hundred thousand years between the different flows of the Columbia River Basalt Group (Tolan and others, 1989). This hiatus lasted long enough for a well-developed soil under forest vegetation to develop along with drainages and other geological structures. In the east, the Vantage Member consists mostly of sandstone. In the west, it varies, containing clastic and volcaniclastic sediments (Vogt, 1981).

**Wanapum Basalt.** The next Columbia River Basalt Group flow to follow the Vantage Member is the Wanapum Basalt. This formation contains more FeO and TiO₂ than MgO, thus differing chemically from the Grande Ronde Basalt (Vogt, 1981). The Wanapum Basalt is medium-grained, olivine-bearing, with either aphanitic or plagioclase-bearing phaneritic texture (Swanson and others, 1979).

The Wanapum Basalt consists of four members according to varying petrology and magnetic polarity: Eckler Mountain, Frenchman Springs, Roza, and Priest Rapids Members (Swanson and others, 1979). Only the Frenchman Springs, Roza, and Priest Rapids Members have been identified in western Oregon (Tolan and Beeson, 1984), with only the Frenchman Springs and Priest Rapids Members found within the Bull Run Watershed (Vogt, 1981).
**Saddle Mountains Basalt.** Of the Saddle Mountains Basalt flows, only the Pomona Member reached western Oregon (Tolan and Beeson, 1984) but this unit has not been observed within the Bull Run Watershed (Vogt, 1981).

**Rhododendron Formation**

Overlying, and sometimes interbedded with the Columbia River Basalt Group is the Rhododendron Formation (Tolan and Beeson, 1984), middle-Miocene in age (Beeson and Tolan, 1990). Rhododendron Formation consists of andesitic to dacitic volcaniclastic rocks produced by different episodes of explosive andesitic volcanism in the Cascade Mountains (Tolan and Beeson, 1984). Evidence of the specific source of this volcanism lies buried beneath more recent lava produced by Mt. Hood, near the Hood River Meadows area (Wise, 1969).

The Rhododendron Formation accumulated on the surface of the Columbia River Basalt Group in one of several parallel synclines created by north-south compressional stress (Gannett, 1982; Tolan and Beeson, 1984). This stress deformed the Columbia River Basalt Group, causing northeast-southwest trending anticlines and synclines. Included, among these were the Mosier-Bull Run and Mt. Hood-Dalles synclines, in which the Rhododendron Formation collected (Gannett, 1982; Tolan and Beeson, 1984) (Figure 9). Tolan and Beeson (1984) describe two studies, which name these units the Dalles Formation and the Chenoweth Formation of the Dalles Group. Peck (1964) refers to this unit as the Sardine Formation.

Within the Bull Run Watershed, the Rhododendron Formation crops out with varying thickness along the valley walls of the Bull Run River and along many of the major tributaries in the western two-thirds of the watershed (Beaulieu, 1974). Composition is variable: agglomerate, lahars, pyroclastic flows, lava flow, flow breccia, tuff-breccia, lapilli tuff, conglomerate, and fluvial deposits (Peck, 1964;
Figure 9: Pathways of the Columbia River Basalt. These flows were intra-canyon flows following structural features in western Oregon and Washington. (Tolan and Beeson, 1984)
The major units within the stratigraphic section of the Rhododendron Formation are lapilli tuffs and breccias of ash flow origin. These units comprise two-thirds of the section. They appear higher in the sequence, with a maximum combined thickness of 150 meters (500 feet). The remaining third of the section consists of laharc breccias which predominate the lower sections of the stratigraphy and total no more than 60 meters (200 feet) in total thickness. Tuffs comprise a minor part of the Rhododendron Formation, occurring in the middle of the section as local interbeds between coarser pyroclastic units and averaging 9-18 meters (30-60 feet) in thickness. (Schulz, 1980)

The maximum thickness of the Rhododendron Formation was documented at the type section near Zigzag at 430 meters (1,400 feet) (Wise, 1969). Maximum thickness within the Bull Run Watershed has been recorded near Reservoir #1 at 160 meters (500 feet), consisting of volcanic breccia and agglomerate (Beaulieu, 1974). The unit narrows to a thickness of 50 meters (160 feet) near the North Fork Bull Run River, before narrowing even further to the east (Beaulieu, 1974). This reduction could represent localization of volcanic accumulation in topographic lows (Beaulieu, 1974). In these areas, the Rhododendron Formation consists of varicolored pyroclastic and platy andesite porphyry (Beaulieu, 1974).

Extensive alteration of the pyroclastic rocks in the Rhododendron Formation occurs where lava flows have remained virtually unaltered. These volcaniclastics consist most commonly of hypersthene- and hornblende-andesite. The pumice clast within these volcaniclastics either do not have any mafic minerals or contains only hornblende crystals. Plagioclase phenocryst appears widely throughout the matrix of the tuffs and sandstones. Most of the hypersthene has been altered to montmorillonite and celadonite, whereas the plagioclase has evolved to laumontite. Most of the augite
found within the matrix has remained unaffected. Montmorillonite and zeolites have also replaced the glass matrix (Wise, 1969).

**Pliocene Sedimentary Rocks**

The Rhododendron Formation is overlain by Pliocene sedimentary rock equivalent to the Troutdale Formation and Sandy River Mudstone of Trimble (1963). These sediments consist of fluvial conglomerate, sandstone, and siltstone in bluffs approximately 120 meters (400 feet) high which overlook the Bull Run River downstream from the Little Sandy River (Beaulieu, 1974).

The Troutdale Formation is divided into two sections: the Lower Troutdale Formation (equivalent to Sandy River Mudstone) which is characterized by quartzite-bearing basaltic gravel and micaceous arkose sandstones and the Upper Troutdale Formation which is characterized by fluvially deposited hyaloclastite, lithic sand, basaltic gravel, and conglomerate (Tolan and Beeson, 1984; Swanson, 1986). The presence of quartzite and other non-Cascadian clasts in gravel of the Troutdale Formation suggests that its lower member was deposited by an ancestral Columbia River (Swanson, 1986). The transition from the lower to the upper member of the formation reflects the onset of High Cascade high-alumina basaltic volcanism and its interaction with the ancestral Columbia River (Swanson, 1986). This transition is assumed to have taken place in early-Pliocene when high-alumina basaltic eruptions were occurring throughout the Cascades (Swanson, 1986).

Two laharic mudflows have been found interbedded within the lower member of the Troutdale Formation in the Old Maid Flat, west of Mt. Hood (Swanson, 1986). These mudflows have been correlated with the Rhododendron Formation and are lithologically similar to a dacite flow near Lolo Pass, northwest of Mt. Hood (Swanson, 1986).
**Pliocene and Quaternary Volcanic Rocks**

Younger Pliocene and Quaternary volcanic rocks cover 80 percent of the watershed (Beaulieu, 1974). These deposits can measure greater than 600 meters (2,000 feet) thick. They consist of basaltic andesite and lesser amounts of olivine basalt, hornblende andesite, and equivalent pyroclastics which overlie the Columbia River Basalt Group, the Rhododendron Formation, and the Troutdale Formation with local unconformity (Schulz, 1980). These deposits can be subdivided into: Pliocene volcanic rock, Quaternary volcanic and intrusive complex, and Quaternary basalt and andesite.

Pliocene volcanic rock constitutes the bulk of the Pliocene and Quaternary volcanic rocks which form lava plains in the west and glaciated peaks in the east (Beaulieu, 1974; Schulz, 1980). These plains and peaks consist of massive to platy flows of andesite, with subordinate thin massive flows of basalt, and minor volcanic breccias (Beaulieu, 1974). Basaltic andesites predominate in these flows, with texture varying from dense to porous, aphanitic to coarsely porphyritic (Schulz, 1980). These flows could be equivalent to the Boring Lava of Trimble (1963) in the Portland area (Beaulieu, 1974).

The Quaternary volcanic and intrusive complex consists of thick breccias of hornblende andesite associated with intrusions near Blazed Alder Butte (Beaulieu, 1974; Schulz, 1980). These units overlie the Pliocene volcanic rocks and Rhododendron Formation with local unconformity (Schulz, 1980).

Quaternary basalt and andesite consist of minor flows and cinder cones exposed locally within the watershed (Schulz, 1980). Walker Prairie and West Aschoff Butte comprise of bedded cinder cones (Schulz, 1980). A series of basaltic
andesite flows appears at the lower end of Bull Run Lake (Beaulieu, 1974; Schulz, 1980). Various features within these units suggest that some of these materials were extruded underneath glacial ice (Schulz, 1980).

**Surficial Deposits and Glacial Activities**

Surficial deposits within the watershed consist of unconsolidated surficial Quaternary alluvium, terrace material, landslide debris, glacial deposits, and talus. Glacial deposits within the watershed are limited. Glacial scouring and cirque formation failed to occur below 610 meters (2,000 feet); thus, the western half of the watershed shows few signs of glacial activity. In the east, terminal moraines appear at the head of Log Creek and at the outlet of Bull Run Lake. Numerous cirques exist at the headwaters of North Fork, Falls Creek, Log Creek, Bull Run Lake, Hickman Creek, Nanny Creek, Cedar Creek, Fir Creek, and the drainages of Big Bend Mountain. Hickman Lake, Bull Run Lake, and Blue Lake are alpine lakes formed in these glacial cirques. (Schulz, 1980).

**Soils**

The soils are developed on the more recent pyroclastic materials that lie atop of the basaltic bedrock of the Columbia River Basalts, and other bedrock comprising the Rhododendron and Troutdale equivalent formations. The U.S. Forest Service has completed several soil surveys within the watershed categorizing these different soil types. The major composite survey of the Mt. Hood National Forest is the Soil Resource Inventory (SRI) conducted by Howes (1979). A more site-specific survey, with field-testing, was compiled by Stephens (1964) which concentrates on the Bull Run - Sandy area.
According to the SRI (Howes, 1979), the main units surrounding the reservoir are 338, 339, and 340 (Figure 10). Unit 338 (type location NE1/4, SE 1/4, Sec. 26, T1S, R5E) slopes from 0 to 30 percent all aspects, exhibits an organic layer 2.5 to 5 centimeters (1 to 2 inches) thick, and a soil depth from 66 to 178 centimeters (26 to 70 inches). Surface layers are very dark brown to dark brown stony silt loam; are moderate, very fine, and/or fine granular texture; are moderate, medium and/or coarse subangular blocky in structure; and are slightly hard, friable, slightly sticky, and/or slightly plastic consistency. Soil pH ranges between 6.0 and 6.5; bulk density measures 0.77 g/cm³; and thickness varies from 15 to 45.7 centimeters (6 to 18 inches). Subsoil layers are dark brown to brown stony clay loams; are moderate, fine medium and/or coarse subangular blocky in structure; and are hard, friable, slightly sticky, and/or slightly plastic in consistency. Soil pH ranges between 5.5 and 6.5, and thickness varies from 51 to 127 centimeters (20 to 50 inches).

Unit 339 (type location NE1/4, NE1/4, Sec. 21, T1S, R6E) slopes from 30 to 60 percent, north and east aspect, exhibits an organic layer 1.3 to 5 centimeters (0.5 to 2 inches) thick, and a soil depth from 51-140 centimeters (20 to 55 inches). Surface layers consists of very dark brown to brown stony silt loams; are moderate, very fine, and/or fine granular texture; are moderate, medium and/or coarse subangular blocky structure; are slightly hard, friable, slightly sticky, and/or slightly plastic in consistency; and contain 50 percent coarse fragments. Soil pH ranges between 6.0 and 6.5, and thickness varies from 38 to 127 centimeters (15 to 50 inches). Subsoil layers are dark brown to brown stony clay loams; are moderate, fine medium and/or coarse subangular blocky structure; are hard friable, slightly sticky, and/or slightly plastic consistency; with 50 to 70 percent coarse fragments. Soil pH ranges between 5.5 and 6.5, and thickness varies from 38 to 102
Figure 10: Soil Resource Inventory soil units around Reservoir #1. Compiled by the U.S. Forest Service for the entire Mt. Hood National Forest. (Howes, 1979)
Unit 340 (type location NE1/4, NE1/4, Sec. 26, T1S, R6E) slopes from 30 to 60 percent, south and west aspect, exhibits an organic layer 1.3 to 2.5 centimeters (0.5 to 1 inches) thick, and a soil depth from 48 to 119 centimeters (19 to 47 inches). Surface layers consist of very dark brown to brown stony silt loams; are moderate, very fine, and/or fine granular texture; are moderate, medium and/or coarse subangular blocky structure; are slightly hard, friable, slightly sticky, and/or slightly plastic in consistency; and contain 40 to 50 percent coarse fragments. Soil pH ranges between 6.0 and 6.5, and thickness varies from 10 to 30.5 centimeters (4 to 12 inches). Subsoil layers are dark brown to brown stony clay loams; are moderate, fine medium and/or coarse subangular blocky structure; are hard friable, slightly sticky, and/or slightly plastic consistency; with 60 percent coarse fragments. Soil pH ranges between 5.5 and 6.5, and thickness varies from 38 to 89 centimeters (15 to 35 inches).

Bull Run-Sandy Soil Report (Stephens, 1964) identifies three units surrounding the reservoir: Aschoff stony loam, Bull Run silt loam, and Headwork silt loam (Figure 11). Aschoff series (type location NE1/4, SE1/4, Sec. 26, T1S, R5E) is a well-drained soil of moderately fine texture. It is derived from medium textured glacial till consisting of basalt, andesite, and tuff. Soil pH ranges between 6.0 and 6.3, and percent organic matter ranges between 7.8 to 8.0 in the surface soils and average 1.4 in subsurface soils. Surface soil has an approximately 2.5-centimeter (one-inch) thick layer of very dark brown, stony silt loam. Subsoil has an approximately 7.6-centimeters (three-inches) thick layer of dark brown, stony silt clay loam. Coarse, rounded fragments comprise 40 to 70 percent of the volume.

Bull Run series (type location NW1/4, NW1/4 Sec. 36 T1S R5E) is a well-drained soil of medium texture derived from wind-laden silts produced by glacial
Figure 11: Bull Run-Sandy Soil Survey units around Reservoir #1. Orange areas represent soils classified as Headworks silt loam, dark blue represents Bull Run silt loam, and brown represents Aschoff stony loam. Compiled by the U.S. Forest Service. (Stephens, 1964) (scale 1:63,360)
grinding of basalt and andesite bedrock. Soil pH ranges between 5.6 and 5.8; percent organic matter ranges from 12.6 to 32.4 in surface soils and from 1.3 to 7.9 in subsurface soils; and bulk density ranges from 0.72 to 0.83 g/cm³ in subsurface soils. The organic layer is thin. Surface soil measures approximately 15 centimeters (6 inches) thick and consists of dark brown silt loam. Subsurface soil varies from approximately 0.6 to 6 meters (2 to 20 feet) thick and consists of dark brown silt loam. No coarse fragments appear in the Bull Run Series.

Headwork series (type location SE1/4, SE1/4, Sec. 30 T1S R6E) is a well-drained soil of medium texture derived from wind-laden silts produced by glacial grinding of basalt, andesite, and tuffs. Soil pH ranges between 4.2 and 5.8; organic matter measures approximately 15 percent in surface soils and from 1.9 to 8.2 percent in subsurface soils. Organic layer is moderately thick. Immediately below the organic layer lies a very thin, intermittently very dark gray, bleached horizon and a very thin, intermittently dark reddish brown, iron-stained horizon. Below this horizon, lies a surface soil layer of approximate 0.3-meter (one-foot) thickness; very dark brown color and moderate structure. Below this, a subsurface layer measures approximately one meter (three feet) thick and consists of dark yellowish brown silt loam.

**Geologic History**

The oldest rocks in the watershed are the Columbia River Basalt Group. The Columbia River basalt began erupting from fissures in the east, with larger volume flows extending west across the Columbia Plateau and through east-west trending structural lows. With each successive flow, the structural lows began to fill, creating a relatively flat topography. (Vogt, 1981)
The R2 low MgO Grande Ronde Basalt was the first flow of the Columbia River Basalt Group to enter the Bull Run area. During or after the R2 low MgO Grande Ronde Basalt, some type of structural deformation began. A structural high was created around Blazed Alder Creek restricting the succeeding N2 low MgO Grande Ronde Basalt from covering this area but not the succeeding N2 high MgO Grande Ronde Basalt (Vogt, 1981). During the N2 high MgO Grande Ronde Basalt, folds and drainages developed along with some local volcanism to the east in the Old Maid Flat area (Vogt, 1981).

A quiescent period occurred between Grande Ronde and Wanapum Basalts allowing some gentle folds to develop. The Grande Ronde Basalt weathered, soil developed, trees grew, and drainages formed creating the Vantage Horizon. Columbia River basalt flows, re-activated with the Wanapum Basalt of which only the Frenchman Springs and Priest Rapid Members entered the area, flattening the topography by filling drainages and other topographic lows (Vogt, 1981).

During or shortly after the Frenchman Springs Member, north-south compression began creating a new structural relief forcing the succeeding rivers to develop farther north, obstructing the Columbia River basalt from entering the area, with the exception of the Priest Rapids Member (Vogt, 1981). As the Columbia River Basalt Group volcanism ceased in the late-Miocene, this deformation continued as the north limb of the anticline failed, resulting in a north-west thrust producing tectonic breccia (Vogt, 1981).

High Cascades eruptions covered most of the drainage basin with andesitic lavas and pyroclastics. Cascadian high-alumina basalt began erupting during early-Pliocene covering most of the study area with volcaniclastics of the Rhododendron Formation as thick as 600 meters (2000 feet) in some locations (Schulz, 1980).
Muds and sandy muds equivalent to the lower member of the Troutdale Formation and the Sandy River Mudstone also began to fill the area (Swanson, 1986).

Pleistocene glaciation created cirques in the upper elevations, adding glacial deposits to the soils within the watershed (Beaulieu, 1974). Additional surficial deposits of alluvium in the valleys, and landslides in the slopes, have been produced throughout the Quaternary.
PREVIOUS WORK

Pre-impoundment Study

Previous studies conducted within the watershed have been primarily directed toward dam construction and water quality. Earlier studies, conducted by the City of Portland, Bureau of Water Works, in late 1800s and early 1900s, were performed in order to determine the suitability of the area as a municipal water source. Most of these early studies involved surveying and mapping the river for potential dam sites. After the site for Reservoir #1 was located, a more extensive survey of the area surrounding the future reservoir location was conducted (City of Portland, 1924). A map was created that identified pre-impoundment conditions of the reservoir (City of Portland, 1926a). This survey also calculated water volume estimates at different elevations within the reservoir (City of Portland, 1925).

Williams (1926) supplemented the pre-impoundment survey with a detailed description of the geology around the dam with limited discussion farther upstream. His report includes details of two trenches and several pits dug near the dam location. Trenches were cut from the 265 meter (870 foot) elevation of the river bank to the 312 meter (1022 foot) elevation on the north canyon face and the 310 meter (1018 foot) elevation on the south (Figure B1 in Appendix B).

Williams describes the site as having an undisturbed solid wall of basalt from the river's edge up to 30 meters (100 feet) on the north side. Above the basalt wall is an area of varying thicknesses of shattered and broken pieces of basalt. Greatest thickness of this unconsolidated material was 6 meters (20 feet), measured at the 315 meter (1035 foot) elevation. Williams suggests that this thick debris may have
been a slide or talus slope. On the south side, overburden increases, with altered basalt increasing above the 302 meter (990 foot) elevation. (Williams, 1926)

Williams' report includes several cross-sections. Copies of these appear in Appendix B. Cross-section A-A' (Figure B2) runs approximately north-south, just west of the present dam site. Cross-section B-B' (Figure B3) is constructed 46 meters (150 feet) east of the previous cross-section, essentially along the present dam site. Test pits dug near these cross-sections are described in Table B1.

Post-impoundment Study

The lone post-impoundment survey of Reservoir #1 was performed by David Evans and Associates, Inc., in 1991. This survey utilized bathymetric reflection data to produce topographic features of the reservoir floor. They interpreted these data to estimate the sediment thickness on the reservoir floor between 1 to 1.5 meters (3 to 5 feet). Some samples of this material were collected. They describe the material as a brown, silty-sand with 10 to 20 percent organic detritus.

With the methods they used, they could not conclude if a delta-like feature or submarine slide occurred outside North Fork Bull Run River and/or Fir Creek, but they did estimate the sediment thickness in this area between 1.5 to 6 meters (5 to 20 feet). Steep walls were identified as exposed bedrock while other areas showed a large coverage of alluvial and colluvial deposits overlain by a thin 0.6 to 1.2 meter (2 to 4 foot) layer of plant debris identified as the old forest floor. (David Evans and Associates, Inc., 1991a)

Dam Face Study

The City of Portland, Bureau of Water Works, had conducted an internal study in 1988 to observe the structural condition of the upstream dam-face. They hired
Underwater Resources from San Francisco to use an underwater camera, Sea Ferret, to film the areas of concern. They were also interested in determining if any silt had built-up at the base of the dam.

Sea Ferret was lowered down the north half of the dam to observe penstocks and the lowest sluice gate at 265.9 meter (872.5 foot) elevation (Figures C1-C3, Appendix C). While placing the camera on the penstock ledges, the sediment thickness could be measured by how deep the camera's feet settle into the collected sediment. This was estimated at approximately 7.6 centimeters (3 inches). Lowering the camera further down to less than 1.5 meters (five feet) from the reservoir bottom, the propeller on the camera started to create too much disturbance limiting visibility to continue further down. Sediment thickness at the dam face was then estimated to be less than 1.5 meters (five feet) thick. (Frank Galida, City of Portland, Bureau of Water Works, supervising engineer, personal communication)

Geology and Topography

Studies of geology and topography have been conducted by Beaulieu (1974); Schulz (1980); and Vogt (1981), all of which focus upon overall conditions throughout the watershed. Beaulieu concentrates on geologic hazards, Schulz observes soil mass movement, while Vogt describes stratigraphy and structural relationships between various Columbia River Basalt Group units within the watershed.

Land Management Practice Studies

Studies seeking to determine the effects of land management practices on water quality in the Bull Run Watershed include: Miner (1968), on road construction; Luchin (1973), on high water yield; Harr (1980) and Harr and
Fredriksen (1988), on the Fox Creek experimental logging operation; Harr (1982) on fog drip; and Ingwersen (1985) on fog drip.

Luchin’s study constructed models to evaluate the annual water yield from the watershed. These models predicted a lower yield than what was actually produced (Luchin, 1973). A study by Harr on the experimental Fox Creek logging operation tested the hypothesis that the removal of these trees should increase the run-off therefore increasing the annual water yield. Results from this study again showed the predicted annual water yield was significantly lower than what was expected (Harr, 1980). Harr concluded the missing factor in these models was fog drip produced by the standing trees intercepting the fog (Harr, 1982). When calculating in the fog drip factor, predicted yield equaled the actual produced (Harr, 1982). Ingwersen’s study concluded the loss from this fog drip is only encountered in the first 5 to 6 years after harvesting (Ingwersen, 1985). After that time, vegetation re-inhabiting the clear-cut areas can sufficiently intercept the fog as well as the once standing trees with the same results (Ingwersen, 1985).

Harr’s study also addressed sediment discharge into nearby streams. He concluded that construction of permanent logging roads across streams were the main cause for the increase concentration of sediment (Harr and Fredriksen, 1988). An earlier study by Miner had determined, to help reduce the sediment discharge, bridges or culverts need to be constructed to keep tractors out of the stream channels (Miner, 1968).

U.S. Forest Service Studies

U.S. Forest Service documents its activities within the watershed for each upcoming year as required by Public Law #95-200 (U.S. Department of Agriculture, Forest Service, 1992). Some of these activities: road construction,
timber harvest, and fuel reduction methods, were discussed in the Introduction and listed in Appendix A.

Documentation of the fire history within the Bull Run Management Unit has been assembled (Figure 12). The most recent fires recorded around Reservoir #1 are listed in Table 2.

Table 2: Recent fires near Reservoir #1 (Pincha, 1979)

<table>
<thead>
<tr>
<th>Date</th>
<th>Name</th>
<th>Legal Location</th>
<th>Cause</th>
<th>Sq. Kilometers (Acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940-49</td>
<td>T1S R6E Sec 11</td>
<td>Lightning</td>
<td>0.001 (&lt; 0.25)</td>
<td></td>
</tr>
<tr>
<td>1950-59*</td>
<td>T1S R6E Sec 11&amp;14</td>
<td>Man</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-23-66</td>
<td>Big Bend</td>
<td>T1S R6E Sec 16</td>
<td>Lightning</td>
<td>0.001 (&lt; 0.25)</td>
</tr>
<tr>
<td>8-22-70</td>
<td>Damsite</td>
<td>T1S R6E Sec 16 (NW,SW,SE)</td>
<td>Equipment use &amp; Power saw</td>
<td>0.001 (&lt; 0.25)</td>
</tr>
<tr>
<td>10-02-70</td>
<td>Silver</td>
<td>T1S R6E Sec 12</td>
<td>Debris burning &amp; Slash burn</td>
<td>1.23 (304)</td>
</tr>
<tr>
<td>9-16-71†</td>
<td>Linket</td>
<td>T1S R6E Sec 8,10,16</td>
<td>Debris burning &amp; Slash burn</td>
<td>3.88 (960)</td>
</tr>
</tbody>
</table>

* excluding 1956-57 when no fires were reported in the Bull Run Watershed

Other documentation by the U.S. Forest Service include the soil surveys which they have conducted. These have been previously discussed in the Regional Geology - Soils section.

Water Quality Test

At selected locations, the City of Portland has utilized various types of tests at different time intervals to collect data on water quality. The Bureau of Water Works lists these data in a document describing type of test, location, and duration of tests (City of Portland, 1991). More recent water quality reports include the following: Shulters and Clifton, (1980), effects from Mount St. Helens ash; Clifton (1985), analysis of biological data; Rinella (1987), variation in water quality; Chester Environmental sediment sampling study including a clay analysis report on the
Figure 12: Fire history map within the Bull Run Management Unit. Brown areas represent fires pre-1600s, green is pre-1800s, and yellow is from 1850-1900. All other colored regions are post-1900s. This map is taken from the U.S. Forest Service internal report by Pincha, 1979.
sediment within the reservoir (1993); and LaHausen, in preparation, on turbidity sources.

Small quantities of Mount St. Helens ash were recorded in the Bull Run Watershed during the period of April 4, 1980 to June 13, 1980 (excluding April 21, 1980 to May 18, 1980). The maximum amount collected was 6.74 milligrams from May 20 to May 30, 1980 at the Blazed Alder gauge station. Analyzing this material and the quality of the water during this period of time, Shulters and Clifton concluded that there was no detectable change in the chemical characteristics of the water quality. (Shulters and Clifton, 1980)

The biological study by Clifton (1985) concluded that the dominate periphyton was the pene diatom species including *Achnanthes lanceolata*, *A. minutissia*, *Cocconeis placentula englypta*, *Diatoma hiemale mesodon*, and *Hannaea arcus*. Chironomidae, Hydracarina, and *Baetis* were the dominant benthic invertebrate taxa. The diversity of the benthic invertebrates were significantly lower at the North Fork Bull Run River with Chironomids comprising the most abundant species. These conditions attributed to the higher annual sediment yields and instantaneous turbidity in this area. (Clifton, 1985)

The Rinella study was performed from 1978 to 1983 and included evaluations of different factors affecting the quality of the water. There were not any extreme discharge events during this time to adjust their predictive models for these factors. Their report did note that North Fork Bull Run and Main stem differ from the rest of the stations observed in stream flow, yield, and suspended sediment concentrations. (Rinella, 1987)

A clay analysis reported in Chester Environmental study noted the source of the clays within the watershed are from weathering of relatively young volcanic products that are rich in glass. Two samples were analyzed, one from Log Boom #3
in Reservoir #1, and the other from core solids in Reservoir #2. Log Boom #3 consisted of 53 percent 10A-halloysite, trace chlorite, and 47 percent expandable mixed-layer clay with randomly oriented kaolin/smectite mixed-layer clay containing more smectite than kaolin. Core solids consisted of 41 percent 10A-halloysite, trace chlorite, and 59 percent expandable mixed-layer clay with randomly oriented kaolin/smectite mixed-layer clay containing more kaolin layers than were contained in Log Boom #3. Dehydrated 7A-halloysite may occur along with fully-hydrated, 10A-halloysite, and kaolin may exist as an individual mineral. (Chester Environmental, 1993)

Flood and Landslide Studies

There are some independent studies conducted for the Bureau of Water Works that dealt with either floods in the area: Hydrocomp (1974), and Hampton (1977); or the North Fork Slide: Stevens, Thompson and Runyan, Inc. (1974), Elliott (1977), and Dames and Moore (1972 a,b,c).

North Fork Slide. An earthen dam was constructed in 1958 on the upper drainages of the North Fork Bull Run River creating Boody Lake. The dam was 12 meters (40 feet) high, impounding a 0.26 square kilometers (0.1 square miles, 65 acres) reservoir with a capacity of 1.5 billion liters (0.4 billion gallons). The drainage basin covers 21.5 square kilometers (8.32 square miles) ranging in elevation from 925 meters (3,035 feet) at the dam crest to 1,222 meters (4,010 feet) on Palmer Peak and almost 1,219 meters (4,000 feet) at Mt. Talapus (Figure D1 in Appendix D). The slope above the dam averages 10 percent whereas below the dam it averages 20 percent. (Stevens, Thompson & Runyan, Inc., 1974)

In the winter of January 1972, the reservoir iced over and a log jam developed behind a pre-existing chain-linked log boom. Temperatures started to rise
changing the snow into rain. A heavy run-off occurred and the excess water backed up behind this obstruction until it broke loose releasing a large volume of water. This release of logs and debris continued to block and back-up the river in several places downstream. (Stevens, Thompson & Runyan, Inc., 1974)

In an area just upstream from the intersection with Eastline Creek, several pre-existing landslides within the Rhododendron Formation had altered the stream channel into two sharp "S" curves (Elliott, 1977). The slopes were already oversteepened from erosion and/or undercutting by the river when the debris from this sudden dam-break, blocked the river again, raising the water more than 4.3 meters (14 feet). Slopes containing a mixture of volcanic debris, scil, and clay of previous mud flow or landslide origin, began to dislodge. The channel shifted to the west eroding a new channel at a lower elevation (Figure D2 in Appendix D). This shift cut into a reddish orange weathered tuffaceous layer which was mostly clay-size with a soft to relatively hard consistency (Dames & Moore, 1972a). (Figures D3-D4, Appendix D)

The slide covered 518 meters (1700 feet) from elevation 488 to 552 meters (1600 to 1810 feet) (Dames & Moore, 1973c) removing an estimated 4,590 cubic meters (6,000 cubic yards) (Stevens, Thompson & Runyan, Inc., 1974). When this material dislodged, the debris had enough force to break through the log jam releasing the material on downstream into the reservoir on January 20, 1972 discoloring the public drinking water for several days (Dames & Moore, 1972a).

1964 Flood. The largest flood documented by the Bureau of Water Works, occurred on December 23, 1964. This flood resulted when a thick snowfall on December 20th left 140 centimeters (55 inches) of snow on the ground, then the temperature started to rise. By December 21st, the snow turned to rain, yielding
4.0 centimeters (1.57 inches) of precipitation that compacted the snow to 114 centimeters (45 inches). Then on December 23rd, 23 centimeters (9 inches) of rain fell reducing the snow pack to 15 centimeters (6 inches). (Hydrocomp, 1974)

Table 3 lists several gauge stations around the watershed and the amount of discharge produced by this flood.

<table>
<thead>
<tr>
<th>Gauge Station</th>
<th>Elevation meters (ft)</th>
<th>Drainage square km (sq miles)</th>
<th>Date</th>
<th>Peakflow liters/second (cubic ft/sec)</th>
<th>Peakflow per sq km (per sq mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blazed Alder Cr</td>
<td>774 (2540)</td>
<td>21 (8.2)</td>
<td>12/20/64</td>
<td>73905 (2610)</td>
<td>3519 (319)</td>
</tr>
<tr>
<td>#14138800*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cedar Creek</td>
<td>597 (1980)</td>
<td>20.5 (7.9)</td>
<td>12/22/64</td>
<td>56350 (1990)</td>
<td>2750 (251)</td>
</tr>
<tr>
<td>(near Brightwood)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bull Run River</td>
<td>173 (568)</td>
<td>277 (107)</td>
<td>12/22/64</td>
<td>710730 (25100)</td>
<td>2566 (235)</td>
</tr>
<tr>
<td>#14139000 @</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salmon River</td>
<td>1050 (3445)</td>
<td>22.5 (8.7)</td>
<td>12/20/64</td>
<td>36811 (1300)</td>
<td>1636 (149.5)</td>
</tr>
<tr>
<td>(near Gov. Camp)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lady Creek</td>
<td>777 (2550)</td>
<td>9.89 (3.8)</td>
<td>12/21/64</td>
<td>20104 (710)</td>
<td>2033 (186)</td>
</tr>
<tr>
<td>(Rhododendron)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* See Figure 5 for location @ West of Reservoir #2

Cs-137 Studies

Cs-137 analysis is used in this study to establish approximate ages of historic sediments in the reservoir. The lone radiation study within the reservoir was conducted by the Oregon State Health Division Radiation Control (Toombs and others, 1973). This was a comprehensive radiation study from 1967-1972 to assure the quality of the water had not been affected by the high levels of radioactive material appearing in the environment during the early 1960s. To determine how to conduct the sampling and testing procedures for this study, reports outside this area also needed to be consulted, and are discussed below.
Cs-137 is an anthropogenic radioisotope that entered the ecosystem during the late 1950's and early 1960's from atmospheric nuclear testing by the United States and Soviet Union (Pennington and others, 1973). Once the radioisotopes were dispersed into the atmosphere they settled out on the earth's surface. Cs-137 strongly adsorbs to clay-size particles, producing a detectable layer that separates the soil into pre- and post-nuclear testing. Detection of these radioisotopes began in 1954 (Pennington and others, 1973). These levels reached a maximum output by 1963-64, with a smaller peak between 1958-59 (Ritchie and others, 1972; Ritchie and others, 1973; Ritchie and McHenry, 1975; Mitchell and others, 1983). The latest distinct detection came around 1970-71 from nuclear testing performed in China (Mitchell and others, 1983). Since that time, there has not been significant input of anthropogenic radioisotopes, dropping the Cs-137 detection level to almost zero.

Cs-137 is mostly concentrated in the upper 5 centimeters (2 inches) of the soil layer, which is most susceptible to erosion (Lomenick and Tamura, 1965; Rogowski and Tamura, 1970a; Ritchie and others, 1973; Ritchie and others, 1974a). Reservoirs have been considered to be "sinks" or "traps" for this eroded material (Ritchie and others, 1974b; Ritchie and McHenry, 1977; Ritchie and McHenry, 1978). Intensity of the erosion affects the concentration of Cs-137. For low storm strength (sheet erosion), the thin upper surface of this soil horizon, rich in Cs-137, is mostly eroded. In a more intense storm strength (gully erosion), thicker sediments are eroded incorporating more soils that will dilute the concentration of the clay associated with Cs-137 (Rogowski and Tamura, 1970b; Brown and others, 1981).

The state study (Tombs and others, 1973) noted variable levels of Cs-137 in the Bull Run reservoir sediment with elevated concentrations observed in 1969.
These elevated concentrations were attributed to an influx of radioactive fallout during 1968 and early 1969, following an unusually severe winter and abnormally heavy snow-pack in the region. It was noted that snow was as fully capable as rain at removing Cs-137 from the atmosphere. A large snow pack would necessarily result in a large spring run-off, which would contribute to an increase of radionuclides in reservoirs. (Toombs and others, 1973)

Table 4: State study results on radionuclides in Reservoir #1 sediments.
(Toombs and other, 1973)

<table>
<thead>
<tr>
<th>Station 1 (59-1 *)</th>
<th>K-40</th>
<th>Cs-137</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection Date</td>
<td>pCi/gram</td>
<td>pCi/gram</td>
</tr>
<tr>
<td>Aug. 4, 1967</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Sept. 27, 1968</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Aug. 21, 1969</td>
<td>1.8</td>
<td>9.0</td>
</tr>
<tr>
<td>Aug. 28, 1970</td>
<td>1.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Aug. 19, 1971</td>
<td>1.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Aug. 8, 1972</td>
<td>1.6</td>
<td>0.5</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Station 2 (59-2 *)</th>
<th>K-40</th>
<th>Cs-137</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection Date</td>
<td>pCi/gram</td>
<td>pCi/gram</td>
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* refer to Figure 5 for station location
METHODS GENERAL STATEMENT

Methods used to complete the objectives of this study include several approaches to estimating the thickness of sediment in the reservoir and on surrounding banks.

A survey of soils immediately above the high-water line of Reservoir #1 was undertaken to predict soil properties within the reservoir prior to its filling. This soil analysis also helped to identify properties of potential slope/bank sediments entering the reservoir.

A differencing map, comparing the pre-impoundment topography of the reservoir floor to post-impoundment conditions was completed to identify any changes in topography reflecting areas of sediment deposition or erosion. These topographic differences are used to help estimate sediment thickness, location, and volume within the reservoir. From this volume, sediment yield rates can be estimated.

An additional estimation of the sediment thickness uses tree-stump identified on strip-charts used to create the post-impoundment map. The trees were cut to a specified height according to the clearing specifications. Measuring the height of each tree-stump on the strip-chart and comparing this height to the height they were cut at could reflect areas where sediment has either accumulated or been lost.

Areas without stumps lack sufficient information to determine whether there were no tree-stumps originally or whether they were entirely covered with sediment. To calculate the volume of sediment for these areas the reservoir was divided into segments and an average was calculated for each segment. Adding these
segments together will give the estimated sediment volume for the reservoir. This method does not address sediment thickness where trees did not grow or where stumps are completely covered by sediment.

Finally, gravity-core samples of the post-impoundment sediment were collected from the reservoir floor. These samples reflect the actual amount of sediment accumulated at specific site locations. This method did not cover areas of steep cliffs to protect the nose of the gravity core from impacting the solid bedrock. Values of sediment thickness determined from these cores are then compared to the estimates predicted from the differencing and tree-stump methods. The core samples were also examined for post-impoundment stratigraphy to evaluate depositional history. Volume, sediment yield rate, and historical rate changes are calculated from the gravity core results.

This study started in Fall of 1992 with the production of the differencing map on the Intergraph System at the Water Bureau. Soil collection began in early-summer of 1993. Gravity core collection began in late-summer of 1993. Analysis of these samples was conducted from summer of 1993 through summer of 1994.
METHODS SOIL SURVEY

The purpose of this procedure is to determine the approximate properties of the pre-impoundment soils of the reservoir floor. Pre-impoundment soils remain as a sediment source that may be reworked and subsequently re-deposited at greater depths, or be held in suspension, depending on grain-size. Sediments exposed along the upper banks of the reservoir are most susceptible to this process from erosion by wind/wave action and storm/slope run-off. Figures 13 and 14 show several erosional scarps produced in stages during the lowering of the lake in 1993. The average lake level was also calculated to determine the volume of pre-impoundment soils exposed on the upper banks.

Soil Survey

To facilitate the estimation of soil properties within the reservoir floor, a survey of soil conditions immediately above the high-water line of Reservoir #1 was conducted. An analysis of these properties is used to determine the composition of soil entering the reservoir from the upper tributaries. The results of this survey are compared to the U.S. Forest Service soil survey to assure that the reported characteristics are representative of this area.

In order to estimate characteristics of pre-impoundment soil within the reservoir, site selection for the soil samples avoided large changes in topography and geology. According to the geologic map produced by Vogt (1981) most of the reservoir is located within high-Mg Grande Ronde basalt of the Columbia River Basalt Group (Figure 15). Based on the pre-impoundment survey, the reservoir
Figure 13: Erosional shorelines on the banks of Reservoir #1. These shorelines were produced by the lowering of the lake level 6.2 meters (20.5 feet). This picture was taken on the north shore just east of Bear Creek during the fall 1993.
Figure 14: Close up of Figure 13. This photo shows how unstable the erosional shorelines are as they collapse to become more stable. The stump has a diameter of 1.4 meters (4.5 feet) and the measurement from the sediment to the top of the stump was 0.9 meters (3 feet).
Figure 15: Portion of the geological map around Reservoir #1. Geological unit closest to the high-water line is the Grande Ronde Basalt (dark gray). Above this unit is the Frenchman Springs Member (the stippled section). In the higher elevations are the Tertiary-Quaternary volcanic clastics which comprise the Rhododendron Formation. (Vogt, 1981)
floor has an average slope of 10 to 15 degrees with occasional steep cliffs of greater than 30 degrees (Williams, 1926). To reflect these conditions, soil samples were collected approximately 15 to 30 meters (50 to 100 feet) upslope from the reservoir high-water line on slopes ranging from 0 to 27 degrees, averaging 10 degrees.

A majority of the soil pits were located in soils developed on high-Mg Grande Ronde, with several sites located farther up-section to ensure that other geologic units were represented. (Figures 16 and 17) Twelve of the sample sites were on the north side of the reservoir, near road FS-10, of which three were in the Frenchman Springs basalt (N-1, N-4, N-10) and one was in the Rhododendron Formation (N-12). The ten sites on the south side, were accessed by boat from the reservoir and were all located in the high-Mg Grande Ronde.

Pits were dug approximately one meter (three feet) deep, unless obstructed by rocks, roots, or groundwater. Each pit was documented according to definitions described in USDA Soil Conservation Service Agriculture Handbook #436 (Soil Survey Staff, 1975) for the following: location, topography (elevation, slope, aspect), drainage (well drained or poorly drained), vegetation, parent material (which consist of basalts from either: Grande Ronde, Frenchman Springs, or Rhododendron Formation and pyroclastic material of more recent activity), percent stones (material coarser than 2.54 centimeters, one inch), percent root disturbance, stability (ancient or new slide areas), and disturbance (logging, road activity, or fire). Each soil horizon was examined in the field for the following: thickness, moist-color (Munsell’s Soil color chart, 1990), texture (field estimation of grain-size), structure (weak fine sub-angular blocky), wet-plasticity and -consistency (plastic or sticky), and boundary condition (smooth, wavy, irregular, or broken; abrupt, clear, gradual, or diffuse). The site was then
Figure 16: Soil survey location within the geology units. All of the sites were in the Grande Ronde Basalt except for N-1, N-4, and N-10 which were in the Frenchman Springs Member, and N-12 which was in the Rhododendron Formation. (Refer to Figure 17 for site references) (Vogt, 1981)
Figure 17: Location of the soil survey sites. Sites were kept close to the banks of the reservoir to ensure similar topography, relief, and geology in order to remain consistent with the composition within the reservoir.
hand-augered to determine sediment thickness above bedrock.

At two of the 22 sites, a soil pit was foregone because the undergrowth was extremely dense, instead the site was hand-augered for soil depth. At 10 of the 22 sites, a soil pit was dug, but the site was not hand-augered because numerous cobbles and/or boulders made differentiation between bedrock and boulder difficult.

At most sites, samples were collected from each soil horizon and returned to the lab for further analysis. Samples were also taken at five-centimeter (two-inch) increments to an approximate depth of 25 centimeters (ten inches) for Cs-137 analysis. One additional sample was collected from the bottom of each pit.

The portion of the samples used for the Cs-137 analysis were air-dried, then passed through a #35 sieve, 0.5 mm (0.02 inches). Enough material passing through the sieve was collected to fill a pint size plastic tub recording the weight of this material.

In the lab, soils were analyzed according to methods described by the Soil Conservation Service (1972) for the following: percent moisture, pH, dry-color (Munsell's Soil color chart, 1990), texture by the hydrometer using a modified method of Day (1965) (Appendix E) and organic content using the titration method of Walkely-Black (Soil Conservation Service, 1972) (Appendix F). Soils were then classified according to the Soil Taxonomy nomenclature (Soil Survey Staff, 1975).

Bulk density was also calculated for each of the three geological units to compare these values along with other soil characteristics published by the U.S. Forest Service for these soils (Howes, 1979; Stephens, 1964) (Refer to Regional Geology - Soils).
Lake Level Calculations

The upper banks of the reservoir are exposed during summer and fall as stream flow decreases and water demand increases. Drawdown may continue over several months, while recharge may occur in a few days after the start of the winter rainy season. To determine the amount of sediment susceptible to erosion on the upper banks, the acreage and thickness of the sediment exposed during low lake levels were calculated.

To determine this acreage the average lake level for the life of the reservoir was calculated. The dam was completed in March 1929. Storage began on April 29, 1929 and completed on May 15, 1929, covering 33,220,000 cubic meters (26,930 acre-feet, 43,447,000 cubic yards) at a surface elevation of 316 meter (1036 feet) (Hubbard and others, 1991). In October 1954, three 12 meter (40 foot) wide by three meter (9 foot) high gates were installed, increasing capacity to 37,180,000 cubic meters (30,140 acre-feet, 48,626,000 cubic yards) to an elevation of 319 meters (1045 feet). To measure the overall water level for the life of the reservoir, calculations were made from 1930-1993. Separate calculations were also made to separate the periods before and after the addition of the gates in 1954.
METHODS DIFFERENCING MAP

The purpose of comparing the pre-impoundment conditions observed in the 1924 field-survey to post-impoundment conditions observed in 1991 is to determine whether the topography of the lake floor has changed over the life span of the reservoir. Areas increasing in elevation from 1924 to 1991 might represent sediment deposition, while those decreasing in elevation might represent erosional loss. To identify such areas, a bathymetric differencing map was produced. The difference in bottom surface elevation between the two maps might reflect the total volume of sediment within the reservoir. This volume estimate was used to calculate an approximate sediment yield rate for the life span of the reservoir.

A comparison of pre- and post-impoundment surveys was conducted on the Bureau of Water Works Intergraph System, in consultation with Roland Hege, City of Portland, Bureau of Water Works, civil engineering surveyor.

Reproduction of 1924 Pre-impoundment Map

The original pre-impoundment survey of the reservoir floor sought to determine maximum full-pool volume of the reservoir. Field notes for this survey remain on file at the Bureau of Water Works (Field data books #479-482 of the Water Bureau Preliminary Survey for Bear Creek Storage Reservoir on Bull Run River from September 10, 1924, to November 20, 1924, Al Bauer in charge, in storage at the City of Portland, Bureau of Water Works).

An attempt was made to enter the original field data into the Intergraph System. To verify the accuracy of this computer-generated contour map, it was
compared to the original map produced by the Bureau of Water Works in 1925. The original map was constructed by the field surveyor who had conducted most of the original survey, and who understood the data collection and site conditions. Upon close comparison, the two maps failed to agree. Possible reasons for this are:

1. Rugged terrain often forced the survey team off their desired course. The manner in which they adjusted their course was not always clearly stated. Diagrams and illustrations intended to explain these adjustments were often vague and could not be interpreted conclusively.

2. In evaluating short hand notes of the field surveyors, it was assumed that their terminology and methods were consistent with present standards. Following the analysis of the two maps, questions arose as to what type of distance measurements, horizontal or slope, were made when slope angles were taken. Altering selected data did facilitate adjustment of various map features, but it was difficult to determine which data to alter and for what reasons.

3. There were two principal surveyors and each employed different techniques. When deciding where to conduct transit lines at right angles off the main survey line, one surveyor appears merely to have made an informed estimation. A better correlation between the two maps could be produced if some transit lines were adjusted to others than right angles. Again, the problem was in justifying which survey data to alter and by how much.

4. A problem similar to that described above in number 3 was observed with respect to bisecting angles. No notes were kept of departure directions.

5. Stream depths were not recorded along creeks or main streams; thus data on the lower-most depths of these channels are unavailable.

6. This survey was not closed. It was conducted to determine volume capacity and to aid in timber removal. Main lines were run along the upper expected flow
lines, one north and one south, with a third main line along the stream bank. Most of the valley profiles were taken down-slope from flow line to river bank. The lower main line completed the valley profile whenever the upper transit could not reach the river in rugged terrain. Because the traverse was not closed, error estimates could not be calculated.

In light of these problems, any systematic changes to the computer-generated map seemed impractical. Each alteration had to be cross-checked against the 1925 map. If adequate alterations were made, the product would actually reflect the 1925 map. It was decided therefore to abandon the computer-generated map and to digitize the existing 1925 map, instead.

The original 1925 Bureau of Water Works map now exists only on microfilm, but another version of this map was discovered at the Oregon Historical Society: Bull Run Storage Project City of Portland, Bureau of Water Works Bull Run Storage Reservoir, September 20, 1926, surveyed and drawn by Al Bauer, Revised May 13, 1927, by K.D. This map was digitized on the Intergraph System in three dimensions to include contours and stream locations. Digitizing of the 1925 map eliminated data points between contours. The loss of these data will smooth out the topography in a three-dimensional profile.

Reproduction of 1991 Post-impoundment Map

David Evans and Associates, Inc., produced the original post-impoundment map from a bathymetric survey that they conducted in June 1991. To reconstruct this map, coordinates of the original map were entered into the Intergraph System. This produced a detailed outline of the reservoir floor at full-pool height. The accuracy of this map equals that of the original survey as outlined by David Evans and Associates, Inc. (David Evans and Associates, 1991a).
Specifications and procedures used to produce the bathymetric map were taken from David Evans and Associates final report, and personal communication with a project technician (David Evans and Associates, 1991a; David Evans and Associates, 1991b; Ed Pagh, 1993 personal communication). Their study included X, Y, Z triplets at 1.5 meters (5 foot) increments along profiles spaced at 30.5 meter (100 foot) intervals over the full reach of Reservoirs 1 and 2. They employed a 9 meter (30 foot) aluminum V-hull boat. Located amidships was a seachest that housed a 210 kHZ 3 degree beam transducer, positioning mast centered over the transducer, Raytheon R10 radar, KVH electronic fluxgate compass, "E" size plotter, left-right monitor, and printer.

Horizontal positioning was accomplished by a racal "Micro-Fix" microwave system, integrated to a Lietz DT5 theodolite for range-azimuth positioning, with accuracy of ± 1 meter (3 feet) horizontally at 1 second intervals. Vertical positioning was accomplished with an Interspace 448 thermal-printing depth sounder, hardwired for computer data logging and analog record annotation. Equipped with a 3 degree high frequency 210 kHZ transducer to reduce side echo, this apparatus provided an accuracy of ± 3 centimeters (0.1 foot) vertically, included also was an on-board processor capable of integrating and logging depths 15 times per second and positions at 1-second intervals.

The geophysical equipment utilized was a sub-bottom profiler and a bubble pulser. The sub-bottom profiler is a seismic reflection system that operates in conjunction with the bathymetric system to measure thickness of fine-grained sediments in the subsurface. The transceiver is a datasonics SBT-220, the acoustic source is a low frequency 3.5 kHZ transducer, and the display recorder is an EPC 8700 thermal recorder. The bubble pulser is a high-energy, low-frequency sonar system designed to penetrate deposits of coarse-grained sediments.
Overlapping the Two Maps

After the pre- and post-impoundment maps were reproduced to the same scale and entered into the Intergraph System, they needed to be precisely overlaid. To ensure proper alignment, it was necessary to identify key locations within the reservoir. These locations contained hard rock material that has remained unchanged. Using documentation in the pre-impoundment survey and observations recorded in the post-impoundment survey, six key references were identified. One of these was a 296 meter (970 foot) elevation out-crop located south of the river channel near Deer Creek. Other key locations were steep banks documented in the pre-impoundment survey as waterfalls and/or cliffs that could be distinguished in the 1991 survey (Figure 18).

To further refine the alignment on a smaller scale with respect to horizontal, vertical, and angular displacement, profiles were employed. These profiles were systematically produced by drawing a center reference line down the stream channel, then dividing this line into 17 segments. (Figures G1 and G2 in Appendix G)

One map was adjusted relative to the other to produce the best alignment. Adjustments were terminated when improvements to one area began adversely affecting another area. Examples of this appear in several profiles of Figures G3a-G3e in Appendix G. In profiles D-D’ of Figure G3b and J-J’ of Figure G3c, the 1991 map apparently should be adjusted to the right, but in profiles E-E’ and F-F’ of Figure G3b and G-G’ of Figure G3c, the 1991 map appears to require adjustment to the left. Moving the 1991 map in either direction further offset the other profiles.

Once the two profiles were overlaid properly, the stream channel in 1991 appeared to be lower in elevation than in 1924. The problem results from the fact
Figure 18: Key locations used to align the two maps. These locations represent waterfalls (1), steep cliffs (4,2,6,3), or rock out-crops that have remained constant during the life of the impoundment (5).
that stream depths were not recorded in the 1924 survey. The stream channel was filled with water so only bank elevations were recorded, ignoring the topography below the water level. The 1991 bathymetric survey on the other hand, recorded elevations within the stream channel. Comparison of these areas would relate only bank elevations in 1924 to stream depth in 1991 (Figure 19).

Figure 19: Stream channel misrepresented. Bank elevations were only recorded in the 1924 survey, not stream depths. The 1991 survey recorded the stream depth.

The 1991 profile would appear to cut through the 1924 profile, implying erosional loss. Depending on the original stream depth, some areas might actually represent fill regions. Fill quantity would depend on channel depth in 1924.

Original stream depth is important for computer calculations of volume differences between 1924 and 1991. The computer subtracts the elevations of the 1991 site from those of 1924. Area within the stream-bed would be recorded as a negative value, a cut region, thus reducing the overall volume amount within the
reservoir. If, however, this area were actually a fill region, a positive value, the overall volume amount within the reservoir would increase.

A simulated river channel was created to approximate the channel as it existed in 1924. This involved an estimation of the river depth at that time. This was accomplished with use of:

1) Williams' cross-sections shows an approximate river depth of 1.5 meters (5 feet) near the dam site (Figures B1 and B2 in Appendix B).

2) Estimates of the river depth today are assumed to be consistent with past conditions. Observing the balance of the river at selected locations and consulting with Bill Stotts, Supervisor of Water Treatment at Reservoir #2, it was concluded that any estimate exceeding 3 meters (10 feet) would be unsuitable for present conditions.

3) Rough estimates of stream depth can be determined by projecting the slopes of both banks to a point of intersection (Figure 20). This method is crude because it determines an atypical stream bottom pattern. A stream bottom is usually elliptical, not angular. Using this method, merely as an estimate, the depths along this stretch of the river range from nearly a meter (3 feet) near the dam to 6 meters (20 feet) farther east. According to field logs and the pre-impoundment map, the area nearest to the dam appears shallower than the channel east of Deer Creek.

Based upon these observations, an average stream depth of 2.4 meters (8 feet) was assumed throughout the reservoir. This average might be too deep near the dam and too shallow farther east, but it was considered most representative for this project.

A semi-elliptical template was created to simulate the shape of the stream bottom, flat on the base and curving up on the sides. Width of this template was calculated at 36.6 meters (120 feet) to match the average stream width for the
entire length of the reservoir. The sides were given a vertical:horizontal ratio of 1:1 with the base given 1:8 (Figure 21). For river sections narrower than 36.6 meters (120 feet), the template created a flatter stream bottom and shallower water depth than wider sections. This template was placed perpendicularly along the entire reservoir length of the river, on the calculated center line of the stream, 2.4 meters (eight feet) below bank elevation. Possible errors include choice of size, shape, depth, and depicted center of the stream.

Figure 20: Rough method to estimate depth of stream channel.
A stream width of less than 36.5 meters (120 ft) will have a shallower, flatter base.

Stream width approximated at 36.5 meters (120 feet) across

A stream channel wider than 36.5 meters (120 feet) will have a steeper base.

Figure 21: Template used to establish stream channel in 1924 survey.

Production of the Differencing Map

Once the alignment and stream channel characteristics were determined, the difference between the two topographic regions was calculated, using the cut and fill option on the Intergraph System. This procedure calculates vertical displacement which could exceed true displacement which is perpendicular to the surface. Steeper slopes show greater differences between the vertical and true displacement (Figure 22). This implies that values given for difference in topography could exceed true difference, depending on slope.

A contour map was produced to represent areas of cut and fill. This allowed the computer to calculate total volume within the positive (fill) and negative (cut) regions to determine net volume of displacement within the reservoir. Calculating this volume over the life-span of the reservoir and the drainage basin establishes the sediment yield rate for the drainage basin.
Figure 22: Vertical displacement versus true. The steeper the topography the greater the difference between the two displacements.
METHODS TREE-STUMP ANALYSIS

Bathymetric reflection data produced by David Evans and Associates, Inc., June 1991, identify tree-stumps throughout most of the reservoir bottom. Comparison of the heights of these stumps to the height at which each was originally cut could identify areas of sediment accumulation or removal. Stumps shorter than original height should represent areas of sediment deposition, while stumps taller should represent areas of erosion. Plotting these values on a map produces a representation of estimated sediment thickness and distribution where stumps are exposed.

A field survey was conducted during low-water conditions to determine the average height at which each stump was cut around the rim of the reservoir. Additionally, the amount of sediment lost or gained surrounding each stump was measured to determine the effects from raising and lowering the lake. Divers observed additional stumps at greater depths within the reservoir to ensure that similar stump height conditions existed at these lower depths.

Determination of Original Tree-stump Height

According to clearing specifications for logging within the reservoir, each tree-stump was required to be cut at a specific height:

The clearing of the Bull Run Storage Basin shall consist of the removal of all vegetable matter from the ground surface, such as all brush, trees, snags, down timber, limbs, decayed logs, decayed stumps to a depth of one (1) foot below ground surface, timber, bark and chips.... All brush and small trees under 12 inches in diameter shall be cut at the surface of the ground. The larger trees, requiring a cross-cut saw to fall, may have a stump two feet
high for trees two feet in diameter, and for all larger trees a maximum height of three feet above ground level will be permitted. (City of Portland, 1926d)

No records were taken on how accurately these stumps were cut. Also, if stumps were cut at the specified three-foot height (0.9 meters), and if one foot (0.3 meters) of forest duff was removed, the stumps would have been four feet (1.2 meters) above ground surface. Photographs of the clearing operation proved only partially useful. Actual height of each stump cannot be determined without a scale, but the effects of the removal of the organic material on the forest floor can be noted (Figures 23 and 24).

Tree-stump height was defined as the distance from the top of the stump to the original reservoir floor. The original reservoir floor was defined as the surface exposed after removal of the organic material. This material would have included the O-horizon and perhaps partly the A-horizon, leaving the B-horizon intact. By definition, the O-horizon is the "surface accumulation of mainly organic matter overlying mineral soil", and the A-horizon is the "accumulation of humified organic matter mixed with mineral fraction, where the latter is dominant. This can be on the surface or below the O horizon" while the B-horizon "shows little or no evidence of original sediment or rock structure" (Birkeland, 1984).

To determine the original reservoir floor with respect to the stump and root profile, a survey was conducted on trees with diameter greater than 0.3 meters (one foot) located above the rim of the reservoir. Trunk-swells were found to start above the soil surface, with the first strong lateral roots resting atop the B-horizon (Figure 25). These lateral roots measured approximately 7.5 to 15 centimeters (three to six inches) in diameter and were located primarily in the A-horizon with the O-horizon covering their tops. Distance from the top of a stump to the tops of its lateral roots define the original reservoir floor and therefore equals the stump
Figure 23: Photo of the 1927 clearing operation. Stump heights can be observed but no measurements can be made. Several stumps are charred from clearing operation and several wild fires leaving almost no ground material on the reservoir floor (City of Portland, Bureau of Water Works historical archives, unpublished, 1927).
Figure 24: Reservoir floor and remaining tree-stumps after 1927 clearing (City of Portland, Bureau of Water Works historical archives, unpublished, 1927).
Figure 25: Modern lateral root system. Swell starts above forest floor with lateral root appearing to level out above B-horizon. Taking into account the lateral root thickness and amount of organic material removed from reservoir floor, it was decided that lateral root tops should determine original reservoir floor.
height for this project (Figure 26).

Large trees, of diameter greater than 1.5 meters (five feet), were also observed for stump and root profile. Such trees often have larger aprons of decayed material, some as high as 1.5 meters (five feet), around their trunks. Some of these larger trees may have been cut before removal of organic material, at a height one meter (three feet) above the tops of their aprons. After removal of organic material surrounding these stumps, their average height could have been as much as 2.5 meters (eight feet) (Figure 27).

Because the height could differ on the up-, mid-, and down-slope sides of the stump, measurements were taken from the top of the stump to the top of the lateral root on the up-, mid-, and down-slope side of each stump.

In the survey (to establish actual cutting procedures) the stump height, diameter, and the degree of slope on each stump's site were recorded. The stump diameter reflected different stump heights allowed in the clearing specification, while slope reflected different interpretations as to how high the stumps were cut. For example, on steep slopes a stump could measure 1.8 meters (six feet) high on the down-hill side, 0.3 meters (one foot) on the up-hill side, and one meter (three feet) high in the middle. Sediment accumulation on the up-hill side would create an appearance of a shorter stump, whereas erosion on the down-hill side would suggest a taller stump.

Data surveyed on exposed tree stumps around the reservoir sides, below full-pool height, were then grouped according to degree of slope on which each stump was located. These stumps were also grouped according to diameter. Average stump height was then calculated for each group to determine potential effects of both slope and diameter.
The organic material removed approx. 0.6 meters (one foot) ---,------r---

A-horizon ----------------~----

Stump Height

1 meter (3 feet)

O-horizon

Original reservoir floor

B-horizon

Lateral root

Figure 26: Stump height definitions. Stump height is defined as distance from stump top to original reservoir floor. Original reservoir floor is defined as surface exposed after removal of organic material. Organic material would have comprised most of O-horizon and possibly part of A-horizon, but none of B-horizon. Field survey data indicate trunk-swell beginning above the soil surface with the first strong lateral root resting atop B-horizon. The lateral root typically measures from 7.5-15 cm (3-6 inches) in diameter and spans most of A-horizon. Distance from stump top to lateral root top (which necessarily locates original reservoir floor) thus equals the stump height.
Figure 27: Larger-diameter tree within the watershed. This displays how a thick organic layer surrounds the base. The lateral roots cannot be seen without removing about 1.5 meter (5 feet) of organic material.
Sediment Lost/Gain Surrounding Each Tree-stump

The upper shore of the reservoir is most affected by the fluctuation of the lake level, exposing the upper shores to wave action and recharge from rain. This exposure could remove the sediment from the upper banks and re-deposit this material down-slope. Measuring the amount of sediment lost or gained surrounding each stump on the upper shore will help evaluate the effects of this exposure.

To determine whether such erosion existed, additional measurements were taken from the top of each stump to sediment on up-, mid-, and down-slope sides. This measurement was then subtracted from the stump height. If the distance from the top of the stump to the sediment were less than the stump height, then the resulting positive value identified sediment accumulation. If the measurement exceeded the stump height, the resulting negative value indicated sediment loss.

To field check these calculations, small pits were dug approximately one meter deep (0.3 feet) every 3 meters (10 feet) from the water line to the upper shore at one location at the west end of the reservoir. (Figure 28). Detailed descriptions of the soil profile were recorded to establish whether any scouring in this material occurred. Samples were taken to conduct grain-size analysis and to evaluate whether the down-slope trend in texture reflects any changes in sediment composition.

Tree-stumps Observed by Divers

To ensure that the stump height conditions from the upper shore were consistent with those at lower elevations within the reservoir, divers measured stumps at three locations. To simplify the underwater operation, only slope, stump diameter, and stump to top of lateral-root and stump to top of sediment on the mid-slope were measured. Site selection included one dive in deep water near the dam
Figure 28: Dive survey locations. Also noted is location of samples taken on shore.
Another was chosen in shallower water where several stumps could be seen on bathymetric charts (Site 2). Site 2 could have been exposed during one of several yearly drawdowns. The last site (Site 3) was chosen in steep incline region to determine whether underwater stumps on steep slopes displayed similar characteristics to those at the upper shore elevations.

Production of Tree-stump Analysis Map

Tree-stumps were identified on bathymetric strip-charts produced for the bathymetric/geophysical survey conducted by David Evans and Associates, Inc., in June 1991. Their survey utilized an echosounder and sub-bottom profiler to produce depth profiles from seismic reflections. Point reflectors on these strip-charts were interpreted as remnant tree-stumps (David Evans and Associates, 1991a,b; Ed Pagh, technician, David Evans and Associates, Inc., personal communication, 1993).

All original bathymetric strip-charts were studied for anomalies in the reservoir floor. Anomalies were then categorized as fish, hard rock, or tree-stumps. Fish were identified as solid markings with no connection to the bottom. Hard rock showed as a solid line on flat surface and as a more broadly dispersed pattern on steeper slopes (side echo). Tree-stumps produced point reflectors weakly connected to the bottom (Figure 29) (Descriptions as explained by Ed Pagh, technician, David Evans and Associates, Inc., personal communication, 1993). A number of reflections differed from the above ideal descriptions. Consequently, ambiguous anomalies were examined for the presence of steep, treeless walls, indicating a greater potential for non-stump anomalies. Adjoining strip-charts were also used to test for local stump exposure (Figures 30 and 31).

Average tree-stump height determined from the field survey (1.2 meters, 4
Figure 29: Bathymetric strip-chart, range line #22. Technicians have noted trees and hard rock (noted as side echo). Horizontal lines represent 0.6 meters (2 foot) depth increments below the water line (318 meters, 1044 feet - June 17, 1991) (David Evans and Associates, Inc., field data, unpublished data, 1991).
Figure 30: Bathymetric strip-chart, range line #48, north-south. In this passing, faint specks on the north slope appear to represent fish. In the second passing, which was run in the opposite direction (Figure 31), these specks define trees. Specks in this figure thus represent partial reflections from tree-stumps nearby (David Evans and Associates, Inc., field data, unpublished, 1991).
Figure 31: Bathymetric strip-chart, range line #48, south-north. Tree-stumps are more clearly defined on this nearby pass. (David Evans and Associates, Inc., field data, unpublished, 1991)
feet, see Results Tree-stump Analysis) was subtracted from height observed on strip-charts. For heights greater than the original (1.2 meters, 4 feet), the difference was a negative value (cut), while for heights less than the original, the difference was a positive value (fill) (Figure 32). These values were then recorded by location, plotted on a base map, and contoured using the Bureau of Water Works, Intergraph System.

**Volume and Sediment Yield Rate Calculations**

Tree-stumps were not observed in all areas covered by the bathymetric survey. These areas could represent excess sediment obscuring the stump or an area where no stumps existed. These areas could have even been erosional sites where the stumps were removed. Insufficient data were available in these locations to evaluate a possible interpretation. For these locations the area was left blank.

To calculate a volume using the tree-stump analysis, the reservoir was divided into several segments. The average sediment accumulation or loss evaluated from the existing tree-stumps was calculated for each segment. Taking this average, a volume was calculated for each segment. Summing up each segment produced the overall coverage. This volume is limited by the restriction inherently produced by the height of each stump. Any sediment gain or lost greater than the stump height will not be reflected.

Taking this volume over the duration of the reservoir impoundment and the drainage basin area, produces a sediment yield rate. (See Results Tree-stump Analysis)
Figure 32: Example of cut or fill determination. Measurements greater than the average represents a cut, while measurements less than the average represent a fill.
Gravity cores of post-impoundment reservoir sediment were collected to establish historical sedimentation rates and depositional patterns throughout the reservoir. Post-impoundment sediment thickness can be employed to field check distribution and thickness of bottom sediment estimated from the differencing and tree-stump maps. Textural analysis of sediment is used to identify mechanisms of sediment distribution within the basin. A volume and sediment yield rate in the reservoir are then calculated from the average post-impoundment sediment thickness collected in all the cores.

Coring Operation

The City of Portland, Bureau of Water Works, designed and provided a barge for this project. It was outfitted with winch, cable, and generator to lower and raise the gravity-core device (Figure 33). The gravity corer used for this project was a Benthos Gravity Core Model 2171, a general purpose model designed for coring sediment in harbors, rivers, lakes, and/or deep ocean operations (Benthos, Inc., 1976). The coring device measures 7.5 centimeters (3 inches) in diameter and 2 meters (6.5 feet) long. Four 20-kilogram (44-pound) lead weights can be added to it for deeper penetration (Figure 34). A brass nose on the bottom contains a core catcher. Four fins on top of the core barrel keep the coring device upright during free-fall descent.

This device was connected to a cable and slowly lowered to a depth
Figure 33: Barge designed and provided by the Bureau of Water Works.
Figure 34: Benthos gravity coring device.
approximately 6 meters (20 feet) above the reservoir floor, at which time the cable winch clutch was released, allowing the core barrel to free-fall under its own weight. Free-fall was necessary to penetrate the more densely oxidized material of the pre-impoundment surface, thus ensuring recovery of the entire column of post-impoundment sediment.

Inside the core barrel is a clear plastic core liner with a stainless steel core catcher at one end and a suction valve on the other. Once the barrel is withdrawn from the sediment, the core catcher collapses on itself, holding sediment in the tube. Suction from the valve on top also helps to keep the core from slipping out. This device works best in silt and clay. Sand grains tend to hold open the fingers on the core catcher, allowing sediment to escape from the bottom. In areas where sand-sized particles were encountered, the core catcher was lined with a nylon mesh to help collapse the fingers.

A depth finder and contour maps of the reservoir floor were utilized to select coring sites. When positioned over the site, the barge was released from the towboat and anchors were dropped. The core barrel was lowered and following the free-fall, depth finder was read for water column depth while an EDM-total station was used to survey in the barge position from known locations onshore.

The depth finder was equipped with a bottom profile display, that helped to view the reservoir floor, locate the old stream axis, and avoid steep cliff faces. The depth finder served to monitor the core barrel's descent, ensuring free-fall had not begun prematurely (Figure 35).

Sites were chosen to reflect sediment distribution up- and down-stream, as well as laterally throughout the reservoir. Samples were taken in areas of estimated maximum sediment accumulation. Thicknesses in these areas had been estimated from the differencing and tree-stump maps. Additional samples were taken in areas
Figure 35: Depth finder utilized in this project.
of minimal sedimentation, but these areas were generally avoided to protect the nose of the gravity core.

Additional core samples were collected near the dam in the deepest region of the reservoir. These samples were taken below elevation 296 meters (970 feet), lowest recorded reservoir level (City of Portland, 1991), and thus represent sites thought to be the least disturbed by fluctuating water levels in the reservoir.

Sediment retention problems were encountered during core recovery. The geometry of the winch housing (Figure 36) required that the coring device be laid horizontally to remove the inner core. Vertical removal, however, would have been preferred, as horizontal positioning may have allowed fines to be lost during water removal. In addition, the surface sediments were very unconsolidated, therefore, handling the coring device when horizontal might have caused mixing of samples in the upper section of the inner core.

Additional problems occurred with the cable housing. A guide was not provided for the assembly, thus allowing the cable to bind and loop. At times during core retrieval, a loop would suddenly slip, thereby plunging the coring device downward anywhere from 1 to 1.8 meters (3 to 6 feet). This jarred the material in the inner core, ejecting sediment from the top of the barrel. As a result, the top several centimeters of these samples were considered contaminated and non-representative. Small and/or disturbed samples were collected in plastic bags; otherwise, they remained in the plastic core tubes.

To ensure that the sediment collected was representative and that the gravity core was working properly, the divers who measured tree-stumps also documented sediment thickness at various dive sites. In addition to concern that sediment was being lost from cores during recovery, it was thought that thickness might be non-representative due to the compaction created by the force of the coring operation.
Figure 36: Core recovery system. Winch housing system measures approximately 1.8 meters (6 feet) high and unfortunately was not equipped with a guide system.
Compaction was calculated at 30 percent, based upon mud-lines observed on the core barrel exterior. Mud-line heights were compared to core lengths to determine the difference between core penetration and recovered core length.

**Opening and Logging Core Tubes**

Core tubes were placed in a freezer to preserve them until needed. Each was opened with a router bit which cut the full length of the core on two sides. The router bit was positioned to cut only plastic, so as not to allow the bit to contaminate the sample by transferring sediment from one position in the core to another.

Core tubes were then laid flat on a table prior to prying open the two halves. A trowel was inserted width-wise through the sediment, removed, cleaned, and re-inserted farther up the core. The trowel was not allowed to transfer sediment lengthwise along cores, thus avoiding contamination. Once the sediment was cut lengthwise, the two halves were laid open. The better of the two halves was marked and reserved for detail logging, and X-raying. The other half was utilized for Cs-137 and grain-size analyses. Cores were returned to the freezer when not in use for subsampling.

Core tube logging included identification of pre- and post-impoundment sediments. Post-impoundment accumulation was measured and recorded. Further logging included notations of stratigraphy, changes in textural consistency, color, and organic content in an attempt to identify historical depositional events and to correlate such events among all the cores.

**Testing Bagged and Core Samples**

Samples transferred into plastic bags were inspected for the presence of pre-impoundment sediment. Samples containing no detectable pre-impoundment sediment...
were used for grain-size analysis using the modified method of Day (1965), as described in Appendix E. This analysis revealed overall grain-size distribution at each core site for the life span of the reservoir.

To quantify textural variations and percent organic matter, grain-size and percent organic matter analyses were conducted on samples collected in the plastic core tubes. These analyses were also conducted on different layers within the cores. Variations among the grain-size and percent organic matter will help substantiate sediment dispersal patterns in the reservoir. The same modified methods of Day (1965) and Walkely-Black (Soil Conservation Service, 1972) were used to conduct the grain-size analysis and percent organic matter (Appendix E and F).

X-radiograph

In order to provide a more detailed evaluation of sediment stratigraphy, selected samples were X-radiographed at Oregon State University (OSU). Thin, equally sized slabs could have been cut from the samples, thus ensuring proper density-contrast control. But, cutting these samples could have disturbed the remaining material making it unsuitable for further lab testing. Due to the limited number of samples collected, the open half-sections of the core tubes were X-rayed.

OSU's radiography equipment is limited to X-raying only 23-centimeter (9-inch) lengths. To process longer cores, markers were placed at the ends of each 23-centimeter (9-inch) segment. These markers overlapped on each X-radiograph to facilitate collation of film segments. Once the X-radiograph negatives were developed, they were reproduced as positive photographs. For this process, contact prints were utilized; dark areas thus represent high-density areas.
Cs-137 Analysis

Cs-137 analysis was employed to establish a time-line for post-impoundment sedimentation rates. The Cs-137 marker is used to establish what had accumulated before and after nuclear testing. Samples of approximately one-centimeter (0.4-inch) thickness were taken at specified locations in the half-core prepared for Cs-137 analysis. Upon removal of the one-centimeter (0.4-inch) plugs from the core, the outer rim of sediment was removed to eliminate possible contamination from the coring operation. These samples were air dried under clean conditions to avoid further contamination. When dry, the samples were crushed to a consistent size, weighed, and placed in a plastic film canister. Each canister was then placed on the gamma-ray spectrometer and analyzed for as long as three days.

Activities of Cs-137 in each sample plug were plotted as a function of depth in the core. These plots facilitate identification of sediments deposited before and after 1954. It was hoped that the maximum peaks of 1958-59 and 1963-64 (Ritchie and others, 1972; Ritchie and others, 1973; Ritchie and McHenry, 1975; Mitchell and others, 1983) and possibly the less distinct peaks of 1970-71 (Mitchell and others, 1983) could be correlated.

The amount and type of clays need to be determined to more accurately interpret the Cs-137 results. Grain-size analysis help determine the amount of clay in each sample while clay analysis will help determine the types of clay present.

Clay Analysis

Several sample plugs from one of the gravity cores and a sample selected from within the reservoir drainage area were analyzed for clay minerals on PSU's X-ray diffractometer. Each half-core was kept frozen until the clay analysis was to
begin, at which time a two to three-centimeter (0.8 to 1.2-inch) plug was cut from
the half-core and submitted to the diffractometer technician for preparation.

All samples were treated with hydrogen peroxide to remove organic matter.
Fractions measuring less than two microns (0.002 millimeters, 0.00008 inches)
were centrifuged away from each sample. Oriented clay sub-samples were prepared
from the centrifuged fraction, utilizing porous ceramic tiles as a mounting surface.
Three sub-samples were prepared from each sample. One of the three was analyzed
without further treatment, another was saturated with potassium, and the last one
was saturated with magnesium. The magnesium-saturated sub-sample was also
treated with glycerol. Each sub-sample was analyzed on the Norelco X-ray
diffractometer at a scan speed of one degree per minute. After initial X-ray runs,
untreated sub-samples were treated with DMSO (dimethylsulfoxide), and potassium
saturated sub-samples were subjected to heat treatments. First treatment lasted for
one hour at 250 °C; the second, at 550 °C, also lasted for one hour. Diffractograms
were analyzed for clay mineral peak location, intensity, shape and width associated
with the different potassium sample preparations above. Clay minerals in the cores
were identified through analysis of these data.
RESULTS SOIL SURVEY

Soil Description

Figure 17 shows the soil survey sites used in this study. The results of field observation and lab analysis for each of these sites, using the descriptive format of the Soil Taxonomy (Soil Survey Staff, 1975) are shown in Appendix H. The same results are listed in non-descriptive, tabular form in Appendix I, Tables 11-14.

Several varieties of B-horizon can underlie O-, A-, or O- & A-horizons. The B-horizon generally observed in this study area was the Bw, which has "development of color or structure with little or no apparent illuvial accumulation of material" (Birkeland, 1984). Bulk densities calculated for the B-horizon soil samples were 0.72 g/cm$^3$ for the Grande Ronde Basalt, 0.71 g/cm$^3$ for the Frenchman Springs Member, and 0.89 g/cm$^3$ for the Rhododendron Formation. Average bulk density for the soil thus equals 0.78 g/cm$^3$ ± 0.10.

Tests for organic matter in the soil indicate high concentrations near the surface, due to densely accumulated forest duff. Organics decrease with depth, but concentrations remain relatively high. This high percentage results from the high charcoal content found in most of the soil profiles, reflecting the extensive fire history within the area (Figure 12). A comment appears in the soil profile description in Appendix H for the soil sites located close to these more recent fires. Test results from the percent organic matter were also used to better distinguish between O- and A-horizons. O-horizon contains greater than 50 percent organic matter, and A-horizon contains greater than 50 percent mineral fraction (Birkeland, 1984).
Grain-size analysis indicated the majority of the soil sections to be silt loam, with a limited number of loam and sandy loam textures. Overall average soils characteristics for the area are as follows: silt loam, with 5.2 pH, and bulk density of 0.78 g/cm³. Soils are slightly plastic, with slightly to non-sticky consistency, and weak fine subangular blocky structure. Bw2 horizon most often observed contained a quartz-rich, sandy loam material.

Soil development is young and the soils are very porous. The soils are basically developed in pyroclastic materials that lie on the bedrocks of Columbia River Basalt, Rhododendron Formation, and Troutdale Formation equivalent sediments. Soil characteristics appear to be dictated by the pyroclastics, not the bedrock parent material.

These soils were classified as Typic Udivitrud, with isolated pockets of Humic Udivitrud where there is a thick A- and B-horizon. Udivitrud soils are commonly rich in vitric (glassy) volcanic pyroclastic material, and developed in a Udic moisture regime (during most years, the soil never dries in any strata for 90 cumulative days) (Soil Survey Staff, 1975).

**Predicted Volume of Pre-impoundment Soil**

Using the average forest soil thickness determined from this study, the pre-impoundment soil thickness within the reservoir was estimated. With this thickness a volume of potential sediment source from within the reservoir can be calculated. Comparing this calculated volume to the estimated volume within the reservoir, an evaluation can be made as to whether or not this source contributed significantly to the reservoir fill.

The average thickness of each soil horizon appears in Table 5. Overall soil thickness averages 126 centimeters (49.5 inches). By comparison, in the SRI,
overall soil thickness ranged from 66 to 178 centimeters (26 to 70 inches) for unit 338, 51 to 140 centimeters (20 to 55 inches) for unit 339, and 48 to 119 centimeters (19 to 47 inches) for unit 340 (Howes, 1979). In the Bull Run-Sandy Soil Study, the Aschoff series varied from 102 to 178 centimeters (40 to 70 inches); and the Bull Run and Headwork series varied from 76 to 152 centimeters (30 to 60 inches) (Stephens, 1964). Overall thickness from these previous studies thus ranged from 48 to 178 centimeters (19 to 70 inches), with an average of 113 centimeters (44.5 inches). (Refer to Regional Geology - Soils)

Table 5: Soil thickness and projected volume.

<table>
<thead>
<tr>
<th>Horizons</th>
<th>Average Thickness</th>
<th>Volume within</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1,675,395 m³ (414 acres)</td>
</tr>
<tr>
<td>O</td>
<td>9.32 cm (3.67 in)</td>
<td>156,100 m³ (204,000 yd³)</td>
</tr>
<tr>
<td>A</td>
<td>15.7 cm (6.19 in)</td>
<td>253,400 m³ (345,000 yd³)</td>
</tr>
<tr>
<td>B</td>
<td>1.10 m (43.3 in=3.61 ft)</td>
<td>1,840,000 m³ (2,410,000 yd³)</td>
</tr>
<tr>
<td>O+A</td>
<td>25.3 cm (9.86 in)</td>
<td>420,000 m³ (549,000 yd³)</td>
</tr>
<tr>
<td>A+B*</td>
<td>1.26 m (49.5 in=4.12 ft)</td>
<td>2,100,000 m³ (2,750,000 yd³)</td>
</tr>
</tbody>
</table>

* total soil column above bedrock

This study therefore is reflective of the local conditions projected for this area. The thicknesses calculated from this study will then be used to describe the conditions within the reservoir.

Assuming similar conditions existed within the reservoir before filling, the pre-impoundment volume of unconsolidated material can be calculated by projecting these soil layer thicknesses over the acreage bounded by the reservoir. According to the Water Bureau's report of 1925, surface area of the reservoir at full capacity (319 meter, 1045 foot, elevation) measures 1,675,396 square meters (18,033,810 square feet, 414 acres). Projecting each horizon thickness, determined from this study, over this area produced the following volumes for each
soil horizon, Table 5. Combining these horizons, the total soil column contains a volume of 2,100,000 cubic meters (2,750,000 cubic yards).

**Predicted Volume of Sediment Exposed on Upper Shores**

Volumes calculated above reflect the total soil column available as a sediment source in the reservoir. Not all of this column is exposed to the erosive activities created by the raising and lowering of the reservoir. To determine that volume, the average lake levels were calculated (Table 6). This area exposed will be used to calculate the volume of pre-impoundment sediment available as a sediment source.

Average level for the life span of the reservoir (1930 - October 1993) equals 314.6 meters ± 1.76 (1032.3 feet ± 5.78). Average before the gates were added in 1954, equals 315.6 meters ± 0.87 (1034.4 feet ± 2.87). After the gates were added which raised the potential lake level 2.7 meters (9 feet), the average level dropped to an average of 314.2 meters ± 2.05 (1031.0 feet ± 6.74).

Assuming an average lake level of 315 meters (1032 feet), the area most often exposed throughout the year equals 161,803 square meters (1,741,626 square feet) (City of Portland, 1925).

To estimate maximum average acreage exposed by the drawdown, the lowest yearly reservoir levels were averaged (Table 7), equaling 305.4 meters ± 7.32 (1002.0 feet ± 24.03). Calculating the reservoir area exposed at this elevation equals 524,839 square meters (5,649,322 square feet) (City of Portland, 1925).
Table 6: Average yearly reservoir levels, 1930-1993
(City of Portland Bureau of Water Works, Unpublished Data)

<table>
<thead>
<tr>
<th>Year</th>
<th>Yearly lake level average meters (feet)</th>
<th>Year</th>
<th>Yearly lake level average meters (feet)</th>
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</tr>
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Averages:

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+ or - 1.76 (5.78)
+ or - 0.87 (2.87)
+ or - 2.05 (6.74)
To determine the potential volume of sediment exposed at these different depths, the soil layer thickness estimated in the soil survey was projected over these exposed areas. Combining O-, A-, and B-horizons the soil thickness is 135.1 centimeters (53.2 inches), assuming the soil surface was undisturbed. But the

<table>
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<th>Lowest lake level that yr.</th>
<th>Year</th>
<th>Date</th>
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<td>303.2 (994.9)</td>
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<td>1974</td>
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<td>1975</td>
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<td>310.9 (1020.0)</td>
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<td>308.1 (1010.8)</td>
<td>1976</td>
<td>Oct. 24</td>
<td>301.2 (988.3)</td>
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<td>1945</td>
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<td>309.3 (1014.8)</td>
<td>1977</td>
<td>Aug. 24</td>
<td>304.8 (1000.1)</td>
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<td>1946</td>
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<td>309.9 (1016.7)</td>
<td>1978</td>
<td>Oct. 27</td>
<td>308.6 (1012.4)</td>
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<td>1979</td>
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<td>299.0 (980.9)</td>
</tr>
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<td>1948</td>
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<td>1980</td>
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<td>1949</td>
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<td>1981</td>
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<td>297.5 (975.9)</td>
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<td>1950</td>
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<td>309.8 (1016.5)</td>
<td>1982</td>
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<td>1951</td>
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<td>1983</td>
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<td>1952</td>
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<td>1984</td>
<td>Sept. 5</td>
<td>307.5 (1008.9)</td>
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<td>1953</td>
<td>Dec. 27</td>
<td>307.6 (1009.2)</td>
<td>1985</td>
<td>April 30</td>
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<td>1954</td>
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<td>1986</td>
<td>Sept. 23</td>
<td>301.6 (989.6)</td>
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<td>1987</td>
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<td>295.7 (970.0)</td>
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<td>1956</td>
<td>Oct. 15</td>
<td>314.9 (1033.2)</td>
<td>1988</td>
<td>Oct. 20</td>
<td>301.4 (988.7)</td>
</tr>
<tr>
<td>1957</td>
<td>Oct. 1</td>
<td>306.4 (1005.2)</td>
<td>1989</td>
<td>Oct. 14</td>
<td>304.9 (1000.4)</td>
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<td>1958</td>
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<td>1990</td>
<td>Oct. 3</td>
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<tr>
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<td>1991</td>
<td>Oct. 23</td>
<td>298.1 (977.9)</td>
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<td>1960</td>
<td>Jan. 10</td>
<td>270.5 (867.5)</td>
<td>1992</td>
<td>Sept. 4</td>
<td>301.8 (990.3)</td>
</tr>
<tr>
<td>1961</td>
<td>Jan. 28</td>
<td>301.8 (990.1)</td>
<td>1993</td>
<td>Nov. 30</td>
<td>301.2 (988.1)</td>
</tr>
</tbody>
</table>

| Averages: | 30-93 | 305.4 (1002.0) | + or - 7.32 (24.03) |
|          | 30-54 | 309.6 (1015.7) | + or - 3.49 (11.44) |
|          | 55-93 | 302.7 (993.0)  | + or - 7.87 (25.80) |

Table 7: Lowest yearly reservoir levels, 1930-1993
(City of Portland Bureau of Water Works, Unpublished Data)
reservoir area was cleared of organic matter according to the 1926 clearing specifications:

The clearing of the Bull Run Storage Basin shall consist of the removal of all vegetable matter from the ground surface, such as all brush, trees, snags, down timber, limbs, decayed logs, decayed stumps to a depth of one (1) foot below ground surface, timber, bark and chips. Grubbing or blasting of stumps is not contemplated, nor stripping of the sod or top layer of soil. (City of Portland, 1926d)

To determine the thickness of the pre-impoundment soil, the average thickness estimated by combining the A- and B-horizon, 125.5 centimeters (49.5 inches), was used. If only organic material and not mineral soil was removed, this organic material would exist primarily within the O-horizon and occasionally in the A-horizon leaving the B-horizon intact. The volume of the pre-impoundment soil exposed to these erosive activities would then be calculated by projecting the 125 centimeters (49.5 inches) over the 161,803 square meters (1,741,626 square feet, 40 acres), the average area exposed determined by the average lake level, establishing a sediment volume of 203,000 cubic meters (266,000 cubic yards).

To calculate the maximum sediment volume exposed the average sediment thickness of 125.5 centimeters (49.5 inches) was projected over the area exposed determined by the lowest yearly reservoir level, 524,839 square meters (5,649,322 square feet, 130 acres), yielding a total of 660,000 cubic meters (863,000 cubic yards).

Cs-137 Analysis on Soil Samples

Samples were collected in each soil pit at 5-centimeter (two-inch) increments to evaluate the concentration of the Cs-137 and how this concentration varies with depth. Soils in the watershed erode and are deposited into the reservoir.
Locating the concentrated levels of Cs-137 within these soils will help evaluate the effects of different types of erosion and on these concentrations.

Sample locations N-4, south-facing slope, and S-7, north-facing slope, were the only samples tested for Cs-137. Each container with the 5-centimeter (two-inch) depth samples was placed on Portland State University's gamma-ray spectrometer for approximately 24 hours. Results were interpreted by the ORTEC 92X Spectrom Master analyzer and appear in Appendix J. Table J1 lists amounts of Cs-137 in each sample, along with several other nuclei, only the Cs-137 is interpreted in this study. Table J2 lists the same results as does Table J1, however, the values are normalized to the amount of clay in each sample. Clay content is important, because Cs-137 adsorbs to clay particles. High clay content in a sample generally increases the concentration of Cs-137, in soils exposed to Cs-137 fallout.

Figures J1 and J2 demonstrate the Cs-137 concentration versus depth in the corresponding soil. Overall, Cs-137 decreases rapidly within the first few centimeters, becoming negligible in deeper sample sections. For example, sample N-4, A-horizon (sample depth 0 to 2.5 centimeters, 0 to 2 inches) the Cs-137 concentration was 0.71 pCi/gram while the following B-horizon sample (sample depth 2.5 to 10 centimeters, 2 to 4 inches) was 0.13 pCi/gram (Table J1).
REPRESENTATION OF THE 1924 SURVEY

The original pre-impoundment survey map, contoured at 3 meter (10 foot) intervals, was digitized into the Bureau of Water Works Intergraph System, including stream locations (refer to Method Differencing Map). Entering the elevations of each contour produced a three-dimensional map which was considered to be less accurate than the original survey.

Traverse surveys such as this usually begin and end at the same point, creating a closed path. Error estimates for this type of survey depend on how nearly the traverse path closes. However, no such measurement was taken for the original survey. To determine what the error might have been, a 1910 survey text on topographic survey techniques was consulted: "under unfavorable circumstances an accuracy 1 in 500 is easily attained, while under favorable circumstances this accuracy may be increased to 1 in 2000 or more" (Johnson and Smith, 1910).

Based upon comments in the 1924 field notes that refer to the rugged terrain in this area, the 1 in 500 feet (0.3 to 150 meters) error value was adopted. The final digitized map was produced on the Intergraph System with 3 meter (10 foot) contour intervals. (Figure G1 in Appendix G)

REPRESENTATION OF THE 1991 MAP

Reproduction of the 1991 bathymetric data utilized data points from the original survey produced by David Evans and Associates, Inc. After pitch, roll, squat (boat displacement), lake tide, and instrument precision were adjusted, the overall
vertical accuracy was reported to be at ± 9 centimeters (0.3 feet) (David Evans and Associates, 1991a). Contours from these data could have been produced at 0.3 meters (1 foot) intervals, but to compare this map accurately with the 1924 map, contours were produced at 3 meters (10 foot) intervals. (Figure G2 in Appendix G)

Production of the Differencing Map

After overlaying the pre- and post-impoundment surveys as accurately as possible (refer Methods Differencing Map), variations between the two maps were utilized to produce a differencing map. This map represents changes in topographic relief between pre- and post-impoundment. Contour lines at 3 meters (10 foot) intervals were constructed around the corresponding values of displacement. When the two maps were almost equal in elevation (no differences), they fluctuated in and out, from cut to fill, in small amounts. This is due primarily to the fact that the digitized 1924 map flattens the topography between points, whereas the 1991 map shows more contrast (Figures G3a-G3e in Appendix G). This fluctuation produces more contours at the zero contour as the map alternates between positive and negative. To avoid confusion in these areas, the zero contour was eliminated. Accuracy of this map was limited by the accuracy of the 1924 traverse, which was estimated at 1 foot in every 500 feet (0.3 to 150 meters) as compared to ± 9 centimeters (0.3 feet) calculation for the 1991 traverse. (Figure K1, Appendix K)

To better distinguish between cut and fill areas, a shaded map, Figure K2, was produced. This map separates only cut from fill regions and does not indicate specific amounts of net relief. Errors resulted when displacements were calculated near steep slopes. On such steep slopes, a small error in horizontal position translates into a large error in net topographic difference (vertical change) between
the two survey maps. For example, more contours and shading exist along the steeper south bank than along the less steep north bank of the reservoir.

**Volume and Sediment Yield Rate Calculations**

From the differencing map, the computer calculated the volume amount for each cut and fill region. Subtracting the total cut volume from the total fill volume provides an estimate of the net sediment volume within the reservoir: 2,641,000 cubic meters (3,460,000 cubic yards).

To calculate the net historical sediment yield rate, the net volume was multiplied by the estimated dry bulk density of the material within the reservoir (0.56 g/cm³, refer Results Coring) then divided by the size of the drainage basin (193.3 square kilometer, 74.6 square miles) (Hubbard and others, 1991) and life span of the impoundment (62 years, 1929 to 1991). These calculations provide a preliminary sediment yield rate of 120 tonnes/km²/yr (310 tons/mi²/yr). This first order sediment yield rate is better constrained by the tree-stump and gravity coring analysis discussed in the next sections.
RESULTS TREE-STUMP ANALYSIS

Average Stump Height

The field survey included observations of 193 exposed tree-stumps around the entire perimeter of the lake at low water conditions, between 319 and 307 meter (1045 and 1006.6 foot) elevations. Stump height was measured on up-, mid-, and down-slope sides, from top of each stump to top of the lateral root. Up- and down-slope sides were averaged and found to be very similar to mid-slope measurements. Stump height was taken as either the mid-slope reading, or the average between up- and down-slope readings when the mid-slope was not recorded. Stump height could not be recorded for stumps that had an excess of sediment accumulated, covering the lateral root.

Stumps were grouped according to diameter and degree of slope on which they stood to determine if either of these factors significantly affected average stump height. All 193 stumps were arranged into the following slope categories: 0-5, 6-10, 11-15, 16-20, 21-30, and 31-65 degrees. All stumps were then arranged into diameter categories: 0.30-0.59 (1-1.9), 0.60-0.75 (2-2.4), 0.76-0.89 (2.5-2.9), 0.90-1.05 (3-3.4), 1.06-1.19 (3.5-3.9), 1.20-1.35 (4-4.4), 1.36-1.49 (4.5-4.9), 1.50-1.65 (5-5.4), 1.66-1.79 (5.5-5.9), and 1.80-3.50 (6-11.5) meters (feet). Average stump height was then calculated for each group (Table 8).

Average stump height equaled 1.2 meters ± 0.44 (4.0 feet ± 1.45). Overall, the slope did not show any trends in the results but the diameter did show an increasing stump height with an increasing diameter. Therefore, the diameter was
considered the most dominate controlling factor on the height each stump was cut at. Stumps on the bathymetric charts were then compared to this average of 1.2 meters (4.0 feet) when determining the amount of sediment lost or gained around each stump.

Table 8: Average stump height.

<table>
<thead>
<tr>
<th>Slope (degrees)</th>
<th>Number of Stumps</th>
<th>Average Stump Height (meters)</th>
<th>Standard deviation + or -</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>38</td>
<td>1.2 (3.8)</td>
<td>0.37 (1.23)</td>
</tr>
<tr>
<td>6-10</td>
<td>47</td>
<td>1.0 (3.4)</td>
<td>0.30 (1.10)</td>
</tr>
<tr>
<td>11-15</td>
<td>38</td>
<td>1.0 (3.4)</td>
<td>0.43 (1.40)</td>
</tr>
<tr>
<td>16-20</td>
<td>36</td>
<td>1.0 (3.2)</td>
<td>0.26 (0.82)</td>
</tr>
<tr>
<td>21-30</td>
<td>14</td>
<td>1.5 (4.8)</td>
<td>0.51 (1.63)</td>
</tr>
<tr>
<td>31-65</td>
<td>19</td>
<td>1.5 (5.0)</td>
<td>0.67 (1.53)</td>
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<tr>
<td>Average</td>
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<td>1.2 (4.0)</td>
<td>0.42 (1.38)</td>
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<table>
<thead>
<tr>
<th>Diameter (meters)</th>
<th>Number of Stumps</th>
<th>Average Stump Height (meters)</th>
<th>Standard deviation + or -</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30-0.59 (1.0-1.9)</td>
<td>14</td>
<td>0.8 (2.6)</td>
<td>0.18 (0.57)</td>
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<tr>
<td>0.60-0.75 (2.0-2.4)</td>
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<td>0.9 (2.8)</td>
<td>0.28 (0.93)</td>
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<tr>
<td>0.76-0.99 (2.5-3.2)</td>
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<td>1.6 (3.2)</td>
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<tr>
<td>0.80-1.05 (3.0-3.4)</td>
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<td>1.1 (3.7)</td>
<td>0.35 (1.14)</td>
</tr>
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<td>1.05-1.19 (3.5-3.9)</td>
<td>18</td>
<td>1.3 (4.3)</td>
<td>0.60 (1.96)</td>
</tr>
<tr>
<td>1.20-1.35 (4.0-4.4)</td>
<td>22</td>
<td>1.2 (4.1)</td>
<td>0.40 (1.30)</td>
</tr>
<tr>
<td>1.36-1.49 (4.5-4.9)</td>
<td>18</td>
<td>1.3 (4.2)</td>
<td>0.65 (2.14)</td>
</tr>
<tr>
<td>1.50-1.65 (5.0-5.4)</td>
<td>16</td>
<td>1.5 (5.0)</td>
<td>0.58 (1.90)</td>
</tr>
<tr>
<td>1.56-1.79 (5.5-5.9)</td>
<td>13</td>
<td>1.4 (4.5)</td>
<td>0.18 (0.58)</td>
</tr>
<tr>
<td>1.80-3.50 (6.0-11.5)</td>
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<td>1.7 (5.7)</td>
<td>0.14 (1.36)</td>
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<td>Average</td>
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<td>1.2 (4.0)</td>
<td>0.44 (1.45)</td>
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</tbody>
</table>

Sediment Lost/Gain on Upper Shore

To calculate the amount of sediment lost or gained surrounding each stump on the upper shore, the distance from the top of the stump to the top of the sediment was subtracted from the stump height (Table 9). The average amount of sediment lost or gained at each stump in the 319 to 307 meter (1045 to 1006.6 foot) elevation range, was estimated at 0.04 meters ± 0.37 (0.14 feet ± 1.20). This value reflects
a relative no net gain or loss of sediment. Sediment could have been lost and replaced over time. These values indicate only that the balance of sediment along the upper elevations has remained relatively constant over the life span of the reservoir.

Table 9: Average sediment lost or gained on upper shores.

<table>
<thead>
<tr>
<th>Diameter (feet)</th>
<th>Number of Stumps Observed</th>
<th>Average Stump Height (feet)</th>
<th>Average Stump Height (feet)</th>
<th>Sediment Lost or Gained + or - (feet)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30-0.59</td>
<td>14</td>
<td>0.8 (2.6)</td>
<td>-0.07 (-0.24)</td>
<td>0.27 (0.89)</td>
<td></td>
</tr>
<tr>
<td>0.60-0.75</td>
<td>21</td>
<td>0.9 (2.8)</td>
<td>-0.06 (-0.18)</td>
<td>0.39 (1.28)</td>
<td></td>
</tr>
<tr>
<td>0.76-0.89</td>
<td>26</td>
<td>1.0 (3.2)</td>
<td>-0.09 (-0.29)</td>
<td>0.30 (0.97)</td>
<td></td>
</tr>
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<td>0.90-1.05</td>
<td>21</td>
<td>1.1 (3.7)</td>
<td>-0.01 (-0.04)</td>
<td>0.31 (1.01)</td>
<td></td>
</tr>
<tr>
<td>1.06-1.19</td>
<td>18</td>
<td>1.3 (4.3)</td>
<td>0.04 (0.12)</td>
<td>0.38 (1.24)</td>
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<tr>
<td>1.20-1.35</td>
<td>22</td>
<td>1.2 (4.1)</td>
<td>-0.01 (-0.04)</td>
<td>0.39 (1.28)</td>
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<tr>
<td>1.36-1.49</td>
<td>18</td>
<td>1.3 (4.2)</td>
<td>0.04 (0.14)</td>
<td>0.33 (1.09)</td>
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<td>1.50-1.65</td>
<td>16</td>
<td>1.5 (5.0)</td>
<td>0.09 (0.88)</td>
<td>0.39 (1.29)</td>
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<tr>
<td>1.66-1.79</td>
<td>13</td>
<td>1.4 (4.5)</td>
<td>0.09 (0.29)</td>
<td>0.32 (1.03)</td>
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</tr>
<tr>
<td>1.80-3.50</td>
<td>22</td>
<td>1.7 (5.7)</td>
<td>0.28 (0.93)</td>
<td>0.40 (1.32)</td>
<td></td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td>1.2 (4.0)</td>
<td>0.04 (0.14)</td>
<td>0.37 (1.20)</td>
<td></td>
</tr>
</tbody>
</table>

Pits Dug on Upper Shore

Fifteen pits were dug 3 meters (10 feet) apart on the north shore east of Bear Creek starting at the water-level to the upper shore to a depth of one meter (three feet) (Figure 28). Water level was at 307 meters (1006.6 feet), slope 15°, and shore length 45 meters (147.6 feet). Most of the pits contained a mixed A- and B-horizon. On the eleventh pit, 33 meters (108.3 feet), from water-level, the horizons became distinct with the A-horizon being about 7.5 centimeters (3 inches) thick and the B-horizon showing more oxidized material.

Grain-size analyses were conducted on these samples and classified according to the unconsolidated sediment nomenclature of Folk (1954) (Table 10). Grain-size fractions employed in this nomenclature are gravel, sand, and mud, where mud combines the silt and clay fractions.
From this grain-size analysis, the texture changes slightly in the eleventh pit to a coarser material (sandy loam). Thirty-three meters (108.3 feet) upslope from the water line on a 15° slope, reflects an 8.5 meter (28.0 feet) vertical displacement, equaling the 315.3 meter (1034.6 foot) elevation.

Table 10: Grain-size analysis on upper shore samples.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Elevation meters (feet)</th>
<th>Gravel</th>
<th>Sand</th>
<th>Mud</th>
<th>Sediment Name</th>
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<tbody>
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<td>T-3</td>
<td>306.8 (1006.6)</td>
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<td>60</td>
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<tr>
<td>T-6</td>
<td>307.8 (1009.1)</td>
<td>13</td>
<td>39</td>
<td>43</td>
<td>sandy loam</td>
</tr>
<tr>
<td>T-9</td>
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<td>17</td>
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</tr>
<tr>
<td>T-12</td>
<td>309.5 (1016.8)</td>
<td>9</td>
<td>29</td>
<td>62</td>
<td>silt loam</td>
</tr>
<tr>
<td>T-15</td>
<td>310.7 (1019.3)</td>
<td>14</td>
<td>31</td>
<td>55</td>
<td>silt loam</td>
</tr>
<tr>
<td>T-18</td>
<td>311.5 (1021.8)</td>
<td>17</td>
<td>33</td>
<td>50</td>
<td>silt loam</td>
</tr>
<tr>
<td>T-21</td>
<td>312.2 (1024.4)</td>
<td>10</td>
<td>32</td>
<td>58</td>
<td>silt loam</td>
</tr>
<tr>
<td>T-24</td>
<td>313.0 (1026.9)</td>
<td>16</td>
<td>31</td>
<td>51</td>
<td>silt loam</td>
</tr>
<tr>
<td>T-27</td>
<td>313.8 (1029.5)</td>
<td>9</td>
<td>33</td>
<td>57</td>
<td>silt loam</td>
</tr>
<tr>
<td>T-30</td>
<td>314.6 (1032.0)</td>
<td>15</td>
<td>31</td>
<td>54</td>
<td>silt loam</td>
</tr>
<tr>
<td>T-33</td>
<td>315.3 (1034.6)</td>
<td>19</td>
<td>37</td>
<td>44</td>
<td>sandy loam</td>
</tr>
<tr>
<td>T-33 A-horizon</td>
<td>315.3 (1034.6)</td>
<td>19</td>
<td>37</td>
<td>44</td>
<td>sandy loam</td>
</tr>
<tr>
<td>T-36</td>
<td>316.1 (1037.1)</td>
<td>15</td>
<td>34</td>
<td>56</td>
<td>silt loam</td>
</tr>
<tr>
<td>T-36 A-horizon</td>
<td>316.1 (1037.1)</td>
<td>15</td>
<td>34</td>
<td>56</td>
<td>silt loam</td>
</tr>
<tr>
<td>T-36 B-horizon</td>
<td>316.1 (1037.1)</td>
<td>15</td>
<td>34</td>
<td>56</td>
<td>silt loam</td>
</tr>
</tbody>
</table>

In the Results Soil section, the average lake level from 1930-54, equaled 315 meters (1032 feet) (Table 6). This level appears to be consistent with the findings in these pits as explained below. Above this level, the surface was more scoured with cobble armoring the shore. Below this level are mixed sediments from pre-existing soil or extra basinal sediments transported into this shoreline. (Figure 37)

Observations by Divers:

The first dive site is located approximately 1 kilometer (0.6 miles) east of the dam closer to the south shore (Figure 28). At the time of the dives, the water level was at elevation 311.56 meters (1022.17 feet). This high water level required a 36.6 meter (120 foot) dive to observe the reservoir floor at the 275
Figure 37: Armoring of the shores.
meter (902 feet) elevation. Darkness at this depth limited the divers' ability to find tree stumps safely. They did, however, note a change in current direction. Winds were easterly, while bottom current was moving toward the dam at approximately one-half knot (0.257 meters/second, 0.844 feet/second). Divers also observed small ripple marks of approximately 0.6 centimeters (0.25 inches) height and 5-centimeter (2-inch) spacing in silts with the sediment thickness estimated at 15 centimeters (6 inches).

The second dive was made in an area observed on the strip-charts to contain several tree-stumps, located approximately 150 meters (500 feet) west of Cougar Creek, near the north shore (Figure 28). This was a 14 meter (46 foot) dive to the 297 meter (976 foot) elevation. Stumps in this area could have been exposed during one of several yearly drawdowns. Divers did find mud cracks in the bottom sediments that were not filled with sediment. Sixteen stumps were observed, several of which were topped with a light dusting of sediment.

The third dive was located in a narrow channel east of Deer Creek and west of the log boom (Figure 28). This site was chosen for its steep terrain. This was an 18 meter (60 foot) dive to observe the 293 meter (962 foot) elevation. Four stumps were observed, atop each, one to two centimeters (0.4 to 0.8 inches) of silt had accumulated. Overall, sediment thickness in this area was estimated to exceed 65 centimeters (25.6 inches) at a depth of approximately 15 meters (50 feet), and to exceed 100 centimeters (39 inches) near the valley floor at 18 meter (60 foot).

Stumps that were observed by the divers with an exposed lateral root, showed sediment accumulation and stump heights similar to those calculated for stumps in the upper elevations. Measurements for submerged stumps were not included in the above calculations of exposed stumps so as to keep stumps at different elevations separate.
Tree-stump Analysis Map Production

The tree-stump map was produced by calculating the difference between the stump height observed on reflection data and the estimated stump height of 1.2 meters (4.0 feet). Areas without stumps were left blank and could be interpreted as any of the following: areas with sufficient fill to obscure stumps from view; cliffs too steep to support trees; areas where no trees grew or where stumps were removed.

In areas where data were available, differences between actual stump height and the estimated 1.2 meters (4.0 feet) were plotted on the Intergraph System, then contoured at 0.3 meters (one foot) intervals. Accuracy was estimated at ± 9 centimeters (± 0.3 feet), based on the reported accuracy of the bathymetric reflection data (David Evans and Associates, Inc. 1991).

To better distinguish the cut regions (negative values) from the fill regions (positive values), a shaded map was produced shading all of the negative regions. For reference purposes, stream drainage was added from the pre-impoundment survey map and may not have been precisely located. (Figure L1 in Appendix L)

Volume and Sediment Yield Rate Calculations

The Intergraph System could not calculate a volume displacement from this analysis due to the lack of a complete coverage. To calculate an approximate evaluation of this volume, the reservoir was divided into segments of similar topography. For each segment, the average sediment loss or gain was determined by the existing tree-stumps. Taking this average over the area occupied by each segment, a volume was calculated for each segment. Adding each segment together permitted a determination of the overall volume. (Figures L2-L5 in Appendix L)
When evaluating and reading the bathymetric strip-charts, the tree-stumps become less apparent in the far east end of the reservoir. To make this volume calculation, the study area was confined from the dam in the west to Fir Creek in the east. The upper boundary was limited near the 317 meter (1040 foot) elevation as outlined by the 1924 survey. This region covers 1,520,232 square meters (16,363,636 square feet) as compared to the reported area at the 317 meter (1040 foot) elevation of 1,609,724 square meters (17,326,920 square feet) (City of Portland, 1925).

Totaling up each segment produced an estimated volume predicted by the tree-stump analysis which equaled 192,500 cubic meters (252,000 cubic yards). The estimated volume was then multiplied by the estimated bulk dry density of the material within the reservoir (0.56 g/cm$^3$, refer to Results Coring) then divided by the size of the drainage basin (193.3 square kilometer, 74.6 square miles) (Hubbard and other, 1991) and life span of the impoundment (62 years, 1929 to 1991). These calculations provide a sediment yield rate of 9.0 tonnes/km$^2$/yr (22.9 tons/mi$^2$/yr). This value is limited by the height of the tree-stumps (1.2 meters, 4.0 feet) and cannot account for areas of greater sediment accumulation.
RESULTS CORING

Forty-one gravity core sites in the reservoir were occupied, covering the entire length of the reservoir (Figure 38). When the amount of sediment recovered was small and/or disturbed during recovery, samples were transferred to plastic bags, sixteen of which were collected. When sediment was recovered without being disturbed, samples were left in the plastic core liners. Thirty such intact core samples were logged, sub-sampled, and then sealed for archiving in the freezer.

Core logs

Core tubes were opened and logged, to describe the pre- and post-impoundment sediments. Pre-impoundment sediment was identified as having a coarse texture and containing either charcoal, oxidized sediments with soil pedons, A- and/or B-horizons, roots, or cobbles (diameter greater than 64 mm, 2.52 inches). In several cores, this soil horizon was topped by a thin (approximately 2.5 centimeters, one inch) burnt organic layer that possibly reflected the pre-impoundment clearing and burning operation. Post-impoundment sediment was identified as having a finer texture with finely-laminated layers of reduced muds. Post-impoundment sediments were further logged in detail for thickness, color changes, organic matter, texture, and bedding contacts.

Two anomalous event-layers in the post-impoundment sediments were identified in most of the cores except for one (7-42c), in which three events existed. In some of the cores, the two events were so close together they blended in as one. The older of the two event-layers is light brown and/or gray in color while the
Figure 38: Core sites within Bull Run Reservoir #1. Numbers on map are first two digits of sample identification number.
younger event-layer is light orange-brown and/or orange-gray. These event-layers exhibit a sharp contact at the base and a relatively sharp contact at the top. Higher resolution examinations of the contact relationships are discussed later under core X-radiography.

The amount of accumulated sediment was measured as follows: before the first event (B), within the first event (E1), at the midsection between the two events (M), within the second event (E2), after the second event (A), and overall (O). (Figures 39 & 40)

Figure 39: Positioning reference for different layers within the core.

Figure M1 in Appendix M illustrates the simplified graphics of these core logs for each core tube. Pre-impoundment soil appears as one continuous block and is not further divided. Post-impoundment sediment is separated into the material contained within each anomalous event-layer and into the rest of the material not
Figure 40: Core 5-9c and 3-11c. Observing the different layers collected within the post-impoundment sediment.
contained in these layers. For clarity, the two anomalous event-layers are displayed as the same light brown mud or sand, whereas, the material not contained within the anomalous event-layer is not further divided and is only described as a dark gray silt or sand. In several locations, lenses of organics and coarse sediment appear within the post-impoundment horizon but are not shown in these simplified graphics unless they represented a thick segment of the section. Overall, post-impoundment sediment thickness decreases and becomes texturally finer towards the west, as does sediment in both of the anomalous event-layers.

Core X-radiographs

Eleven cores were X-radiographed to reveal details too fine to be seen by the naked eye, when examining the cores. X-radiographs also served to document the accuracy of the core logging and to establish how much of the core was disturbed during the coring operation. Re-mixing of sediment during the coring operation was distinctly evidenced by the loss of laminated muds near the top of cores (Appendix N, Figures N1-N3, cores 38-37c, 5-9c, 3-11c). Horizontal positions of the laminations helped to verify that the core barrel had entered the mud vertically and had not distorted the estimates of the sediment thickness. Also noted were some dewatering cracks from freezing and thawing of the cores (Figure N3, core 3-11c).

The X-radiographs confirmed and separated the anomalous event-layers that had been visually identified in the cores. In the cores containing only small amounts of post-impoundment sediment (less than 20 centimeters, 8 inches) the anomalous event-layers appeared to blend together when examined visually. However, in the X-radiographs these layers remained distinctly separate (Figures N1, N4, N5; core 38-37c, 35-5cb, 40-6c).
Post-impoundment sediment deposited in layer B is the least dense of all the material collected, shown by the high contrast low density X-radiograph film used. Some very faint, thinly-layered laminations (< 1 millimeter, 0.04 inches) can be seen within this sediment, but they are largely indistinguishable particularly in cores containing little post-impoundment sediments.

Event E1 exhibits a very sharp, distinct basal contact (<1 millimeter, 0.04 inches) and a relatively sharp upper contact (1 to 2 millimeters, 0.04 to 0.08 inches). The basal contact appears more distinct due to the extreme change in the density of the material across the contact. The upper contact is less distinct because material deposited in layer M is denser than that deposited in B thus creating a more subtle density contrast. Fine laminations (2 millimeter, 0.08 inches) can be seen which are thicker and less uniformity than those of the preceding layer (B).

Material in layer M is denser than B and is finely laminated (approximately 1 millimeter, 0.04 inches). These laminations are not as thick as those found in E1 (approximately 2 millimeter, 0.08 inches) but they are thicker than those deposited in B (< 1 millimeter, 0.04 inches).

Event E2 exhibits a less distinct basal contact (1 to 2 millimeters, 0.04 to 0.08 inches) as compared to E1. This is primarily due to the similar densities in E2 and M at that contact. The upper contact is also less distinct (1 to 2 millimeters, 0.04 to 0.08 inches) and usually occurs in close proximity to the material disturbed by the core collection. Material in E2 is again finely laminated (approximately 2 millimeters, 0.08 inches), with occasional thicker laminations (approximately 4 millimeters, 0.16 inches).

The material deposited in layer A was disturbed in most of the cores during core recovery. In the cores containing a sufficient amount of undisturbed material,
however, this layer appears to be finely laminated (approximately 1 millimeter, 0.04 inches) and less dense than E1 and E2, and similar to layer M.

Overall, the laminations cannot reflect seasonal varves. More than 64 laminations can be counted between and within the anomalous event-layers. Such laminations might correlate to individual storm events, lowering/raising of the lake, or other phenomena. Multiple laminations within the anomalous event-layers show that these events contained multiple episodes of sediment input, whereas the sharp contacts that bound the event-layers show the events themselves to be discrete and of relatively limited duration.

**Sediment Thickness**

**Core tubes.** Total amount of post-impoundment sediment collected in each core tube was measured and recorded in Table 11. This sediment averaged 25 centimeters ± 28.39 (10 inches ± 11.18), decreasing toward the dam, varying from 10 centimeters ± 5.98 (4.1 inches ± 2.35) in the west (sample location 1 through 18) to 51 centimeters ± 33.89 (20 inches ± 13.35) in the east (sample location 19 through 41). Each sample was plotted on a graph comparing the amount of sediment collected to the sample elevation, producing a visual representation of sediment accumulation vertically throughout the reservoir (Figure 41).

This vertical representation shows that the accumulation is greater at higher elevations and decreases steadily to approximately the 295 meter (968 foot) elevation, where it increases briefly before decreasing to a more even distribution throughout the depth of the reservoir. With only several samples representing each elevation, these patterns could represent only local variations. The first two samples at the higher elevations reflect material deposited near the mouths of Fir Creek and North Fork Bull Run River (2-12c and 3-11c). The three located at the apparent
point of increase below the 295 meter (968 foot) elevation are grouped closely just
west of the far east log boom (8-40ca, 8-40cb, and 9-1c). Other possible mediating
factors at other sites are listed in Table 11.

Table 11: Amount of sediment collected in core tubes, arranged by elevation.

<table>
<thead>
<tr>
<th>Site (§)</th>
<th>Elevation (meters (ft))</th>
<th>Sediment Accumulated (centimeters (inches))</th>
<th>Comments:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-12c</td>
<td>310 (1017)</td>
<td>113 (44.5)</td>
<td>Outside Fir Creek (shallow)</td>
</tr>
<tr>
<td>3-11c</td>
<td>307 (1007)</td>
<td>56 (22.0) (+)</td>
<td>Outside North Fork Bull Run River (shallow)</td>
</tr>
<tr>
<td>5-9c</td>
<td>303 (994)</td>
<td>47 (18.5)</td>
<td>Outside North Fork Bull Run River (shallow)</td>
</tr>
<tr>
<td>7-42c</td>
<td>300 (984)</td>
<td>25 (9.8)</td>
<td>Shallow</td>
</tr>
<tr>
<td>22-25c</td>
<td>298 (978)</td>
<td>7 (2.8)</td>
<td>Shallow</td>
</tr>
<tr>
<td>23-35c</td>
<td>297 (974)</td>
<td>0 (?)</td>
<td>On top of a canyon wall (shallow)</td>
</tr>
<tr>
<td>8-40cb</td>
<td>295 (968)</td>
<td>75 (29.5)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>9-1c</td>
<td>295 (968)</td>
<td>87 (34.3)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>3-40ca</td>
<td>295 (968)</td>
<td>79 (31.1)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>20-26c</td>
<td>293 (962)</td>
<td>26 (7.9) (?)</td>
<td>Outside Deer Creek</td>
</tr>
<tr>
<td>30-3c</td>
<td>290 (951)</td>
<td>9 (3.5)</td>
<td>Possibly inside an old stream channel</td>
</tr>
<tr>
<td>10-39c</td>
<td>289 (948)</td>
<td>26 (10.2) (?)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>11-38c</td>
<td>289 (948)</td>
<td>21 (8.3) (?)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>13-33c</td>
<td>288 (945)</td>
<td>16 (6.3)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>21-27c</td>
<td>288 (945)</td>
<td>22 (8.7)</td>
<td>Just downstream of the narrow canyon</td>
</tr>
<tr>
<td>14-34c</td>
<td>288 (945)</td>
<td>12 (4.7)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>41-7c</td>
<td>283 (928)</td>
<td>7 (2.8)</td>
<td>Atop of a canyon wall</td>
</tr>
<tr>
<td>27-22c</td>
<td>282 (925)</td>
<td>13 (5.1)</td>
<td>Atop of a 6 meter (20 foot) wall</td>
</tr>
<tr>
<td>25-24c</td>
<td>280 (919)</td>
<td>6 (2.4)</td>
<td>Atop of a canyon wall</td>
</tr>
<tr>
<td>34-18c</td>
<td>279 (915)</td>
<td>5 (2.0)</td>
<td>Atop of a canyon wall</td>
</tr>
<tr>
<td>28-36c</td>
<td>277 (909)</td>
<td>8 (3.1)</td>
<td>Atop of a canyon wall</td>
</tr>
<tr>
<td>24-8c</td>
<td>276 (906)</td>
<td>19 (7.5)</td>
<td>Possibly inside old Bull Run channel</td>
</tr>
<tr>
<td>35-5ca</td>
<td>275 (903)</td>
<td>13 (5.1)</td>
<td>Possibly inside old Bull Run channel</td>
</tr>
<tr>
<td>35-5cb</td>
<td>275 (902)</td>
<td>8 (3.1)</td>
<td>Possibly inside old Bull Run channel</td>
</tr>
<tr>
<td>29-21c</td>
<td>275 (902)</td>
<td>11 (4.3)</td>
<td>Possibly inside old Bull Run channel</td>
</tr>
<tr>
<td>31-4c</td>
<td>273 (896)</td>
<td>4 (1.6)</td>
<td>Possibly inside old Bull Run channel</td>
</tr>
<tr>
<td>40-6c</td>
<td>273 (896)</td>
<td>17 (6.7)</td>
<td>Possibly inside old Bull Run channel</td>
</tr>
<tr>
<td>36-14c</td>
<td>270 (886)</td>
<td>5 (2.0)</td>
<td>Possibly inside old Bull Run channel</td>
</tr>
<tr>
<td>37-15c</td>
<td>270 (886)</td>
<td>10 (3.9)</td>
<td>Possibly inside old Bull Run channel</td>
</tr>
<tr>
<td>36-37c</td>
<td>269 (882)</td>
<td>15 (5.9)</td>
<td>Possibly inside old Bull Run channel</td>
</tr>
</tbody>
</table>

Average amount: 25 (9.9) ± 28.39 (11.18)

§ = The first number on the sample refers to the sample location in Figure 38
? = The contact with the pre-impoundment was not sure.
+ = The pre-impoundment was not collected.
Figure 41: Vertical Sediment Distribution, Core Samples
**Bagged samples.** To ensure equal comparisons among bagged samples, all post-impoundment sediment, and only post-impoundment sediment, should have been recorded. This was difficult to accomplish, however, because material collected was not intact. To determine whether any pre-impoundment material had been collected, samples were examined for oxidized sediment. Problems occurred when the original surface had been a stream channel. These sediments would not have been oxidized; and the sediment collected would have been coarser. This coarser sediment created additional problems with the coring operation. Gravel jammed the core catcher fingers open, thereby releasing some of this sediment before it reached the barge.

The amount of sediment collected in these cores were recorded before transferring the this material into the plastic bag (Table 12). The total amount of post-impoundment sediment collected in these samples averaged 31.4 centimeters ± 21.05 (12.4 inches ± 8.28). This sediment increased in thickness toward the dam varying from 41.3 centimeters ± 22.4 (16.3 inches ± 8.81) in the west (sample location 19 through 41) to 21.5 centimeters ± 2.45 (8.5 inches ± 0.98) in the east (sample location 1 through 18). This pattern differs from the observations made in the core tubes. Some possibilities for this could be that most of the eastern bagged samples were collected in the older stream channel which would contain coarser sediment holding the fingers on the coring devise open, losing the finer sediment. Or, these samples were collected inside the narrow channel; 1-13b, 12-29b, 15-28b, 16-31b, 17-32b, and 18-30b as compared to the western samples; 19-2ba, 19-2bb, 25-24b, and 33-19b which were not. Additional variables to consider at each site are listed in Table 12.

Comparing the samples vertically by plotting the sediment accumulation relative to the corresponding elevations shows more variation than that found in the
core tubes (Figure 42). There does appear to be an apparent increase in the sediment accumulation near the 288 to 290 meter (945 to 951 foot) elevations, which was also observed in the core tubes. Other fluctuations below this depth could reflect different sample sites, either collected in the older stream channel, reflecting a low accumulation (samples 17-32b, 26-23b, and 39-16b), or sites not in the channel reflecting a higher accumulation (samples 25-24b and 33-19b). Additional variables to consider at each site are listed in Table 12.

Table 12: Amount of sediment collected in plastic bag, arranged by elevation.

<table>
<thead>
<tr>
<th>Site (1)</th>
<th>Elevation (meters)</th>
<th>Sediment Collected (centimeters)</th>
<th>Comments:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-13b</td>
<td>307 (1007)</td>
<td>15 (5.9)</td>
<td>Old Bull Run River channel (shallow)</td>
</tr>
<tr>
<td>4-10b</td>
<td>300 (986)</td>
<td>18 (7.1)</td>
<td>Outside North Fork Bull Run River (shallow)</td>
</tr>
<tr>
<td>6-41b</td>
<td>299 (982)</td>
<td>100% organics, a lot lost during recovery</td>
<td></td>
</tr>
<tr>
<td>18-30b</td>
<td>298 (978)</td>
<td>20 (7.9)</td>
<td>Possibly inside old side stream channel</td>
</tr>
<tr>
<td>19-2bb</td>
<td>294 (964)</td>
<td>30.5 (12.0)</td>
<td>Outside Deer and Cougar Creek</td>
</tr>
<tr>
<td>9-1b</td>
<td>293 (961)</td>
<td>15 (5.9)</td>
<td>Core collection problems</td>
</tr>
<tr>
<td>19-2ba</td>
<td>292 (958)</td>
<td>30.5 (12.0)</td>
<td>Outside Deer and Cougar Creek</td>
</tr>
<tr>
<td>30-3b</td>
<td>290 (951)</td>
<td>79 (31.1)</td>
<td>Possibly inside old side stream channel</td>
</tr>
<tr>
<td>15-28b</td>
<td>289 (948)</td>
<td>20 (7.9)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>16-31b</td>
<td>288 (945)</td>
<td>18 (7.1)</td>
<td>Possibly inside old side stream channel</td>
</tr>
<tr>
<td>12-29b</td>
<td>286 (938)</td>
<td>46 (18.1)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>17-32b</td>
<td>283 (928)</td>
<td>20 (7.9)</td>
<td>Inside a narrow canyon</td>
</tr>
<tr>
<td>25-24b</td>
<td>280 (919)</td>
<td>79 (31.1)</td>
<td>On top of a six meter (20 ft.) wall</td>
</tr>
<tr>
<td>32-20</td>
<td>276 (906)</td>
<td>20 (8.0)</td>
<td>Did not keep sample</td>
</tr>
<tr>
<td>26-23b</td>
<td>275 (902)</td>
<td>15 (5.9)</td>
<td>Possibly in old Bull Run channel</td>
</tr>
<tr>
<td>33-19b</td>
<td>272 (892)</td>
<td>46 (18.1)</td>
<td>Core collection problems</td>
</tr>
<tr>
<td>39-16b</td>
<td>265 (879)</td>
<td>30.5 (12.0)</td>
<td>Possibly in old Bull Run channel</td>
</tr>
<tr>
<td>Average:</td>
<td>31.4 (12.4)</td>
<td>+ or - 21.05 (8.2)</td>
<td></td>
</tr>
</tbody>
</table>

1 = The first number on the sample refers to the sample location in Figure 38

Combined: Combining the results of the core tube and bagged samples into one distribution (Table 13) changed the average sediment accumulated to 28 centimeters ± 26.00 (11 inches ± 10.23). Another graph was created to show the distribution of this sediment vertically throughout the reservoir (Figure 43). The addition of the
Figure 42: Vertical Sediment Distribution, Bagged Samples
Table 13: All samples collected, arranged by elevation.

<table>
<thead>
<tr>
<th>Site (1)</th>
<th>Elevation meters (ft)</th>
<th>Sediment Collected centimeters (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-12c</td>
<td>319 (1017)</td>
<td>113 (44.5)</td>
</tr>
<tr>
<td>1-13b</td>
<td>307 (1007)</td>
<td>15 (5.9)</td>
</tr>
<tr>
<td>3-11c</td>
<td>307 (1007)</td>
<td>56 (22.0) (+)</td>
</tr>
<tr>
<td>5-9c</td>
<td>303 (994)</td>
<td>47 (18.5)</td>
</tr>
<tr>
<td>4-10b</td>
<td>300 (986)</td>
<td>18 (7.1)</td>
</tr>
<tr>
<td>7-42c</td>
<td>300 (984)</td>
<td>25 (9.8)</td>
</tr>
<tr>
<td>22-25c</td>
<td>298 (978)</td>
<td>7 (2.8)</td>
</tr>
<tr>
<td>18-30b</td>
<td>298 (978)</td>
<td>20 (7.9)</td>
</tr>
<tr>
<td>23-35c</td>
<td>297 (974)</td>
<td>0 (?)</td>
</tr>
<tr>
<td>8-40cb</td>
<td>295 (968)</td>
<td>75 (29.5)</td>
</tr>
<tr>
<td>9-1c</td>
<td>295 (968)</td>
<td>87 (34.3)</td>
</tr>
<tr>
<td>8-40ca</td>
<td>295 (968)</td>
<td>79 (31.1)</td>
</tr>
<tr>
<td>19-2bb</td>
<td>294 (964)</td>
<td>30.5 (12.0)</td>
</tr>
<tr>
<td>20-26c</td>
<td>293 (961)</td>
<td>20 (7.9) (?)</td>
</tr>
<tr>
<td>9-1b</td>
<td>293 (961)</td>
<td>15 (5.9)</td>
</tr>
<tr>
<td>19-2ba</td>
<td>292 (958)</td>
<td>30.5 (12.0)</td>
</tr>
<tr>
<td>30-3b</td>
<td>280 (951)</td>
<td>79 (31.1)</td>
</tr>
<tr>
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<td>280 (951)</td>
<td>9 (3.5)</td>
</tr>
<tr>
<td>15-28b</td>
<td>288 (945)</td>
<td>20 (7.9)</td>
</tr>
<tr>
<td>10-39c</td>
<td>289 (946)</td>
<td>26 (10.2) (?)</td>
</tr>
<tr>
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<td>289 (946)</td>
<td>21 (8.3) (?)</td>
</tr>
<tr>
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<td>287 (943)</td>
<td>16 (6.3)</td>
</tr>
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<td>288 (945)</td>
<td>22 (8.7)</td>
</tr>
<tr>
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<td>288 (945)</td>
<td>12 (4.7)</td>
</tr>
<tr>
<td>16-31b</td>
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</tr>
<tr>
<td>12-29b</td>
<td>286 (938)</td>
<td>46 (18.1)</td>
</tr>
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</tr>
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</tr>
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</tr>
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</tr>
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</tr>
<tr>
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</tr>
<tr>
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<td>277 (909)</td>
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</tr>
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<td>276 (906)</td>
<td>20 (8.0)</td>
</tr>
<tr>
<td>24-8c</td>
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<td>19 (7.5)</td>
</tr>
<tr>
<td>26-23b</td>
<td>275 (902)</td>
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</tr>
<tr>
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<td>275 (902)</td>
<td>13 (5.1)</td>
</tr>
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</tr>
<tr>
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<td>275 (902)</td>
<td>11 (4.3)</td>
</tr>
<tr>
<td>31-4c</td>
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<td>4 (1.6)</td>
</tr>
<tr>
<td>40-6c</td>
<td>273 (896)</td>
<td>17 (6.7)</td>
</tr>
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</tr>
<tr>
<td>36-14c</td>
<td>270 (886)</td>
<td>5 (2.0)</td>
</tr>
<tr>
<td>37-15c</td>
<td>270 (886)</td>
<td>10 (3.9)</td>
</tr>
<tr>
<td>38-37c</td>
<td>269 (882)</td>
<td>15 (5.9)</td>
</tr>
<tr>
<td>39-16b</td>
<td>258 (879)</td>
<td>30.5 (12.0)</td>
</tr>
<tr>
<td><strong>Average:</strong></td>
<td><strong>28 (11.0) + or (-26.00 (10.23)</strong></td>
<td></td>
</tr>
</tbody>
</table>

† = The first number on the sample refers to the sample location in Figure 38

? = The contact with the pre-impoundment was not sure.

* = The pre-impoundment was not collected.
Figure 43: Vertical Sediment Distribution, Core Tube and Bagged Samples
bagged samples greatly increases the variation in local sediment thickness reflecting
the increased complication encountered when studying the bagged sample.
Uncertainty of whether the material measured in the bagged sample was only post-
impoundment sediment and if all of the sediment was collected, suggests inclusion of
these samples should not be pursued.

Events. Each core tube was also measured for the amount of material
contained in each part of the stratigraphic layer (Table 14). Overall averages for the
30 cores are: B, 11.05 centimeters ± 9.67 (4.35 inches ± 3.81); E1, 3.30
centimeters ± 2.81 (1.30 inches ± 1.105); M, 6.29 centimeters ± 8.01 (2.48
inches ± 3.15); E2, 2.93 centimeters ± 2.29 (1.15 inches ± 0.90); and A, 7.53
centimeters ± 7.22 (2.96 inches ± 2.84). From these measurements, the two
anomalous event-layers (E1 & E2) make-up 20 percent of the total post-
impoundment sediment volume accumulated in the reservoir. All of these thickness
measurements are quite small, so even minute adjustments in contact positions for
each layer will affect said measurements significantly.
<table>
<thead>
<tr>
<th>Site (1)</th>
<th>Before</th>
<th>E1</th>
<th>E1</th>
<th>Middle</th>
<th>E2</th>
<th>After</th>
<th>E3</th>
<th>Top</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm (in)</td>
<td>cm (in)</td>
<td>cm (in)</td>
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<td>cm (in)</td>
<td>cm (in)</td>
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<td>6 (2)</td>
<td>6 (2)</td>
<td>5 (2)</td>
<td>17 (7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-11c</td>
<td>17 (7)</td>
<td>4 (2)</td>
<td>6 (2)</td>
<td>4 (2)</td>
<td>16 (6)</td>
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<td></td>
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<tr>
<td>4-9c</td>
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<td>1 (0.4)</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
<td>2 (1)</td>
<td>3 (1)</td>
<td>5 (2)</td>
<td></td>
</tr>
<tr>
<td>7-42c</td>
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<td>23 (9)</td>
<td>19 (7)</td>
<td>3 (1)</td>
<td>18 (7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-40ca</td>
<td>28 (11)</td>
<td>7 (3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-1c</td>
<td>30 (12)</td>
<td>7 (3)</td>
<td>25 (10)</td>
<td>8 (3)</td>
<td>17 (7)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>10-39c</td>
<td>2 (1)</td>
<td>4 (2)</td>
<td>8 (3)</td>
<td>7 (3)</td>
<td>5 (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13-33c</td>
<td>6 (2)</td>
<td>2 (1)</td>
<td>2 (1)</td>
<td>2 (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14-34c</td>
<td>8 (3)</td>
<td>2 (1)</td>
<td>2 (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-26c</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21-27c</td>
<td>14 (6)</td>
<td>8 (3)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>22-25c</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>23-35c</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-6c</td>
<td>11 (4)</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
<td>2 (1)</td>
<td>4 (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-24c</td>
<td>3 (1)</td>
<td>3 (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27-22c</td>
<td>3 (1)</td>
<td>1 (0.4)</td>
<td>4 (2)</td>
<td>3 (1)</td>
<td>2 (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28-36c</td>
<td>4 (2)</td>
<td>4 (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29-21c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-3c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31-4c</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34-18c</td>
<td>0</td>
<td>0.5 (0.2)</td>
<td>1.5 (0.6)</td>
<td>0.5 (0.2)</td>
<td>2.5 (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>5 (2)</td>
<td>3 (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35-5cb</td>
<td>4 (2)</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36-14c</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37-15c</td>
<td>6 (2)</td>
<td>0.5 (0.2)</td>
<td>0.5 (0.2)</td>
<td>1.5 (0.6)</td>
<td>1.5 (0.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38-37c</td>
<td>6 (2)</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
<td>6 (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-6c</td>
<td>11 (4)</td>
<td>1 (0.4)</td>
<td>3 (1)</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41-7c</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total accum.</td>
<td>221 (87)</td>
<td>66 (26)</td>
<td>107 (42)</td>
<td>44 (17)</td>
<td>113 (44)</td>
<td>3 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>average amount</td>
<td>11.05</td>
<td>3.30</td>
<td>6.29</td>
<td>2.93</td>
<td>7.53</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.d. + or -</td>
<td>9.67</td>
<td>2.81</td>
<td>8.01</td>
<td>2.29</td>
<td>7.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>avg of all events</td>
<td>3.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.d. + or -</td>
<td>2.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 = The first number on the sample refers to the sample location in Figure 38
** = No data.

Divers Observations

The divers employed to measure the tree-stumps also attempted to measure the amounts of post-impoundment sediment accumulated. Based on probe penetrations, their findings are rough estimates. Overall, these estimates are
greater than the thickness measured in the cores. The western-most location, Site 1 (Figure 28), was estimated at 15 centimeters (6 inches), while approximately 9 centimeters (3.5 inches) of post-impoundment sediments were cored near that location. At the eastern-most location, Site 3, divers estimated between 65 to 100 centimeters (2 to 3 feet). Near this location, along the stream axis, a little more than 26 centimeters (10 inches) were retrieved in the gravity core.

These differences between what they observed and what was retrieved in cores could reflect: local variability, sediment column compaction or dewatering from coring, and/or inability of the hand probe method to identify the top of the pre-impoundment.

Divers also described the sediment as having a thin, spongy top layer with a firmer under layer. Further discussion of the diver’s observations appears in the Results Tree-stump Analysis section.

**Bulk Density of Reservoir Sediments**

Bulk densities were measured down-core for four of the longer cores: 3-11c, 5-9c, 8-40cb, and 9-1c (refer to Figure 38 for location). These bulk densities were measured at approximate 2.5-centimeter (one-inch) increments, but restricting sampling to intervals within the different layers (B, E1, M, E2, and A) to determine if the different layers could be discriminated on the basis of bulk density (Tables O1-O4, Figures O1-O4 in Appendix O).

Averages for the different layers, are listed in Table 15. The results clearly show significant differences between the layers. Material deposited in layer B exhibits the lowest density. Layer M is denser than either the B or A, with B the least dense of the three. Anomalous event-layers E1 and E2 are denser yet, with the later,
E2, the denser of the two. These results substantiate X-radiograph interpretations of the different layers.

Table 15: Dry bulk densities for selected core samples.

<table>
<thead>
<tr>
<th>Core</th>
<th>Overall-Av. Bulk Density</th>
<th>A-Average Bulk Density</th>
<th>E2-Average Bulk Density</th>
<th>M-Average Bulk Density</th>
<th>E1-Average Bulk Density</th>
<th>B-Average Bulk Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gr/cm³</td>
<td>gr/cm³</td>
<td>gr/cm³</td>
<td>gr/cm³</td>
<td>gr/cm³</td>
<td>gr/cm³</td>
</tr>
<tr>
<td>3-1c</td>
<td>0.59</td>
<td>0.49</td>
<td>0.94</td>
<td>0.57</td>
<td>0.69</td>
<td>0.46</td>
</tr>
<tr>
<td>5-9c</td>
<td>0.59</td>
<td>0.55</td>
<td>0.89</td>
<td>0.62</td>
<td>0.77</td>
<td>0.47</td>
</tr>
<tr>
<td>8-40cb</td>
<td>0.53</td>
<td>0.48</td>
<td>0.78</td>
<td>0.65</td>
<td>0.72</td>
<td>0.39</td>
</tr>
<tr>
<td>9-1c</td>
<td>0.54</td>
<td>0.48</td>
<td>0.67</td>
<td>0.57</td>
<td>0.73</td>
<td>0.46</td>
</tr>
<tr>
<td>Average</td>
<td>0.56</td>
<td>0.50</td>
<td>0.82</td>
<td>0.60</td>
<td>0.73</td>
<td>0.44</td>
</tr>
<tr>
<td>sd + or -</td>
<td>0.03</td>
<td>0.03</td>
<td>0.12</td>
<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Grain-size Analysis of Bagged Samples

Grain-size analysis of bagged samples served to document only the composite grain-size distribution at each location over the life span of the reservoir. Ideally, only post-impoundment sediment should have been analyzed. Problems with ensuring exclusion of all pre-impoundment soils as described in the sediment thickness section, pertain to this analysis as well.

All samples that were determined to be representative of post-impoundment deposition were analyzed for the different grain-size fractions. These fractions were then categorized according to the unconsolidated sediment nomenclature of Folk (1954). Appendix P, Table P1 displays percentages of fractions found in each sample, along with their classifications. The samples were divided into east- and west-end of the reservoir to reflect changes along the length of the reservoir. From this analysis mud constitutes the dominant grain-size fraction of the post-impoundment sediments.
To observe smaller variations within the size fractions, mud was subdivided into silt and clay. These fractions are also listed in Table P1 showing the silt component to be the dominant grain-size.

Similarly, to observe even smaller fluctuations, the silt component was further divided into smaller fractions (Table P1). This division shows fine silt to be the dominant grain-size throughout the reservoir. A bar graph (Figure P1) was created to reflect the overall distribution patterns of these samples from west to east along the length of the reservoir. This graph shows a relatively uniform increase in the coarser fractions (coarse and medium silt) with more variation in the finer material (fine and very fine silt, and clay).

Overall, looking at the bar graphs the west side samples coarsen toward the dam while the east side shows no significant pattern. Comparing the overall averages between the east and west samples the two ends do not appear to show any significant difference. The coarsening of the west samples could reflect the loss of the top clay layer on the samples collected farther west. Several of these samples were collected in plastic bags because of the problems that occurred during core recovery, such as core 33-19b. Other various on-site conditions possibly impacting these results are listed in Table 12.

Comparing these samples to their corresponding elevations (Table P2, Figure P2) shows the grain-size decrease until approximately 294 meter (964 foot) elevation before fluctuating radically to about 286 meter (938 foot) elevation. At that depth, the variation decreases before increasing in grain-size again near the lower depths near 275 meter (902 foot) elevation. Again, these observations are from a limited number of samples for each elevation, and they might not accurately represent total reservoir conditions.
Grain-size and Organic Matter in Cores

Grain-size and organic content were conducted on several of the 30 sites collected in the core tubes. Twenty-four of the 30 cores were analyzed for the composite, Q (total post-impoundment layer) collected from throughout the core to measure the overall grain-size at each specific location. Other analysis were also conducted on each layer (B, E1, M, E2, and A) to reveal any changes in strata over time. Only 8 of the 30 cores contained enough material in each layer for this analysis, thus reducing the level of representation for each layer.

Combined Layers. Grouping all of the analyzed samples (Q, B, E1, M, E2, and A) and separating them into only east and west categories provides insight into combined trends along the length of the reservoir. Table Q1, in Appendix Q, lists samples representing the reservoir's east side, while Table Q2 lists samples for the west side. Averages appear at the bottom of each table, with the combined average for all samples listed at the bottom of Table Q2.

The combined average shows mud as the dominant size fraction. Of the mud's two main components, silt and clay, silt is the dominant size fraction. Silt was further subdivided (Tables Q1-Q2), with fine silt comprising the overall dominant grain-size fraction. These averages show sediment growing finer toward the dam. This differs from the grain-size results observed within the bagged samples. This could be because of more samples collected, fewer of these samples being collected in the old stream channel, certainty of only the post-impoundment analyzed, and/or fewer problems collecting these samples therefore losing less of the upper mud layer.

The organic content is highest in the sand fraction, at 44 percent ± 16.39, as compared to the silt and clay fraction, at approximately 11 percent ± 4.14.
Individual Layers - West to East. To observe grain-size changes with respect to time, each layer was analyzed separately. Core samples were grouped and averaged for each layer analyzed (total), as well as for the east and west ends of the reservoir (Table Q3). According to these results, total averages differ very slightly between layers. Layer B has a somewhat coarser texture than the other layers, but overall the layers differ only by one to two percent in the different grain-size fractions. The major difference between the layers exists in percent organic matter, with E1 and E2 containing noticeably lower percentages than the other layers.

Mud fraction is the dominate size fraction. Further dividing the mud fraction into silt and clay, silt is more dominate than the clay size fraction. Dividing the silt fraction into smaller fractions, fine silt is the dominate size-fraction observed throughout the reservoir (Table Q3). A bar graph was produced to visually observe the changes in these size-fractions from west to east, Figures Q1-Q6.

Observing these layers separately from east to west shows each layer becoming finer toward the dam. This again differs from what the bagged samples showed and could reflect increased sample sites, less samples collected in the stream channel, only the post-impoundment analyzed, and/or fewer collection problems. These results further confirm the inconsistency of the bagged samples, and substantiates their exclusion form the overall evaluation. Variations in this fining trend can be noted in the bar graphs, but these variations are attributed primarily to local variations, as noted in Table 11.

By arranging each layer of every sample analyzed according to its respective elevations, observations can be made vertically within the reservoir (Table Q4). Each layer is graphed in Figures Q7-Q12, comparing the percent sand and mud in
each sample to their corresponding elevation to give a vertical distribution of this material.

All layers display a decrease in the sand fraction and an increase in the mud fraction up to approximately the 290 to 295 meter (950 to 968 foot) elevation. At this elevation the process reverses itself before leveling off to more of a steady state in all layers except O which fluctuates somewhat at the lower depths. Once again, the number of cores analyzed are limited. The first two samples from higher elevations represent material deposited near the mouths of Fir Creek and North Fork Bull Run River (2-12c and 3-11c). The two located at the apparent point of increase near the 295 meter (968 foot) elevation are grouped closely just west of the east log boom (8-40cb and 9-1c). Other possible mediating factors that could control sediment grain-size at other sites are listed in Table 11.

**Individual cores.** Only eight cores contained enough material to test all layers. Variations within one core from layer to layer illustrated changes in local distribution patterns over time (Figures R1-R8 in Appendix R, refer to Tables Q1 and Q2 for data). According to these graphs, events E1 and E2 appear to consist of coarser grain-size fractions in the east and finer in the west. Material in layer B apparently represents the coarsest of all of the sediment collected.

**Cs-137 Analysis on Core Samples**

Cs-137 analysis was conducted on several cores to determine whether the sediments were deposited before or after the 1954 onset of atmospheric nuclear testings. To properly test for low concentrations of Cs-137, large samples of sediment, approximately 500 grams, are optimum. Analyzing smaller samples required longer time to analyze and could be less accurate but yielded a better time resolution.
The highest resolution approach would have been to separate samples into yearly increments. To estimate how much sediment represented a possible yearly deposit, the average accumulation for all cores of 25 centimeters (10 inches) (Table 11) was divided by the 64 year life-span of the reservoir, resulting in an average, for this purpose only, of 0.4 cm/year (0.15 inches/year). To test each yearly deposit, each sample would have had to be 0.4 centimeters (0.15 inches) thick, which is too small for analysis, so yearly samples could not be compared. A one-centimeter (0.4-inch) thick sample was considered the minimum necessary to ensure valid results.

With all layers identified in the cores, a dating procedure was developed to ensure that each of the layers were tested separately. This constraint meant some of the smaller cores contain too small of amount of sediment for Cs-137 testing. Only two of the larger cores, 8-40cb and 9-1c, were utilized to determine when the Cs-137 had begun to accumulate in the reservoir. Five other cores were tested to establish whether Cs-137 varied within and between the anomalous event-layers E1 and E2.

Concentrations of Cs-137 determined in this analysis are listed in Table S1, Appendix S, along with other anthropogenic radioisotopes. For this study, however, only the distribution patterns of Cs-137 are compared.

Samples were counted for as long as three days, which required that not all of the one-centimeter (0.4-inch) samples could be analyzed. Samples located near the start of the Cs-137 accumulation were fully analyzed, but not all of the other locations within the core could be as fully tested. This discontinuity thus created uncertainty with regard to the precise locations of some peak concentrations.

These data were graphed to display the distribution pattern throughout the cores (Figures S1 and S2). This graph compares only the depth of each sample to the
amount of Cs-137 detected. The depth axis therefore does not completely represent all of the depth within the core. For the positions of each sample analyzed in these cores, Figures S3 and S4 show detailed logs with the sample location identified.

Down-core Cs-137 concentrations within both of the longer cores established the 1954 time-line (Pennington and others, 1973). Other major peaks identified in these distributions could represent the highest levels of discharge for Cs-137 in 1958-59 and 1963-64, (Ritchie and others, 1972; Ritchie and others, 1973; Ritchie and McHenry, 1975; Mitchell and others, 1983), as does a more recent peak in 1970-71 (Mitchell and others, 1983). Table 16 shows a comparison of these peaks observed in Figures S1-S2.

Table 16: Comparison of Cs-137 peaks within cores.

<table>
<thead>
<tr>
<th>Core</th>
<th>Post-impoundment Started</th>
<th>Cs-137 started</th>
<th>Depth cm (ft)</th>
<th>Depth cm (ft)</th>
<th>Depth cm (ft)</th>
<th>Depth cm (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-40cb</td>
<td>1954</td>
<td>1958-59</td>
<td>2.5</td>
<td>2.1</td>
<td>2.0</td>
<td>2.9</td>
</tr>
<tr>
<td>9-1c</td>
<td>1963-64</td>
<td>1970-71</td>
<td>2.9</td>
<td>2.6</td>
<td>2.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

These positions are still imprecise. In some instances, samples adjacent to both sides of peaks were not tested, thus placing in question the true magnitude of those peaks. Also, because samples were one-centimeter (0.4-inch) thick, they could have represented greater than one-year increments. When the results of Table S1 are normalized with grams of clay (Table S2) the peaks are less distinct (Figures S5 and S6).

These results indicate that most of the material within the cores has been deposited after 1954, including both of the anomalous event-layers E1 and E2. The initial accumulation of Cs-137 appears sharply, thus reflecting low mobility and minimal diffusion of Cs-137 at depth.
Comparisons of E1 and E2, within and between cores failed to reveal any consistent distinguishing characteristics between them. In some cores, the concentration of Cs-137 is higher in E1, while in others the E2 layer is higher. But when comparing the two events with surrounding material, E1 appears to exhibit a more immediate decline in concentration at the beginning of deposition than does E2. Once the deposition begins, E1's Cs-137 concentration increases significantly, whereas E2 is more constant. E1 appears to have occurred after the 1963 peak, while E2 appears to have occurred after the 1970 peak.

**Clay Analysis**

Clay analysis was conducted to determine whether the clay type within the reservoir was constant through time. This knowledge is necessary to ensure the results of the Cs-137 analysis are correctly interpreted. Cs-137 adsorbs to clay and thus could exhibit different adsorption rates for different clays.

Sediment within the cores generally appear to be consistent, except that of events E1 and E2. These event-layers might differ compositionally from the rest of the post-impoundment sediments because they were produced by different sources, or depositional conditions. Two possible sources for these anomalous event-layers are the flood of 1964 and the landslide of 1972 (Refer to Previous Work section).

The 1964 flood correlates well with results of the Cs-137 analysis of E1. Preceding the E1 layer there was a possible 1963 peak, and sediment at the start of the event contained low detectable concentrations of Cs-137. A flood would dislodge coarse material at its onset, thus reducing concentrations of Cs-137. As the storm abated, finer particles would fallout. Because Cs-137 would be attached to these finer particles, its concentration would increase.
Results of the Cs-137 analysis on E2 correlate well with the 1972 slide. Samples analyzed before E2 possibly identified the 1970 peak. Characteristically, E2 decreases in concentrations of Cs-137, though not as dramatically as does E1. If E2 had resulted from this slide, it most likely would not have been a deep-seated slide, which means that deeper, Cs-137 poor soil would not have been dislodged. Instead, mostly shallow, Cs-137 rich soil was dislodged. Cs-137 analysis of soil samples shows the highest concentrations of Cs-137 to exist within 5 to 10 centimeters (2 to 4 inches) of the surface. (Refer to Results Soil Survey)

This landslide also removed material from the Rhododendron Formation which, in this area, consists of several highly-altered zones rich in clay minerals. This suggests that fine particles were released by the slide, thereby maintaining Cs-137 concentrations, in contrast to the flood, which produced an influx of coarse material that might have reduced Cs-137 concentrations.

Characteristics of E2 and the slide differ only in the estimated volume of displaced material 4,600 cubic meters (6,000 cubic yards) (Stevens, Thompson & Runyan, Inc., 1974). Projecting this volume over the reservoir surface at full-pool height (319 meter, 1045 foot elevation) results in 0.27 centimeters (0.1 inches) thick deposit. Based upon sediment thickness reported in Table 14, average thickness for E2 was 2.93 centimeters (11.5 inches). This thickness projected over the reservoir surface would produce 49,000 cubic meters (64,200 cubic yards) of material. Which is an order of magnitude greater than the approximation of Stevens, Thompson & Runyan, Inc. (1974).

If E1 had resulted from the flood, it would have contained material similar to the primary watershed source, but in different quantities. If E2 were from the landslide, the composition of deposited sediments would vary within individual cores as a function of variable source supply or of depositional environment.
To test these possibilities layers A and B were analyzed to determine if any changes had occurred in the clay-mineralogy over the life span of the reservoir. Additional analyses were conducted on E1 and E2 samples to determine if these events differed compositionally from the general clay mineralogy within the reservoir. Layer M was analyzed to determine if the system returned to the condition similar to that found in layer (B) prior to the first event (E1). An additional sample was taken from the landslide scarp to evaluate whether this material could be the source of the E2 layers.

Results of this analysis are listed in Table 17. As interpreted by the lab technician, Reka Gabor, samples B, M, and A are very similar. Both contain fully-hydrated (10-angstrom) halloysite, which expands when it adsorbs organic molecules into its structure. B, M, and A samples also contain an expanding mixed-layer clay composed of smectite and dehydrated (7-angstrom) halloysite. The most prominent feature of this mixed-layer clay is that when treated with glycerol, its diffractogram quality deteriorated significantly and its prominent 14A-reflections disappeared. Smectite and 7A-halloysite may also be present as distinct minerals, along with trace amounts of chlorite. In E1 and E2 10A-halloysite is the dominant mineral, and expandable mixed-layer clay is present in small amounts only. Sample NF-6 (North Fork Slide) contains only 10A-halloysite and a trace of expandable mixed-layer clay.

Based upon the foregoing results, clay mineralogy within the reservoir appears to have remained constant over the life span of the reservoir. However, events E1 and E2 differ compositionally from the other reservoir sediments, demonstrating that the events are anomalous in regards to sediment source. The system was able to return the previous sediment source distribution in-between the two events.
Table 17: Clay analysis results on reservoir samples.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Halloysite</th>
<th>Mixed layer</th>
<th>Chlorite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before (*)</td>
<td>58%</td>
<td>42%</td>
<td>trace</td>
</tr>
<tr>
<td>E-1</td>
<td>84%</td>
<td>16%</td>
<td>----</td>
</tr>
<tr>
<td>M</td>
<td>60%</td>
<td>40%</td>
<td>trace</td>
</tr>
<tr>
<td>E-2</td>
<td>85%</td>
<td>15%</td>
<td>----</td>
</tr>
<tr>
<td>After (*)</td>
<td>59%</td>
<td>41%</td>
<td>trace</td>
</tr>
<tr>
<td>NF-6</td>
<td>100%</td>
<td>trace</td>
<td>----</td>
</tr>
</tbody>
</table>

* Sample may contain distinct smectite and 7A halloysite mineral.

Volume and Sediment Yield Rate Calculations

To calculate the volume of sediment within the reservoir from post-impoundment core sediment, the average thickness of 25.2 centimeters (9.92 in, 0.827 feet) was utilized (Table 11). Projecting this thickness over the reservoir surface of 1,675,396 square meters (18,033,810 square feet, 414 acres) at full capacity (319 meter, 1045 foot elevation) produced a volume of 422,000 cubic meters (552,000 cubic yards).

To estimate the sediment yield rate, this volume was multiplied by 0.56 g/cm³ (dry-bulk density of material within the reservoir, Table 15), then divided by the size of the drainage basin, 193.3 square kilometers (74.6 square miles) (Hubbard and others, 1991) and by the life span of the impoundment, 64 years (1929-1993). This produced a sediment yield rate of 19.1 tonnes/km²/yr (48.7 tons/mi²/yr).

To determine whether this rate has changed over the life span of the reservoir, the different layers within the cores were compared. Assuming that E1 resulted from the 1964 flood and that E2 resulted from the 1972 landslide, the
reservoir history can be divided into three periods: prior to the flood 1930-1964 (not including the material in E1), 1965-1972, and post-1972 (not including the material within E2) (Table 18).

Table 18: Volume, rate, and sediment yield rates for core layers.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Duration</th>
<th>Accumulation</th>
<th>Volume</th>
<th>Sedimentation rate</th>
<th>Sediment yield rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm (in)</td>
<td>m3 (yd3)</td>
<td>cm/yr (in/yr)</td>
<td>tonnes/km2/yr</td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>1/30 to 1/65</td>
<td>11.05 (4.35)</td>
<td>185,000 (242,000)</td>
<td>0.32 (0.12)</td>
<td>15.3</td>
</tr>
<tr>
<td>Middle</td>
<td>1/65 to 1/72</td>
<td>6.29 (2.48)</td>
<td>105,000 (138,000)</td>
<td>0.90 (0.35)</td>
<td>43.6</td>
</tr>
<tr>
<td>After</td>
<td>1/72 to 8/93</td>
<td>7.53 (2.96)</td>
<td>126,000 (165,000)</td>
<td>0.35 (0.14)</td>
<td>17.0</td>
</tr>
<tr>
<td>Overall</td>
<td>5/29 to 8/93</td>
<td>25.2 (9.92)</td>
<td>422,000 (552,000)</td>
<td>0.39 (0.16)</td>
<td>19.1</td>
</tr>
</tbody>
</table>

Post-1972 accumulation (After) could exceed that listed above if several upper layers of sediment were lost during core recovery (See Methods Coring). Greater accumulation would necessarily increase the sedimentation rate. Since accumulation values for all layers were small even minor adjustments of those values will change the overall sedimentation rate considerably.

Cs-137 analysis also made subdivision within the cores. The problem with the results from these observations is that only the longer cores were analyzed. Sedimentation rate would necessarily be greater for these cores, but shorter cores could not be analyzed. Also the anomalous event-layers could not be removed from the volume.

Utilizing these time segments identified within the longer cores for a comparison of rate change only, averages for each division were calculated for the two cores (Table 19).

These calculations denote a change over time, as did the previous calculations. There appears to be a low accumulation during the early years of the reservoir and a maximum during the 1960s and early 1970s. The present rate is somewhat lower than the historical maximum, but remains higher than during the early years.
Table 19: Volume, rates, and sediment yield rate determined from Cs-137

<table>
<thead>
<tr>
<th>Section</th>
<th>Accumulation</th>
<th>Volume</th>
<th>Sedimentation rate</th>
<th>Sediment yield rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm (in)</td>
<td>m3 (yd3)</td>
<td>cm/yr (in/yr)</td>
<td>tonnes/km²/yr</td>
</tr>
<tr>
<td>1929-1954</td>
<td>8.5 (3.3)</td>
<td>142,000 (186,000)</td>
<td>0.34 (0.13)</td>
<td>16.50</td>
</tr>
<tr>
<td>1954-1958</td>
<td>11.0 (4.3)</td>
<td>184,000 (241,000)</td>
<td>2.75 (1.08)</td>
<td>133.50</td>
</tr>
<tr>
<td>1958-1963</td>
<td>8.5 (3.3)</td>
<td>142,000 (186,000)</td>
<td>1.7 (0.67)</td>
<td>82.53</td>
</tr>
<tr>
<td>1963-1970</td>
<td>28.0 (11.0)</td>
<td>469,000 (614,000)</td>
<td>4.0 (1.57)</td>
<td>194.18</td>
</tr>
<tr>
<td>1970-1993</td>
<td>25.0 (9.8)</td>
<td>419,000 (548,000)</td>
<td>1.5 (0.76)</td>
<td>93.36</td>
</tr>
</tbody>
</table>

Three Methods Compared

Overall volume and sediment yield rates determined by the core method equaled 422,000 cubic meters (552,000 cubic yards) and 19.1 tonnes/km²/yr (48.7 tons/mi²/yr) respectively, while equivalent values determined by the differencing map method equaled 2,641,000 cubic meters (3,460,000 cubic yards) and 123.4 tonnes/km²/yr (314.6 tons/mi²/yr), and the tree-stump analysis equaled 192,500 cubic meters (252,000 cubic yards) and 9.0 tonnes/km²/yr (22.9 tons/mi²/yr). Volume of the differencing map method exceeded that of the core method by a factor of 6.26 and the tree-stump was 2.19 times less than that of the coring.

Comparing site-specific amounts of sediment collected within several of the cores to the estimated amount predicted on the differencing and tree-stump methods, the differencing map method exceeded the amount found in the core by a factor of ten ± 19.50, while the tree-stump estimates exceeded the actual collected by a factor of 2 times ± 2.03 (Table 20).

Not all of the samples were used because of site specific variations creating erroneous results. An example of this is observed in sample 23-35c which was taken from a steep cliff along the old river channel. Steep areas were found to
produce errors in the differencing map and were thus judged non-representative.

For these calculations, sample 23-35c and others were omitted.

In the above comparison, the differencing map estimated amount of sediment within the reservoir is high, but when considering the distribution amounts, the coverage is at least representative. A better representation is offered by the tree-stump map, though its lack of coverage presents a major problem. Still, when producing a sediment-distribution map for the reservoir, the tree-stump map would provide the most accurate reference. The differencing map would have to suffice in areas not covered by the tree-stump map adjusting the estimated sediment thicknesses.
Table 20: Site-specific comparison of the three different methods.

<table>
<thead>
<tr>
<th>Site (%)</th>
<th>Amount within (cm, ft)</th>
<th>Amount within (Map, cm, ft)</th>
<th>Amount within (Tree stump)</th>
<th>Amount times greater on</th>
<th>Amount times greater on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Core</td>
<td>Differencing</td>
<td>Tree stump</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>cm (ft)</td>
<td>Map, cm (ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-12c</td>
<td>113 (3.7)</td>
<td>335 (11)</td>
<td>&gt;91 (3)</td>
<td>3</td>
<td>&gt;0.8</td>
</tr>
<tr>
<td>3-11c</td>
<td>56 (1.8) (+)</td>
<td>427 (14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-9c</td>
<td>47 (1.5)</td>
<td>152 (5)</td>
<td>&gt;91 (3)</td>
<td>3</td>
<td>&gt;1.9</td>
</tr>
<tr>
<td>7-42c</td>
<td>25 (0.8)</td>
<td>213 (7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-40ca</td>
<td>79 (2.6)</td>
<td>274 (9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-1c</td>
<td>87 (2.8)</td>
<td>305 (10)</td>
<td>&gt;91 (3)</td>
<td>4</td>
<td>&gt;1.0</td>
</tr>
<tr>
<td>10-39c</td>
<td>26 (0.85) (?)</td>
<td>91 (3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13-33c</td>
<td>16 (0.5)</td>
<td>-91 (-3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14-34c</td>
<td>12 (0.4)</td>
<td>-30 (-0.98)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-26c</td>
<td>20 (0.7) (?)</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22-25c</td>
<td>7 (0.23)</td>
<td>152 (5)</td>
<td>18 (0.6)</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>23-35c</td>
<td>0 (?)</td>
<td>305 (10)</td>
<td>30 (0.98)</td>
<td>305</td>
<td>30</td>
</tr>
<tr>
<td>25-24c</td>
<td>6 (0.2)</td>
<td>274 (9.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-3c</td>
<td>9 (0.3)</td>
<td>152 (5)</td>
<td>-18 (-0.6)</td>
<td>17</td>
<td>-2</td>
</tr>
<tr>
<td>35-5ca</td>
<td>13 (0.4)</td>
<td>153 (5)</td>
<td>30 (0.98)</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>35-5cb</td>
<td>8 (0.26)</td>
<td>154 (5)</td>
<td>30 (0.98)</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>38-37c</td>
<td>15 (0.5)</td>
<td>91 (3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-6c</td>
<td>17 (0.6)</td>
<td>-396 (-13)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41-7c</td>
<td>7 (0.23)</td>
<td>457 (15)</td>
<td>32 (1)</td>
<td>65</td>
<td>5</td>
</tr>
</tbody>
</table>

*avg 29.6 (0.97)   *sd or + 70.14   9.72

#avg 31.3 (1.03)   #sd or + 19.50   2.03

? = The first number on the sample refers to the sample location in Figure 38.
+ = The contact with the pre-impoundment was not sure.
* = The pre-impoundment was not collected.
* = average of all the cores
# = average omitting core 23-35c
DISCUSSION

Goals of this study are as follows: 1) to establish the distribution patterns of the sediment in Reservoir #1 to help identify potential sediment sources, 2) to calculate sedimentation rates and determine any historical changes in these rates, and 3) to better predict hydrographic conditions leading to anomalous turbidity in Bull Run Reservoir #1. As previously discussed, the methods and results employed to accomplish these goals included: 1) estimation of post-impoundment sediment thickness for the volume of basin fill, 2) calculation of sediment yield rate based on time-stratigraphic markers, thereby identifying any historical changes in that rate, and 3) identification of sediment sources and mechanisms of sediment suspension and transport in the reservoir. The following discussion analyzes the results as they pertain to these goals.

Estimation of Sediment Thickness for Volume

Volume. The volume of sediment within the reservoir was calculated by three different methods: differencing map, tree-stump analysis, and using the material collected within the cores. Differencing method resulted in a volume of 2,641,000 cubic meters (3,460,000 cubic yards) which exceeded the volume calculated using the cores (422,000 cubic meters - 552,000 cubic yards) by a factor of 6.26 times. Tree-stump volume (192,000 cubic meters - 252,000 cubic yards) was 2.19 times less than that of the cores, but these volumes were calculated over a smaller area. Projecting the area used by the tree-stump analysis (1,520,232 squared meters - 16,363,636 squared feet) to equal that of the core method
(1,675,396 squared meters - 18,033,810 squared feet) the tree-stump method still comes out 1.99 times less than that of the cores.

The coring method should be the most accurate of all of the methods, because actual amounts were collected at each site. A major problem, however, is that the cores covered the smallest percentage of the entire reservoir. Additional problems are: cut regions are not reflected in these values, some sediment may have escaped from the top of cores, and some cores did not penetrate the full thickness of the post-impoundment sediments at the east end of the reservoir.

Factors causing the values calculated by the differencing map to be misrepresentative are the techniques used to align the pre- and post-impoundment maps and having to choose a stream pattern for the pre-impoundment survey. With the major source of error most likely coming from how the computer calculated the difference between the two regions which exaggerates the sediment accumulation in steeper slope regions.

The tree-stump method was limited by the height of the stump. Any sediment greater than 1.2 meters (four feet) could not be recorded. Also any area of excess sediment reduction could have removed the tree-stump which would not have been recorded. Other problems occurred in areas where the tree-stumps were not found, mainly the river channel and along cliff walls. To work with these problems, segments were created within the reservoir to calculate average sediment gain or lost in each segment. These segments attempt to group similar topography conditions that would reflect a regular distribution. Choices and decisions in creating these segments are also subjective.

Combining all of these methods were combined into a finalized isopach map (Figures T1- T4 in Appendix T). The same segments created for the tree-stump
analysis were used to make new estimates of averages within each segment. These averages considered the actual amount collected in cores located within these segments and the distribution patterns observed on the differencing map. This new overall method estimated the sediment volume to equal 254,000 cubic meters (332,000 cubic yards) over the 1,520,232 square meter area (16,363,636 square feet). Projecting this volume to cover the area used in the coring method (1,675,396 squared meters - 18,033,810 square feet) would produce 280,000 cubic meters (366,000 cubic yards).

**Distribution.** The overall distribution of this volume over the entire reservoir was estimated most thoroughly by the differencing method, while the tree-stump analysis and the coring method only partially describe this distribution. When comparing the actual amount of sediment collected in cores to the estimated amounts on the differencing and tree-stump maps, the tree-stump method had the most accurate estimates. The tree-stump method differed by only a factor of 2 as compared to the differencing map which differed by a factor of 10 (Table 20). In summary, the tree-stump method yields the best prediction for the sediment thickness while the differencing map only helps to describe the pattern.

Comparing the longitudinal distributions of this sediment as observed from the core samples, there appears to be a delta shaped distribution, thicker upstream, with some fluctuation created by entering side tributaries. The largest deposition is found at the upper end near North Fork Bull Run River and Fir Creek. This thickness continues until just before the narrows where the channel becomes constricted. At this point the distribution is less but the area is steep allowing only a few places for the sediment to settle out.

A secondary delta appears to have developed just outside the narrow canyon, immediately below Deer and Cougar Creeks. This delta is smaller and extends only a
short distance, 122 to 244 meters (400 to 800 feet). The sediment thickness then continues to reduce toward the dam with some fluctuations entering in from side channels on the south shore and from Bear Creek. These observations could not be easily seen on either the differencing or the tree-stump analysis maps.

Vertical distribution of this sediment, as observed from the cores, appears to thin with decreasing elevation. A pocket of accumulation occurs near the 290 to 295 meter (950 to 968 foot) elevation before the distribution becomes almost negligible at lower elevations. This pocket is still questionable with limited sample observed, but this could reflect the redistribution of sediment to lower elevations from the fluctuating lake levels. This pocket is observed in all of the different time segments within the core samples. The lake levels on an average were not drawn down as low during the earlier years, 1930-1954, of the reservoir (309.6 meters, 1015.7 feet) as in later years, 1955-1993 (302.7 meters, 993 feet) (Table 7).

The lack of sediment below the 290 to 295 meter (950 to 968 foot) elevation could reflect an increase in current velocity created by stream constriction at lower elevations, or by water released at the dam for power production. On that day, September 19, 1993, the water was being withdrawn for power production, and underwater currents were noted by divers as they drifted toward the dam, when surface winds were blowing upstream. They also noted small ripples on the reservoir floor. There appears to be ample evidence that sediments are being suspended off the deepest parts of the reservoir floor.

With regards to textural distribution, longitudinally the sediment becomes finer toward the dam. Vertically, the sand fraction decreases as the mud fraction increases with depth, with a small fluctuation in the latter noted between the 290 and 295 meter (950 to 968 foot) elevations. The predominant grain-size fraction is fine silt, which reflects a reservoir dynamics with sufficient length to allow fine silt
to settle out while most of the clay remains in suspension. Over time, the clay should settle out and accumulate at the base of the dam, but this resulting deposit is not observed. This suspended sediment could be escaping the system by spilling over the dam or by flowing through the hydroelectric power house.

**Historical Changes in Sediment Yield Rate**

**Sediment Yield Rates.** The sediment yield rate within the drainage basin was calculated by all three methods. The differencing method produced a rate of 123.4 tonnes/km²/yr, which exceeded by a factor of 6.45 the rate determined from cores of 19.1 tonnes/km²/yr. The tree-stump method produced a rate of 9.0 tonnes/km²/yr which was 2.12 times less than that of the core method. The combined isopach map determined a sediment yield rate of 11.5 tonnes/km²/yr.

Rinella (1987) calculated sediment yield rates determined from daily mean suspended-sediment concentrations and loads at three stream gauge stations entering Reservoir #1. These calculation were for short duration but provide a comparison to the values calculated in this study (Table 21).

**Table 21: Stream yield study by Rinella (1987)**

<table>
<thead>
<tr>
<th>Method</th>
<th>tonnnes/yr (tons/yr)</th>
<th>tonnes/km²/yr (tons/mi²/yr)</th>
<th>Station # (refer Fig. 5)</th>
<th>Years data collected</th>
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</thead>
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<td>Main Stem</td>
<td>4582 (4510)</td>
<td>37.0 (94.2)</td>
<td>14138850</td>
<td>1978-83</td>
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<tr>
<td>Fir Creek</td>
<td>181 (178)</td>
<td>12.8 (32.6)</td>
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<td>1978-83</td>
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<td>North Fork</td>
<td>809 (796)</td>
<td>37.5 (95.7)</td>
<td>14138900</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5572 (5484)</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>tonnnes/yr (tons/yr)</th>
<th>tonnes/km²/yr (tons/mi²/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differencing</td>
<td>23853 (23476)</td>
<td>123.4 (314.6)</td>
</tr>
<tr>
<td>Tree-stump</td>
<td>1740 (1713)</td>
<td>9.0 (22.9)</td>
</tr>
<tr>
<td>Coring</td>
<td>3592 (3534)</td>
<td>19.1 (48.7)</td>
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<tr>
<td>Combined</td>
<td>2223 (2188)</td>
<td>11.5 (29.3)</td>
</tr>
</tbody>
</table>
Looking at the predicted total tons/year entering into the reservoir, 5572 tonnes/yr (5484 tons/yr), it is clear that the differencing map likely over estimates deposition. By comparison, the coring method calculations are within a factor of two of the predicted sediment supply.

One reason the values might differ is that not all of the delivered sediment is necessarily retained within the reservoir. Also, the limited duration of Rinella's study required extrapolations for extreme conditions of discharge. Those extrapolations were not independently confirmed. However both the predicted and measured long-term sediment supply rates are surprisingly low.

Comparing these values to the sediment yield rates calculated for the Coast Range: Umpqua at Elkton, 339.9 tonnes/km²/yr; Siuslaw at Mapleton, 124.8 tonnes/km²/yr; Alsea at Tidewater, 187.3 tonnes/km²/yr; and Yaquina, 128.8 tonnes/km²/yr (Karlin, 1980), the values calculated in this Bull Run study are on an average three times smaller. Some factors causing the Coast Range to differ so much from the Bull Run watershed could be differences in: rainfall, geology, topography, and logging practices. The drainage area in the Coast Range have been heavily logged over the years.

The smaller sediment supply rates in the Bull Run system could be low due to the region being relatively young with a thin soil development. The Bull Run watershed soils contain a higher percent of silt with smaller amounts of clay development which produce high permeability and percolation rates and therefore low sediment run-off by overland flow. Transport of this material would be limited to higher velocity discharges. Precipitation in this area is highest during the winter months when most of it falls as snow, allowing for a slower discharge as the snow melts in spring. An exception to this is when a sudden increase in the temperature melts this snow pack quickly.
**Time Divisions.** The two anomalous event-layers were identified as the 1964 flood and the 1972 North Fork Slide. These event-layers were visually observed while logging the cores, and they were further distinguished by the X-radiography, bulk density, Cs-137, clay analysis, and a low percent of organic matter. Bulk density calculations were able to confirm fluctuations within the accumulated sediment instead of a gradual increase with depth as a result of compaction from the overlying sediment. This technique for identifying anomalous events in lake sediment was also used in a study in Montana. In that study, the same 1964 flood was among the different anomalous events they identified (Spencer, 1991).

The 1964 flood was characterized by a sharp contact of coarser sandy material before fining-up with several pulses. Cs-137 analysis was able to possibly identify the 1963 peak before this event. Concentration of the Cs-137 exhibited an extreme decrease at the start of the event before increasing again shortly later. This could reflect the immediate discharge of material at the start of the flood carrying coarser sandy material which is diluted of Cs-137. As the flood wanes, the finer Cs-137 rich material begins to settle out. Clay analysis confirms that this event was anomalous with respect to the general discharge into the reservoir. The low percent of organic matter reflects a mineral rich event produced possibly from anomalous stream bank erosion.

The material produced by the 1972 North Fork Slide was more orange-brown in color. The event-layer contained a sharp basal contact of clay rich material including several pulses. Cs-137 did not have as sharp of a decline in concentration at the beginning of this event as did the 1964 flood. Just before this event the 1970 peak was possibly identified. Clay analysis identified this event as anomalous in
composition, possibly originating from altered zones in the Rhododendron Formation. Percent organic matter was again low reflecting a mineral-rich event.

The only discrepancy in interpreting the second event as the North Fork Slide is that the volume collected in the cores representing the slide equals 49,000 cubic meters (64,200 cubic yards) of material. This volume is far more than what was estimated to have been released 4,600 cubic meters (6,000 cubic yards) (Stevens, Thompson & Runyan, Inc., 1974). Reasons for this difference might include an under estimate of the original material dislodged during the slides not taking in account the amount of material strip-off from the sides of the river banks. The volume within the reservoir could reflect a higher volume due to sediment already in the channel system being resuspended and remixed during transport to the reservoir.

**Time Divisions Rates.** Using these interpretations of the two anomalous event-layers the accumulated sediment in the cores was separated into different historical time segments. Calculating the sediment yield rate for these different segments (not including the anomalous event-layers) produced: 15.33 tonnes/km²/yr, 1930-1965; 43.62 tonnes/km²/yr, 1965-1972; and 17.00 tonnes/km²/yr, 1972-1993 (Table 18). Each of these rates are still comparatively low, and even minor adjustments to these time-segment thickness will change these results by large magnitudes.

The lowest accumulation occurred during the earlier years of the reservoir. Even allowing for compaction over time this is considerably less than the segment from 1965-1972 but is comparable to the rate calculated for the most recent discharge, 1972-1993. The rate from 1972-1993 could be higher than what is recorded due to the possibility of the upper layers of sediment being lost prior to or during core recovery. During this later time segment (post 1972), the lake levels on the average were drawn down to lower levels (Table 7) possibly resuspending
bottom sediments. Keeping this material suspended would allow more sediment to be discharged out of the reservoir from the spill-over or from the power plant installed in 1981.

The interval from 1965-1972 exhibits the greatest increase in the rate of accumulation. Factors possibly contributing to this increase are stream readjustment after the 1964 storm, and/or increased road construction and logging in the watershed. The 1964 storm created a major flood, and if the streams were greatly disturbed as a result, it would have taken perhaps weeks to even years for them to re-establish equilibrium. Stream banks would have continued to slough-off during this period, which could have produced the sediment pulses observed by sediment laminae in the X-radiographs.

Logging began in the watershed in 1960 with an increase in activity from the early 1960s to early 1970s (Table A1, Figure A1 in Appendix A). Logged areas would need time for shrubs to re-establish themselves on the exposed slopes. If this did not happen by the time of the 1964 flood, these slopes would have been extremely susceptible to storm erosion.

Road construction had a major increase in early 1960s with 1962 having the highest activity (Table A2, Figure A2 in Appendix A). As reported in several studies, roads have contributed to major increase in sediment production (Harr and Fredriksen, 1988; Miner, 1968; Beschta, 1978; Fredriksen, 1965 & 1970; Harr and others, 1975). Combining the increase in road construction with the 1964 flood, the newly developed road culverts would have diverted storm run-off into narrow channels, creating higher discharge volumes and damaging drainage routes.
Sources and Mechanisms of Suspension and Transport

Existing Pre-impoundment Soils. Sediment within the reservoir was initially considered to have come from either the upper tributaries or redistribution of existing soil within the reservoir. The soil study estimates the volume of pre-existing soil within the reservoir at 808,000 cubic meters (1,060,000 cubic yards). Redistribution of this material was thought to occur primarily in the reservoir's upper elevations by the raising and lowering of the water level. The volume of sediment exposed at the 315 meter (1032 foot) elevation, the average lake level, is estimated at 203,000 cubic meters (266,000 cubic yards) and at the 305.4 meter (1002.0 foot) elevation, average lowest yearly draw-down level, it is estimated at 660,000 cubic meters (863,000 cubic yards).

An exact determination could not be made as to how much sediment has been stripped off the upper shores and later redeposited from a secondary source. Examining the stumps and the material in the pits on the upper shores and material collected in cores suggests that most of the pre-impoundment sediments have remained intact. Soil horizons are still preserved and the burnt organic layer still remains from the clearing operation. The existence of tree-stumps along the shore shows the material has not eroded enough to dislodge these stumps and strip them off.

To establish whether the volume of material observed within the reservoir could have come entirely from the upper shore soils, an extreme example was considered in which all the upper shore soils was removed. If all sediment were stripped from elevations 319 to 315 meter (1045 to 1032 feet), the quantity of material produced (203,000 cubic meters; 266,000 cubic yards) would be less than that estimated to exist in the reservoir (422,000 cubic meters; 552,000 cubic yards) by the coring method. This volume is closer to that estimated by the
overall method (254,000 cubic meters; 332,000 cubic yards) but this would require almost all of the surface material to be removed.

At the lowest lake level, 305.4 meter (1002.0 feet), a sufficient quantity of material exists (659,880 cubic meters; 863,091 cubic yards) but it is unlikely more than a half of the entire soil column has been stripped-off. The upper banks thus were considered not to have contributed the entire estimated volume of sediment in the reservoir. The exact amount of side wall contribution cannot be determined from this study.

**Upstream Tributaries.** Distribution patterns of sediment deposition do reflect an upstream source based on core sediment thickness, core sediment grain-size trends, and anomalous event-layers thickness trends. Of the material entering from tributaries, a significant portion of it appears to have resulted from two catastrophic events comprising 20 percent of the total sediment volume deposited.

**Turbidity.** Data collected by the City of Portland, Bureau of Water Works show that turbidity increases toward the dam (Appendix U, Tables U1-U3, Figures U1-U3). From 1977 to 1989, turbidity in station 59-2 (Refer to Figure 5 for location) decreased with depth, with greater than 2 NTU found within 4.6 meters (15 feet) of the surface (Figure U1). During the same period, turbidity in station 59-1 (Refer to Figure 5 for location) also decreased with depth, with more than 3 NTU found within 6.1 meters (20 feet) of the surface (Figure U2). Station 59-0 (Refer to Figure 5 for location) conversely, showed increased turbidity with depth from 1965 to 1982 (excluding 1971 and 1972), with maximum intensity at an approximate depth of 12.2 meters (40 feet) (Figure U3).

In all stations maximum turbidity occurred in the fall and winter months (September to February), with the greatest concentrations close to the surface. The
lower-turbidity, spring and summer months (March to August) exhibited the greatest turbidity concentrations at lower depths. (Figures U4-U16)

These patterns indicate that fluvial sediment is transported toward the dam, producing the delta shaped distribution observed in the cores. Winter river discharge patterns reflect a seasonal increase in rainfall, which increases the amount of sediment discharged into the reservoir. Summer patterns, on the other hand, reflect decreased rainfall, which allows this sediment to settle out of suspension. This is opposite to an expected pattern of seasonal turbidity from wind/wave erosion of the reservoir side walls during summer draw downs.
CONCLUSIONS

The post-impoundment sediment volume was estimated to be between 254,000 cubic meters (332,000 cubic yards) and 422,000 cubic meters (552,000 cubic yards) calculated by the combined stump and coring methods respectively. An underdetermined small amount of fines appears to have escaped the system having been, either discharged through the hydroplant or spilled over the dam, thus making the total sediment volume an approximate calculation.

The distribution of sediment is thicker and coarser to the upstream end; thinning out toward the dam, and becoming texturally finer to the west toward the dam. The vertical distribution of sediment thickness suggests a depositional pocket near the 290 to 295 meter (950 to 968 foot) elevation, which overlies a reduction in depositional thickness to almost negligible levels at lower elevations. The old stream channel does not appear to have accumulated large quantities of sediment which would have been expected in the deepest axis of the reservoir. This lack of accumulation in the channel is probably due to underwater currents and sediment resuspension.

The overall depositional pattern indicates an upstream sediment source, with limited modifications from side tributary streams and minimal contributions from the upper shores in response to raising and lowering of the reservoir. A significant source of sediment was considered to be produced by anomalous events recorded within the watershed which comprised 20 percent of the sediment volume. These two events were the 1964 flood and the 1972 North Fork Slide.
Based on sediment cores throughout the reservoir and a combined isopach method, the overall estimated sediment yield rate of the basin is estimated to be between 11.5 and 19.12 tonnes/km²/yr. This rate has changed over the life span of the reservoir (not including the anomalous events): 15.33 tonnes/km²/yr, 1930-1965; 43.62 tonnes/km²/yr, 1965-1972; and 17.00 tonnes/km²/yr, 1972-1993. The greatest increase occurred in the 1960s and early 1970s. These increases possibly reflect the streams re-establishing themselves after the 1964 flood and/or changes in the land management practices. On the whole, these rates are relatively low as compared to those reported for other drainages in the Pacific Northwest.
SUGGESTED EXTENDED STUDIES

1. To determine the extended effects from the 1964 flood, core samples could be taken from Bull Run Lake. Bull Run Lake should be high enough in elevation that the sediment entering the lake should only be from natural run-off and not from road culverts. The 1972 North Fork Slide would not be recorded in these samples but with the use of incremental bulk density sampling, comparisons can be made with the results from the cores in Reservoir #1. Cs-137 analysis could also be conducted to possibly identify the 1963 and/or 1970 peaks.

2. To determine how much sediment could possibly be leaving Reservoir #1, core samples could be taken at the upper reaches of Reservoir #2 before any major side stream feed into the system. If these samples reflect a small sediment accumulation (10 to 20 centimeters, 4 to 8 inches), possibly not much sediment is leaving Reservoir #1. But if 40 to 50 centimeters (16 to 20 inches) is recovered, the chance of this sediment coming from Reservoir #1 is more likely. At that time, other samples could be taken to establish a better understanding of the sediment patterns of Reservoir #2 to confirm if this possibility does exist.

Core samples should be checked for the anomalous events. Reservoir #2 should record some effects from the 1964 flood. If the 1972 North Fork Slide event is recorded, this material has escaped Reservoir #1.

3. To determine the possible effects of scouring in the old Bull Run River channel in Reservoir #1, current monitors can be installed to record the velocity at different locations within the reservoir during different discharge volumes at the
power plant. Velocities needed to move specific grain-size fractions can be
determined to either occur or not.

4. To determine how much sediment is trapped at the upper elevations, more
core samples in Reservoir #1 at the upper elevations can be taken along the length of
the reservoir to determine if the results in this study were only local variations or
the norm.

5. To determine if the sediment on the upper banks has been removed and
later replaced, more trenches/pits down the slope of these upper shore can be
conducted at lower lake levels. If these trenches/pits are continued to further
elevation depths along the slope, the transition from mixed sediment above the B-
horizon to non-mixed could possibly be identified by the appearance of the brunt
organics. The extent of the upper shore involved in this remixing can be determined
and re-evaluated.
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APPENDIX A

LAND MANAGEMENT PRACTICES
Table A1: Timber harvest coverage  
(U.S. Department of Agriculture Forest Service, 1992)

<table>
<thead>
<tr>
<th>Year</th>
<th>North Fork</th>
<th>Main stem</th>
<th>Fir Creek</th>
<th>Total</th>
<th>Square Kilometers (acres)</th>
<th>Clearcut</th>
<th>Partial cut</th>
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## Table A2: Roads constructed and area reforested.
(U.S. Department of Agriculture Forest Service, 1992)

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<th>Square Kilometers (Acres) of Reforestation</th>
<th>Sum</th>
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<td>North Fork</td>
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<tr>
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<td>0.48 (0.3)</td>
<td>0.48 (0.3)</td>
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| Sum | 25.8 (16) | 102.0 (63.4) | 127.8 (79.4) | 2.12 (523) | 17.02 (4216) | 0.06 (14) | 19.21 (4747) |
### Table A3: Type and area of fuel treatment (U.S. Department of Agriculture Forest Service, 1992)

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<td>0 0.29 (71)</td>
<td>0</td>
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<td>0 0.65 (161)</td>
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<td>0 1.27 (315)</td>
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<td>0 0</td>
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<td>0 0.13 (33)</td>
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<tr>
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<td>0 0</td>
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<td>sum 1.60 (395)</td>
<td>10.8 (2669)</td>
<td>0.06 (14)</td>
<td>12.46 (3078)</td>
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Figure A1: Timber Harvest Practices

Figure A2: Added Road Construction
APPENDIX B

WILLIAMS PRE-IMPOUNDMENT SURVEY
Figure B1: Williams' north-side trench. This is the clean-face solid basalt encountered 30.5 meters (100 feet) above the river. Beyond this is 4.6 to 6.1 meters (15 to 20 feet) of highly altered basalt. (Williams, 1926)
Figure B2: Cross-section A-A' from Williams' base map. This line runs approximately north-south just west of today's location of the dam. Details of the pits located on this cross-section are listed in Table B1. (Williams, 1926)
Figure B3: Cross-section B-B' from Williams' base map. This line is 46 meters (150 feet) to the east of cross-section A-A', located close to today's location of the dam. Details of the pits located on this cross-section are listed in Table B1. (Williams, 1926)
Table B1: Descriptions of the pits in Williams' cross-section. (Williams, 1926)

### Cross-Section A-A'

<table>
<thead>
<tr>
<th>Pit No.</th>
<th>Elevation meters (feet)</th>
<th>Depth meters (feet)</th>
<th>Bedrock at meters (feet)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3'</td>
<td>275.1 (902.4)</td>
<td>1.8 (6)</td>
<td>273.2 (896.4)</td>
<td>Soil and basalt boulders.</td>
</tr>
<tr>
<td>4'</td>
<td>288 (947)</td>
<td>1.2 (4)</td>
<td>287.7 (943.9)</td>
<td>Soil and basalt boulders.</td>
</tr>
<tr>
<td>5'</td>
<td>304.8 (1000)</td>
<td>4.6 (15)</td>
<td>300.2 (985)</td>
<td>Soil and basalt boulders, bedrock jointed.</td>
</tr>
<tr>
<td>6'</td>
<td>316.0 (1036.9)</td>
<td>8.5 (28)</td>
<td>307.5 (1008.9)</td>
<td>Soil, decayed and broken basalt.</td>
</tr>
<tr>
<td>8'</td>
<td>270.5 (887.5)</td>
<td>7.3 (24)</td>
<td>263.2 (863.5)</td>
<td>Soil, gravel and boulders.</td>
</tr>
<tr>
<td>9'</td>
<td>285 (935)</td>
<td>2.1 (7)</td>
<td>282.8 (928)</td>
<td>Soil.</td>
</tr>
<tr>
<td>10'</td>
<td>300.3 (985.4)</td>
<td>0.6 (2)</td>
<td>299.7 (983.4)</td>
<td>Soil on solid rock.</td>
</tr>
<tr>
<td>11'</td>
<td>309.7 (1016)</td>
<td>5.1 (20)</td>
<td>303.6 (996)</td>
<td>Soil, sandy to pebbly silt, basalt boulders.</td>
</tr>
<tr>
<td>12'</td>
<td>323.1 (1060.1)</td>
<td>1.4 (4)</td>
<td>321.9 (1056.1)</td>
<td>Soil and softened basalt.</td>
</tr>
<tr>
<td>14</td>
<td>326.7 (1072)</td>
<td>3.7 (12)</td>
<td>323.1 (1060)</td>
<td>Sandy to pebbly silt, weathered basalt below.</td>
</tr>
<tr>
<td>17</td>
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<td>3.0 (9.9)</td>
<td>322.5 (1058.2)</td>
<td>Soil, broken and weathered basalt.</td>
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</table>

### Cross-Section B-B'

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<th>Pit No.</th>
<th>Elevation meters (feet)</th>
<th>Depth meters (feet)</th>
<th>Bedrock at meters (feet)</th>
<th>Description</th>
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</thead>
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<td>2</td>
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<td>3.3 (11)</td>
<td>?</td>
<td>Bouldery gravel.</td>
</tr>
<tr>
<td>3</td>
<td>275.4 (903.4)</td>
<td>3.0 (10)</td>
<td>273.2 (896.4)</td>
<td>Soil and broken basalt boulders.</td>
</tr>
<tr>
<td>4</td>
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<td>Soil and lava boulders 4 meter (12') cement gravel.</td>
</tr>
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<td>5</td>
<td>307.0 (1007.2)</td>
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<tr>
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<td>317.5 (1041.8)</td>
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<td>303.2 (994.8)</td>
<td>Soil and weathered broken basalt.</td>
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<tr>
<td>8</td>
<td>271.8 (891.7)</td>
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<tr>
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</tr>
<tr>
<td>11</td>
<td>310.2 (1017.7)</td>
<td>5.2 (17)</td>
<td>305.0 (1000.7)</td>
<td>Soil, sandy to pebbly silt, basalt boulders.</td>
</tr>
<tr>
<td>13</td>
<td>322.6 (1058.3)</td>
<td>3.4 (11)</td>
<td>319.2 (1047.3)</td>
<td>Silty to sandy soil, softened basalt.</td>
</tr>
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</table>
APPENDIX C

UPSTREAM DAM FACE
Figure C1: Diagram of upstream dam face. North is to the right where the penstocks are located and the lowest sluice gate is below at the 265.9 meter (872.5 foot) elevation. (City of Portland, 1926b)
Figure C2: Diagram of the northern penstock and sluice gate. (City of Portland, 1926c)
Figure C3: Photo of the upstream face of the dam. North is to the right with the penstocks and lowest sluice gate showing. (City of Portland, Bureau of Water Works unpublished archives)
APPENDIX D

NORTH FORK SLIDE AREA
Figure D1: Location of North Fork Slide in the Bull Run Watershed.
Figure D2: Areas dislodged during the North Fork Slide. (Dames & Moore, 1972a)
Figure D3: Photo North Fork Slide - west bank. Photo taken in the fall of 1993.
Figure D4: Photo North Fork Slide - east bank. Photo taken in the fall of 1993.
APPENDIX E

GRAIN SIZE ANALYSIS PROCEDURE
GRAIN-SIZE ANALYSIS, MODIFIED METHOD OF DAY (1965)

Each sample for the grain-size analysis was air-dried. Approximately 50 grams of soil from each sample was placed in a 400 ml beaker. To each beaker, 50 ml of dispersent (Sodium Hexametaphosphate) was added, along with 100 ml of water. To ensure that the soil was mixed well, each sample was stirred for approximately three minutes, then allowed to soak for 12 to 24 hours.

After the samples had soaked, each was subjected to ultrasound for three minutes to break down the soil structure while maintaining the size fraction (Lewis, 1983). Each sample was then wet-sieved through a #230 sieve (0.063 mm, 0.002 inches). The sieve was placed inside a large funnel, at the base of which was an 800 ml beaker. The sediment was poured onto the sieve, emptying the 400 ml beaker completely. A maximum of 600 ml of water was added to the material on the sieve while the soil was worked gently through the sieve by hand. Material passing through the sieve (< 0.063 mm, 0.002 inches) was collected in the 800 ml beaker.

The coarse fraction remaining on the #230 sieve was oven-dried to prepare the sample for dry-sieving. When the sample was dry, a stack of sieves for the following fractions were arranged: #10 gravels > 2 mm (0.079 inches), #18 very coarse sand 2-1 mm (0.079-0.39 inches), #35 coarse sand 1-0.5 mm (0.039-0.02 inches), #60 medium sand 0.5-0.25 mm (0.02-0.01 inches), #120 fine sand 0.25-0.125 mm (0.01-0.005 inches), and #230 very fine sand 0.125-0.063 mm (0.005-0.002 inches). The oven-dried material on the #230 sieve was placed on the top sieve of the stack. The stack was then placed on a shaker for three minutes.
With fractions separated, material collected in the gravel fraction (>2 mm, 0.079 inches) was weighed and subtracted from the initial weight to ensure that grain-size analysis involved only sand, silt, and clay fractions. Remaining sand fractions were weighed and recorded. Sediment passing the #230 sieve during dry-sieving (< 0.063 mm, 0.079 inches) was added to sediment-rich material in the 800 ml beaker.

This sediment-rich material contained silt and clay fractions. Several methods are available to determine the amount of each of these fractions. For this procedure, a hydrometer was used. The hydrometer functions on the principle that larger size fractions fall out of suspension more quickly than smaller fractions of similar density. The hydrometer method uses a 1000 ml cylinder to suspend the different fractions and a 152H hydrometer with markings from 60 to zero to measure density of the water over time. For these analyses, a material density of 2.65 g/cm$^3$ (quartz feldspar) is assumed.

The material in each 800 ml beaker was poured into individual 1000 ml hydrometer cylinders, ensuring removal of all material from the beaker. Water was then added to fill each cylinder to the 1000 ml line. The jars were then set aside overnight to allow their contents to adjust to room temperature.

Before initiating the test, each sample was stirred continuously with a stir-rod for three minutes. When stirring was terminated, a stop-watch was immediately started. Once timing was begun, the jars remained undisturbed until the final reading was made. The hydrometer was lowered gently into the cylinder and allowed to settle before readings began. The first reading was taken 30 seconds after stirring ended. Subsequent readings were taken at 1, 2, 4, and 6 minutes. These readings varied greatly due to the large amount of material settling out in a short period of
time. To ensure that these readings were representative, the initial 6 minutes were repeated after re-stirring the material for three minutes. (Lewis, 1983)

After readings for the second 6 minutes were taken, additional readings were taken at 8, 15, and 30 minutes, and again at one, two, four, and eight hours (Lewis, 1983). If the hydrometer contained significant suspended sediment after the eight hour readings, additional reading were taken at 24 hours, 72 hours, 7 days, and 31 days.

Organics. The calculation for grain-size analysis should reflect only the fraction of inorganic material. Pre-preparation for these samples did not include removal of organic material. An earlier attempt was made to use hydrogen peroxide to remove the organic material. Due to high organic content, an excessive amount of hydrogen peroxide and extensive cleaning of the material to remove digested organic were necessary. This procedure proved mostly unsuccessful, and organic material was allowed to remain in the sample. Organic content was therefore calculated after size-fractionation then back-calculated from the original sample.

Each sand fraction was weighed and placed in a crucible. To burn out organics, each crucible was placed in a high-temperature oven at 550 °C (1000 °F) for three hours. The actual weight of each fraction was then recorded after the organic was removed and placed in a dissector. For silt and clay fractions, the Walkely-Black method (Soil Conservation Service, 1972) was used (Appendix F).

When values had been corrected for organic content to reflect only the inorganic fractions, they were plotted on a log-arithmetic scale. The curve produced from this plot can then be used to estimate the percentage within specific grain-size fractions.
APPENDIX F

ORGANIC MATTER PROCEDURE
ORGANIC MATTER BY TITRATION, WALKELY-BLACK METHOD
(SOIL CONSERVATION SERVICE, 1972)

A small quantity of air-dried soil was passed through a #35 sieve (0.5 mm, 0.02 inches). Of the soil passing the sieve (< 0.5 mm, 0.02 inches) approximately 0.2 to 0.5 grams was placed in a 100 ml beaker for each sample.

To each sample in the 100 ml beaker, 10 ml of potassium dichromate, 1N, \( K_2Cr_2O_7 \), were added and swirled gently. Then 20 ml of sulfuric acid, \( H_2SO_4 \), were added and swirled for approximately one minute under a vent hood. This mixture was allowed to cool for approximately 30 minutes then poured into a 500 ml Erlenmeyer flask. Two hundred ml of water were used to remove all sediment from the 100 ml beaker and to clean the inside walls of the Erlenmeyer flask, thus ensuring that the entire sample was at the bottom of the flask.

A magnetic stir bar was placed inside the Erlenmeyer flask. The flask was then placed a mechanical stirring plate. Four or five drops of ortho-phenanthroline were added to the mixture as an indicator. With the stir plate operating, ferrous sulfate, \( FeSO_4 \cdot 7H_2O \), was added slowly to the mixture from a burette until the mixture turned from green, to blue, to dark red (the end point). The amount of ferrous sulfate required for titration was recorded and used to calculate the percent organic carbon, which in turn was converted to percent organic matter.
APPENDIX G

PRE- AND POST-IMPOUNDMENT MAP PROFILES
Figure G1: Contour Map of 1924
Pre-impoundment Survey

1" = 1400'

10 Foot Contours
Figure G2: Contour Map of 1991 Post-impoundment Survey

1" = 1400'
10 Foot Contours
Figure G3a: Profile A, B, C. Comparing pre- and post-impoundment surveys.
Figure G3b: Profile D,E,F. Comparing pre- and post-impoundment surveys

DISTANCE FROM THE CENTER (feet)

D

E

F

D'

E'

F'

2:1 Ratio

1991 Bathymetric Survey    1924 Pre-Impoundment Survey
Figure G3c: Profile G, H, I, J. Comparing pre- and post-impoundment surveys.
Figure G3d: Profile K, L, M, N. Comparing pre- and post-impoundment surveys
Figure G3e: Profile O,P,Q. Comparing pre- and post-impoundment surveys

2:1 Ratio

1991 Bathymetric Survey

1924 Pre-Impoundment Survey
APPENDIX H

SOIL SITE DESCRIPTION - SOIL TAXONOMY FORMAT
Soil No.: N-1
Classification: Typic Udvari
tion
Location: Multnomah County, Oregon
- T1S R6E Sec16 SW1/4 of NW1/4
- North side of FS road 10, North side of the dam on the flat,
  0.4 km (0.25 miles) east of Big House
Topography: Elevation 370 meters (1200 feet), 10° slope, aspect S70E
Drainage: Well Drained
Vegetation: Hemlock & Douglas fir (30-40 years)
Parent Material: Frenchman Springs (basalts and pyroclastics)
Sampled by: Doann Hamilton, Daryl Wieneke, and Scott Burns, July 7, 1993
Comments: Root Disturbance: 30%
  Stoniness: 0%
  a lot of charcoal near the top (possible fire of 9/23/66, 8/22/70, or 9/16/71)

**Horizon Characteristics**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Horizon</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>V. Coarse</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
<th>V. Fine</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>0-0.063</td>
<td>&lt;0.004</td>
<td>0.004</td>
<td>0.008</td>
<td>0.004</td>
<td>&lt;0.002</td>
<td>&gt;2mm</td>
<td>throughout</td>
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<tr>
<td>0-2.5</td>
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<td>59</td>
<td>0.063</td>
<td>0.004</td>
<td>0.008</td>
<td>0.004</td>
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<td>&gt;2mm</td>
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<tr>
<td>2.5-7.5</td>
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<td>0.063</td>
<td>0.004</td>
<td>0.008</td>
<td>0.004</td>
<td>&lt;0.002</td>
<td>&gt;2mm</td>
<td>0%</td>
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<tr>
<td>7.5-12.5</td>
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<td>53</td>
<td>0.063</td>
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<td>0.008</td>
<td>0.004</td>
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<td>&gt;2mm</td>
<td>0%</td>
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<tr>
<td>12.5-17.5</td>
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<td>&gt;2mm</td>
<td>0%</td>
</tr>
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<td>Bw1</td>
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<td>0.063</td>
<td>0.004</td>
<td>0.008</td>
<td>0.004</td>
<td>&lt;0.002</td>
<td>&gt;2mm</td>
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<tr>
<td>56-63.5+</td>
<td>Bw2</td>
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<td>0.063</td>
<td>0.004</td>
<td>0.008</td>
<td>0.004</td>
<td>&lt;0.002</td>
<td>&gt;2mm</td>
<td>0%</td>
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<th>Depth</th>
<th>Horizon</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
<th>V. Fine</th>
<th>Coarse fractures</th>
<th>percent</th>
<th>% stones</th>
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<tbody>
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<td>cm</td>
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<td>(0.063)</td>
<td>(0.031)</td>
<td>(0.016)</td>
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<td>(0.004)</td>
<td>(0.002)</td>
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<tr>
<td>0-2.5</td>
<td>A</td>
<td>20.96</td>
<td>15.11</td>
<td>21.54</td>
<td>21.54</td>
<td>15.11</td>
<td>21.54</td>
<td>21.54</td>
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<tr>
<td>2.5-7.5</td>
<td>A</td>
<td>20.96</td>
<td>15.11</td>
<td>21.54</td>
<td>21.54</td>
<td>15.11</td>
<td>21.54</td>
<td>21.54</td>
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<tr>
<td>7.5-12.5</td>
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<td>20.96</td>
<td>15.11</td>
<td>21.54</td>
<td>21.54</td>
<td>15.11</td>
<td>21.54</td>
<td>21.54</td>
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<td>12.5-17.5</td>
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<td>15.11</td>
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<td>21.54</td>
<td>15.11</td>
<td>21.54</td>
<td>21.54</td>
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<td>Bw1</td>
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<td>15.11</td>
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<td>21.54</td>
<td>15.11</td>
<td>21.54</td>
<td>21.54</td>
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<td>15.11</td>
<td>21.54</td>
<td>21.54</td>
<td>15.11</td>
<td>21.54</td>
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<th>Organic Carbon</th>
<th>Organic Matter</th>
<th>Percent Moisture (water)</th>
<th>pH</th>
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<td>cm</td>
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<td></td>
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<td></td>
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<td>13.15</td>
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<td>13.15</td>
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<td>7.5-12.5</td>
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<td>20.96</td>
<td>20.96</td>
<td>20.96</td>
<td>6</td>
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<td>7.5-12.5</td>
<td>Bw1</td>
<td>20.96</td>
<td>20.96</td>
<td>20.96</td>
<td>6</td>
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<tr>
<td>7.5-12.5</td>
<td>Bw1</td>
<td>20.96</td>
<td>20.96</td>
<td>20.96</td>
<td>6</td>
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</table>

$\text{HHHH} = \text{no data collected}$
Soil No.: N-2
Classification: Typic Uduitrand
Location: Multnomah County, Oregon
T1S R6E Sec16 NE1/4 of NW1/4
North side of FS road 10, east of Bear Creek before steep area

Topography: Elevation 340 meters (1120 feet), 5° slope, aspect
Drainage: Well Drained
Vegetation: Hemlock & Douglas fir (75 years), Maples
Parent Material: Grande Ronde (basalts and pyroclastics)
Sampled by: Deann Hamilton, Daryl Wieneke, and Scott Burns, July 7, 1993
Comments: Root Disturbance: 30%
Stoniness: 0%
a lot of charcoal in 0-horizon, less in the horizons below
(possible fire of 9/23/66, 8/22/70, or 9/16/71)

Horizon Characteristics

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15-0 cm (0-6 in.) a lot of charcoal.</td>
</tr>
<tr>
<td>A</td>
<td>0-10 cm (0-4 in.) Dark Reddish Brown (5YR 3/3) (wet), Brownish Yellow (10YR 6/6) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); abundant roots; small amounts of charcoal; abrupt wavy boundary.</td>
</tr>
<tr>
<td>Bw1</td>
<td>10-33 cm (4-13 in.) Dark Yellowish Brown (10YR 3/4) (wet), Yellowish Brown (10YR 5/4) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); roots and small amounts of charcoal; gradual wavy boundary.</td>
</tr>
<tr>
<td>Bw2</td>
<td>33-65+ cm (13-29+ in.) Yellowish Red (5YR 4/6) (wet), Very Pale Brown (10YR 7/4) (dry); silt loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet); roots.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Percent</th>
<th>pH</th>
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</thead>
<tbody>
<tr>
<td>0-10</td>
<td>A</td>
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<td>16.30</td>
</tr>
<tr>
<td>10-23</td>
<td>Bw1</td>
<td>7.23</td>
<td>12.43</td>
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<td>51-63.5</td>
<td>Bw2</td>
<td>0.68</td>
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<th>Depth (cm)</th>
<th>Horizon</th>
<th>Carbon</th>
<th>Organic Matter</th>
<th>Percent</th>
<th>pH</th>
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<td>A</td>
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<td>16.30</td>
<td>41</td>
<td>4.8</td>
</tr>
<tr>
<td>10-23</td>
<td>Bw1</td>
<td>7.23</td>
<td>12.43</td>
<td>38</td>
<td>$$$</td>
</tr>
<tr>
<td>51-63.5</td>
<td>Bw2</td>
<td>0.68</td>
<td>1.17</td>
<td>34</td>
<td>$$$</td>
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<table>
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<tr>
<th>Depth (cm)</th>
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<th>Carbon</th>
<th>Organic Matter</th>
<th>Percent</th>
<th>pH</th>
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<tr>
<td>0-10</td>
<td>A</td>
<td>9.48</td>
<td>16.30</td>
<td>41</td>
<td>4.8</td>
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<tr>
<td>10-23</td>
<td>Bw1</td>
<td>7.23</td>
<td>12.43</td>
<td>38</td>
<td>$$$</td>
</tr>
<tr>
<td>51-63.5</td>
<td>Bw2</td>
<td>0.68</td>
<td>1.17</td>
<td>34</td>
<td>$$$</td>
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<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Carbon</th>
<th>Organic Matter</th>
<th>Percent</th>
<th>pH</th>
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<tbody>
<tr>
<td>0-10</td>
<td>A</td>
<td>9.48</td>
<td>16.30</td>
<td>41</td>
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<td>10-23</td>
<td>Bw1</td>
<td>7.23</td>
<td>12.43</td>
<td>38</td>
<td>$$$</td>
</tr>
<tr>
<td>51-63.5</td>
<td>Bw2</td>
<td>0.68</td>
<td>1.17</td>
<td>34</td>
<td>$$$</td>
</tr>
</tbody>
</table>

$\text{$$$} = \text{no data collected}$
Soil No.: N-3
Classification: Humic Udivistrand
Location: Multnomah County, Oregon
T1S R6E Sec16 NW1/4 of NE1/4
North side of FS road 10, East of Bear Creek in the steep
0.4 km (0.25 miles) east of mile post 10
Topography: Elevation 340 meters (1120 feet), 27° slope, aspect N27W
Drainage: Well Drained
Vegetation: Hemlock & Douglas fir two age stand (150 years and 20 years)
Parent Material: Grande Ronde (basalts and pyroclastics)
Sampled by: Doann Hamilton and Daryl Wieneke, July 8, 1993
Comments: Root Disturbance: 30%

Stoniness: Cobbly at 7%
possible slide area, the young trees have bent knees but not the older, some skeletal cobbles
(could have been a fire in the area in 1966, 70, and/or 71)
no samples taken

Horizon Characteristics
O 2.5-0 cm (1-0 in.)
A1 0-18 cm (0-7 in.) Very Dusky Red (2.5YR 2.5/2) (wet); loam (field); weak fine subangular
blocky; non sticky and non plastic (wet); abundant roots; diffuse wavy boundary.
A2 18-53 + cm (7-21+ in.) Dark Brown (7.5YR 3/3) (wet); silt loam (field); weak fine
subangular blocky; slightly sticky and non plastic (wet); roots.
Soil No.: N-4  
Classification: Typic Udeventrand  
Location: Multnomah County, Oregon  
T1S R6E Sec16 NW1/4 of NE1/4  
South side of FS road 404 (spur off FS 10) after bend in the road  
(1 km (0.6 miles) east from the end of FS 404 where the gravel starts)  
Topography: Elevation 370 meters (1220 feet), 19° slope aspect S30E  
Drainage: Well Drained  
Vegetation: Hemlock & Douglas fir (35-40 years), sparse undergrowth, a lot of rotten down trees  
Parent Material: Frenchman Springs (basalts and pyroclastics)  
Sampled by: Doann Hamilton and Daryl Wieneke, July 8, 1993  
Comments: Root Disturbance: 10% all the way down  

Stoniness: 0%  
small amounts of charcoal (possible fire of 9/23/66, 8/22/70, or 9/16/71)

<table>
<thead>
<tr>
<th>Horizon Characteristics</th>
<th>0-0 cm (0 in.)</th>
<th>2.5-7.5 cm (1-3 in.)</th>
<th>7.5-23 cm (3-9 in.)</th>
<th>23-25.5 cm (9-10 in.)</th>
<th>25.5-30.5 cm (10-12 in.)</th>
<th>30.5-36 cm (12-14 in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Very Dusky Red (2.5YR 2.5/2) (wet), Brown-Dark Brown (7.5YR 4/3) (dry); silt loam; weak fine subangular blocky; non sticky and slightly plastic (wet); roots and small amounts of charcoal; abrupt smooth boundary.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B/A</td>
<td>Dark Reddish Brown (5YR 3/4) (wet), Brown-Dark Brown (7.5YR 5/4) (dry); silt loam, weak fine subangular blocky; slightly sticky and slightly plastic (wet); roots and small amounts of charcoal; gradual wavy boundary.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw1</td>
<td>Dark Yellowish Brown (10YR 4/4) (wet), Strong Brown (7.5YR 5/6) (dry); silt loam, weak fine subangular blocky; slightly sticky and slightly plastic (wet); roots and small amounts of charcoal; abrupt wavy boundary.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw2</td>
<td>Strong Brown (7.5YR 4/6) (wet), Yellow (10YR 7/6) (dry); silt loam, weak fine subangular blocky; slightly sticky and slightly plastic (wet); roots.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size class and particle diameter (mm)</th>
<th>% Sand</th>
<th>% Silt</th>
<th>% Clay</th>
<th>Coarse fragments</th>
<th>% Coarse</th>
<th>% Medium</th>
<th>% Fine</th>
<th>&gt;2mm</th>
<th>throughout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-2.5 A</td>
<td>17.44</td>
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<td>2.77</td>
<td>2.77</td>
<td>3.69</td>
<td>23.86</td>
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<td>2.82</td>
<td>4.24</td>
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<th>Organic Matter</th>
<th>Percent</th>
<th>pH</th>
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§§§§ = no data collected
Soil No.: N-5
Classification: none given
Location: Multnomah County, Oregon
T1S R6E Sec16 NE1/4 of NE1/4
North side of road FS 10; 0.4 km (0.25 miles) east of N-3 in the steep
there is a 10+ foot wall of Grand Ronde along the road
Topography: Elevation 350 meters (1160 feet)
Drainage: Well Drained
Vegetation: Hemlock & Douglas fir (100-150 years)
Parent Material: Grande Ronde (basalts and pyroclastics)
Sampled by: Doann Hamilton and Daryl Wienke, July 8, 1993
Comments: No samples taken

Horizon Characteristics
0-106.5 cm (0-42 in.) Undifferentiated soils
R 106.5 cm (42 in.) (hand augered)
Soil No.: N-6
Classification: Typic Uduitrand
Location: Multnomah County, Oregon
T13 R6 E Sec15 NE1/4 of NW1/4
South side of FS 10 on the lobe between Cougar and Deer Creek
0.3 km (0.2 miles) east of the intersection of FS 404 and FS 10
Topography: Elevation 330 meters (1080 feet), 0° slope
Drainage: Well Drained
Vegetation: Hemlock & Douglas fir (35-40 years), sparse undergrowth
Parent Material: Grande Ronde (basalts and pyroclastics)
Sampled by: Doann Hamilton and Daryl Wieneke, July 8, 1993
Comments: Root Disturbance: 5% (all the way down)

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Characteristics</th>
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</thead>
<tbody>
<tr>
<td>O</td>
<td>12.5-0 cm (5-0 in.)</td>
</tr>
<tr>
<td>A</td>
<td>0-15 cm (0-6 in.) Dark Reddish Brown (5YR 2.5/2) (wet), Dark Brown (10YR 3/3) (dry); silt loam; weak fine subangular blocky; non sticky and non plastic (wet); roots and some charcoal; abrupt wavy boundary.</td>
</tr>
<tr>
<td>Bw</td>
<td>15-38+ cm (6-15+ in.) Reddish Brown (5YR 4/4) (wet). Brownish Yellow (10YR 6/6) (dry); silt loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet); roots and less burnt wood.</td>
</tr>
<tr>
<td>R</td>
<td>147 cm (58 in) (hand augered).</td>
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<table>
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<td>15-20 Bw</td>
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<td>20-25.5 Bw</td>
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<th>7.5-15 A</th>
<th>15-20 Bw</th>
<th>20-25.5 Bw</th>
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<td>0.004-0.002</td>
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<td>0.008-0.016</td>
<td>0.004-0.016</td>
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<td>2.93</td>
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<td>12.14</td>
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<td>18.44</td>
<td>3.73</td>
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<td>10.69</td>
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<th>Depth (cm)</th>
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<th>0.094</th>
<th>0.125</th>
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<tbody>
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<td>0-7.5 A</td>
<td>2.5</td>
<td>66</td>
<td>9</td>
<td>3.67</td>
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<tr>
<td>7.5-15 A</td>
<td>3.3</td>
<td>56</td>
<td>11</td>
<td>5.02</td>
</tr>
<tr>
<td>15-20 Bw</td>
<td>37</td>
<td>49</td>
<td>14</td>
<td>8.54</td>
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<tr>
<td>20-25.5 Bw</td>
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<th>7.5-15 A</th>
<th>15-20 Bw</th>
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<td>0.008-0.016</td>
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<td>13.40</td>
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<td>5.86</td>
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<tr>
<td>4.76</td>
<td>8.19</td>
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§§§§ = no data collected
Soil No.: N-7
Classification: Humic Udivitrand
Location: Multnomah County, Oregon
T1S R6E Sec15 NE1/4 or NE1/4
South side of FS 10
0.3 km (0.2 miles) east of the intersection of FS 1010 and FS 10 on the first lobe
Topography: Elevation 330 meters (1080 feet), 0° slope
Drainage: Well Drained
Vegetation: Hemlock & Douglas fir (45-75 years), sparse undergrowth mostly fens
Parent Material: Grande Ronde (basalts and pyroclastics)
Sampled by: Doann Hamilton and Daryl Wienek, July 8, 1993
Comments: Root Disturbance: 5% (all the way down)
Stoniness: 0%
No samples taken

Horizon Characteristics
O 12.5-0 cm (5-0 in.)
A1 0-30.5 cm (0-12 in.) Dark Reddish Brown (5YR 3/4) (wet); loam (field); weak fine subangular blocky; non sticky and non plastic (wet); roots; gradual wavy boundary.
A2 30.5-43 cm (12-17 in.) Dark Brown (7.5YR 3/4) (wet); silt loam (field); weak fine subangular blocky; slightly sticky and non plastic (wet); roots; gradual wavy boundary.
Bw 43-58.5+ cm (17-23+ in.) Brown (7.5YR 4/4) (wet); silt loam (field); weak fine subangular blocky; slightly sticky and slightly plastic (wet); roots.
P 122 cm (48 in.) (hand augered)
Soil No.: N-8  
Classification: Typic Udivirrud 
Location: Multnomah County, Oregon 
T1S R6E Sec11 SW1/4 of SE1/4 
North side of FS 10 just east of North Fork just east of bend in the road 
Topography: Elevation 335 meters (1100 feet), 13° slope, aspect N79E 
Drainage: Well Drained 
Vegetation: Hemlock & Douglas fir (300 years), some young trees with knees (25 years), thick underbrush: Oregon grape, fern 
Parent Material: Grande Ronde (basalts and pyroclastics) 
Sampled by: Doann Hamilton and Daryl Wieneke, July 9, 1993 
Comments: Root Disturbance: 5% 
Stoniness: 0% 
4 lot of moss in the trees. 
(Possible fire area of 1940-1949, and 1950-1959)

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<tr>
<th>Horizon</th>
<th>Characteristics</th>
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<tbody>
<tr>
<td>0</td>
<td>5-0 cm (2-0 in.) Dark Brown (7.5YR 3/3) (wet), Brown (7.5YR 5/4) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); abundant roots; gradual wavy boundary.</td>
</tr>
<tr>
<td>Bw1</td>
<td>10-56 cm(4-22 in.) Reddish Brown (5YR 4/4) (wet), Strong Brown (7.5YR 5/6) (dry); loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet); roots; clear wavy boundary.</td>
</tr>
<tr>
<td>Bw2</td>
<td>56-73.5+ cm (22-29+ in.) Strong Brown (7.5YR 5/8) (wet), Yellow (10YR 7/8) (dry); loamy sand; weak fine subangular blocky; non sticky and non plastic (wet); roots.</td>
</tr>
<tr>
<td>R</td>
<td>100 cm (39.5 in.) (hand augered).</td>
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| Horizon  | Size class and particle diameter (mm) | -----
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<td>Sand</td>
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<tr>
<td>(cm)</td>
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<td>15-20</td>
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<th>V. Fine</th>
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<td>(0.5-0.25)</td>
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<th>Organic Matter</th>
<th>Percent Moisture</th>
<th>pH</th>
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<td>30</td>
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$$ $$ = no data collected
Soil No.: N-9  
Classification: Typic Udivittand  
Location: Multnomah County, Oregon  
T1S R6E Sec11 SW1/4 of SE1/4  
South side of road FS 10, east of North Fork in a clear cut before the steep  
(5 km (3.2 miles) east of N-2)  
Topography: Elevation 350 meters (1160 feet), 12° slope aspect S25E  
Drainage: Well Drained  
Vegetation: was Hemlock & Douglas fir before the cut now shrubs and ferns  
Parent Material: Grande Ronde (basalts and pyroclastics)  
Sampled by: Deann Hamilton, Daryl Wieneke, and Scott Burns, July 7, 1993  
Comments: Root Disturbance: 30%  
Stoniness: 0%  
coarse sandy iron concretions and burn soil (inclusion)  
some charcoal (possible from fires of 1940-1949 or 1950-1959)

### Horizon Characteristics

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>2.5-0 cm (1-0 in.) Dark Brown (7.5YR 3/4) (wet), Yellowish Brown (10YR 5/4) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); roots; abrupt smooth boundary.</td>
</tr>
<tr>
<td>A</td>
<td>0-5 cm (0-2 in.) Dark Brown (7.5YR 3/4) (wet), Yellowish Brown (10YR 5/4) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); roots; abrupt smooth boundary.</td>
</tr>
<tr>
<td>Bw1</td>
<td>5-56 cm (2-22 in.) Dark Yellowish Brown (10YR 3/4) (wet), Yellowish Brown (10YR 5/4) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); roots and some charcoal; gradual wavy boundary.</td>
</tr>
<tr>
<td>Inclusion</td>
<td>43-56 cm (17-22 in.) Dark Yellowish Brown (10YR 4/6) (wet), Reddish Yellow (7.5YR 6/6) (dry) silt loam; weak fine subangular blocky; non sticky and slightly plastic (wet); burnt soil modeled Red (2.5YR 4/6) and Black (2.5YR 2.5/0); abrupt irregular boundary</td>
</tr>
<tr>
<td>Bw2</td>
<td>56-71+ cm (22-28+ in.) Dark Yellowish Brown (10YR 4/6) (wet), Brownish Yellow (10YR 6/6) (dry) silt loam; weak fine subangular blocky; roots; slightly sticky and plastic (wet).</td>
</tr>
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### Particle Size Distribution

<table>
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<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>% Total</th>
<th>% Sand</th>
<th>% Coarse</th>
<th>% Medium</th>
<th>% Fine</th>
<th>% V. Fine</th>
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<tr>
<td>0-5 A</td>
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<tr>
<td>43-56 Inclusion</td>
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### Organic Matter and Moisture

<table>
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<th>Horizon</th>
<th>Organic Matter</th>
<th>Organic Carbon</th>
<th>Percent Moisture (water)</th>
<th>pH</th>
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§§§§ = no data collected
Soil No.: N-10  
Classification: Typic Ud Hist rand  
Location: Multnomah County, Oregon  
T1S R8E Sec11 NE1/4 of SE1/4  
North side of FS 10 east of N-9 just past clear cut starting steep  
Topography: Elevation 390 meters (1280 feet), 7° slope, aspect N42W  
Drainage: Well Drained  
Vegetation: Hemlock & Douglas fir two ages (15-20 years with bent knees, and 150 years with no knees), ferns, clover, and vein undergrowth  
Parent Material: Frenchman Springs (basalts and pyroclastics)  
Sampled by: Doann Hamilton and Daryl Wienke, July 9, 1993  
Comments: Root Disturbance: 1% (one large at bottom)  
A lot of young growth possible slide

Horizon Characteristics

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>5-0 cm (2-0 in.) Black (5YR 2.5/1) (wet), Dark Brown (10YR 4/4) (dry); silt loam; weak fine subangular blocky; non sticky and slightly plastic (wet); abrupt wavy boundary.</td>
</tr>
<tr>
<td>A</td>
<td>0-6 cm (0-2.5 in.) Black (5YR 2.5/1) (wet), Dark Brown (10YR 4/4) (dry); silt loam; weak fine subangular blocky; non sticky and slightly plastic (wet); abrupt wavy boundary.</td>
</tr>
<tr>
<td>BW1</td>
<td>6-25 cm (2.5-10 in.) Dark Brown (7.5YR 3/4) (wet), Brownish Yellow (10YR 6/6) (dry); loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet); modeled Fred (2.5YR 6/6); some charcoal; gradual wavy boundary.</td>
</tr>
<tr>
<td>BW2</td>
<td>25-51 cm (10-20 in.) Yellowish Brown (10YR 5/6) (wet), Yellow (10YR 7/8) (dry); sandy loam; weak fine subangular blocky; burnt wood, large root at the base of the pit; slightly sticky and plastic (wet).</td>
</tr>
<tr>
<td>R</td>
<td>132 cm (52 in.) (hand augered)</td>
</tr>
</tbody>
</table>

![Table](data:text/html;charset=utf-8,%3Ctable%3A%20border%3D1%20cellpadding%3D1%20cellspacing%3D0%3E%3Cthead%3E%3Ctr%3E%3Cth%3E%3C/td%3E%3C/tr%3E%3C/tbody%3E%3C/tbody%3E%3C/table%3E%3Cp%3E%3C/onsole%3E)
Soil No.: N-11
Classification: none given
Location: Multnomah County, Oregon
T1S R6E Sec11 NE1/4 of SE1/4
South side of FS 10 0.3 km (0.2 miles) east of N-10
Topography: Elevation 380 meters (1240 feet)
Vegetation: Hemlock & Douglas fir (100-150 years)
Parent Material: Grande Ronde (basalts and pyroclastics)
Sampled by: Doann Hamilton and Daryl Wieneke, July 9, 1993
Comments: No samples taken

Horizon Characteristics
0-140 cm (0-55 in.) Undifferentiated soils
A 140 cm (55 in.) (hand augered)
Soil No.: N-12
Classification: Thaptic Vitraquand
Location: Multnomah County, Oregon
T1S R6E Sec12 SW1/4 of NW1/4
North side of FS 10 just west of a spur road to a clear cut on the south side
(0.2 km (0.8 miles) east of N-11)
Topography: Elevation 490 meters (1600 feet), 0º slope
Drainage: Poorly Drained
Vegetation: Hemlock & Douglas fir (30-40 years), sparse underbrush vine maple near site, a lot of
rotten down logs
Parent Material: Rhododendron Formation (basalts and pyroclastics)
Sampled by: Doarn Hamilton and Daryl Wienieke, July 9, 1993
Comments: Root Disturbance: massive on top sparse below
  Stoniness: Stony at 50%
  Groundwater level: 38 cm (15 inches)
  Near a drain creek, this is a flat on top of a very steep slope, possible slide area a lot of loose
  skeletal cobbles
  no samples of A2.

Horizon Characteristics
O 13-0 cm (5-0 in.)
A1 0-38 cm (0-15 in.) Black (5YR 2.5/1) (wet), Dark Brown (7.5YR 3/2) (dry); sandy
  loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet); roots; abrupt
  sharp boundary.
A2 38-46+ cm (15-18+ in.) Dark Reddish Brown (5YR 3/2) (wet); sandy loam (field); weak
  fine subangular blocky; sticky and plastic (wet).

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>% Sand</th>
<th>% Clay</th>
<th>% Organic Matter</th>
<th>% Moisture (water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10 A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>46</td>
<td>4</td>
<td>18.24</td>
<td>32.4</td>
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Size class and particle diameter (mm)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>% Silt</th>
<th>% Medium</th>
<th>% Fine</th>
<th>% Very Fine</th>
<th>% Coarse</th>
<th>% Very Coarse</th>
<th>% Clay</th>
<th>% Organic Matter</th>
<th>% Carbon</th>
<th>% Moisture (water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10 A</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>% Silt</th>
<th>% Medium</th>
<th>% Fine</th>
<th>% Very Fine</th>
<th>% Coarse</th>
<th>% Very Coarse</th>
<th>% Clay</th>
<th>% Organic Matter</th>
<th>% Carbon</th>
<th>% Moisture (water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10 A</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>
Soil No.: S-1  
Classification: Typic Udivirrand  
Location: Multnomah County, Oregon  
T1S R6E Sec16 NE1/4 of SE1/4  
South side of the reservoir, near the dam there are three main streams  
this is located just west of the far west stream  
Topography: Elevation 330 meters (1080 feet), 3° slope, aspect N23E  
Drainage: Well Drained  
Vegetation: Hemlock & Douglas fir (150-200 years), a lot of undergrowth: ferns (sawtooth), moss,  
stinging needles  
Parent Material: Grande Ronde (basalts and pyroclastics)  
Sampled by: Doann Hamilton and Daryl Wieneke, July 15, 1993  
Comments: Root Disturbance: 15%  
Stoniness: Cobbly at 2% (average 7.5 cm, 3 inches)  

**Horizon Characteristics**  

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-5 cm (0-2 in.) Very Dusky Red (2.5YR 2.5/2) (wet), Very Dark Grayish Brown (10YR 3/2) (dry); sandy loam; weak fine subangular blocky; non sticky and slightly plastic (wet); abrupt smooth boundary.</td>
</tr>
<tr>
<td>Bw1</td>
<td>5-58 cm (2-23 in.) Dark Reddish Brown (EYR 3/3) (wet), Yellowish Brown (10YR 5/4) (dry); silt loam, weak fine subangular blocky, slightly sticky and slightly plastic (wet); gradual wavy boundary.</td>
</tr>
<tr>
<td>Bw2</td>
<td>58-79+ cm (23-31+ in.) Strong Brown (7.5YR 4/6) (wet), Brownish Yellow (10YR 6/6) (dry); silt loam; weak fine subangular blocky; slightly sticky and plastic (wet).</td>
</tr>
</tbody>
</table>

### Size class and particle diameter (mm)  

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
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<th>0.014</th>
<th>0.004</th>
<th>0.002</th>
<th>0.001</th>
<th>0.0004</th>
<th>0.0002</th>
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<tbody>
<tr>
<td>0-5</td>
<td>A</td>
<td>40</td>
<td>43</td>
<td>17</td>
<td>9.14</td>
<td>8.60</td>
<td>3.64</td>
<td>7.75</td>
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<tr>
<td>5-9</td>
<td>Bw1</td>
<td>20</td>
<td>61</td>
<td>19</td>
<td>1.50</td>
<td>1.99</td>
<td>6.03</td>
<td>6.50</td>
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<tr>
<td>9-12.5</td>
<td>Bw1</td>
<td>32</td>
<td>46</td>
<td>22</td>
<td>2.12</td>
<td>2.90</td>
<td>10.08</td>
<td>10.88</td>
</tr>
<tr>
<td>12.5-17.5</td>
<td>Bw1</td>
<td>23</td>
<td>59</td>
<td>18</td>
<td>2.58</td>
<td>2.90</td>
<td>6.94</td>
<td>7.00</td>
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<tr>
<td>17.5-23</td>
<td>Bw1</td>
<td>26</td>
<td>56</td>
<td>18</td>
<td>1.07</td>
<td>2.50</td>
<td>8.56</td>
<td>8.67</td>
</tr>
<tr>
<td>63.5-79</td>
<td>Bw2</td>
<td>24</td>
<td>60</td>
<td>16</td>
<td>0.36</td>
<td>2.08</td>
<td>8.79</td>
<td>8.73</td>
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### Size class and particle diameter (mm) continued  

<table>
<thead>
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<th>Depth (cm)</th>
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<th>0.014</th>
<th>0.004</th>
<th>0.002</th>
<th>0.001</th>
<th>0.0004</th>
<th>0.0002</th>
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<td>0-5</td>
<td>A</td>
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<td>0.43</td>
<td>0.22</td>
<td>0.08</td>
<td>0.05</td>
<td>0.04</td>
<td>0.02</td>
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<td>5-9</td>
<td>Bw1</td>
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<td>4.55</td>
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<tr>
<td>9-12.5</td>
<td>Bw1</td>
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<td>6.42</td>
<td>3.17</td>
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<td>12.5-17.5</td>
<td>Bw1</td>
<td>9.31</td>
<td>29.96</td>
<td>20.63</td>
<td>6.75</td>
<td>4.50</td>
<td>6.75</td>
<td>21.89</td>
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<tr>
<td>17.5-23</td>
<td>Bw1</td>
<td>7.53</td>
<td>28.15</td>
<td>20.33</td>
<td>6.60</td>
<td>4.80</td>
<td>6.60</td>
<td>1.29</td>
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<tr>
<td>63.5-79</td>
<td>Bw2</td>
<td>10.29</td>
<td>27.62</td>
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<td>4.15</td>
<td>5.93</td>
<td>3.37</td>
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### Depth (cm) | Horizon | Percent | pH |
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<tbody>
<tr>
<td>0-5 A</td>
<td>22.17</td>
<td>38.13</td>
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<td>5-9 Bw1</td>
<td>10.78</td>
<td>16.50</td>
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<tr>
<td>9-12.5 Bw1</td>
<td>7.63</td>
<td>13.13</td>
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<tr>
<td>12.5-17.5 Bw1</td>
<td>6.75</td>
<td>11.63</td>
</tr>
<tr>
<td>17.5-23 Bw1</td>
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<td>10.29</td>
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<tr>
<td>63.5-79 Bw2</td>
<td>2.75</td>
<td>4.72</td>
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$SSS$ = no data collected
Soil No.: S-2
Classification: Typic Udixitrand
Location: Multnomah County, Oregon
T1S R6E Sect16 NE1/4 of SE1/4
South side of the reservoir, near the dam there are three main streams
this is located just west of the middle stream
Topography: Elevation 330 meters (1080 feet), 12° slope, aspect S8E
Drainage: Well Drained
Vegetation: Hemlock & Douglas fir (150-75 years), sparse undergrowth: ferns and moss
Parent Material: Grande Ronde (basalts and pyroclastics)
Sampled by: Dcann Hamilton and Daryl Wieneke, July 15, 1993
Comments: Root Disturbance: 15% dispense
Stoniness: Cobbly at 35% (average 11.5 cm, 4.5 inches) (bigger deeper)

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>13-0 cm (5-0 in.) Grayish Brown (10YR 5/2) (wet), Very Dark Yellowish Brown (10YR 3/4) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); clear wavy boundary.</td>
</tr>
<tr>
<td>Bw 5-10</td>
<td>5-51+ cm (2-20+ in.) Dark Brown (7.5YR 3/4) (wet), Yellowish Brown (10YR 5/8) (dry); silt loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet).</td>
</tr>
<tr>
<td>R</td>
<td>109 cm (43 in.)  (hand augered)</td>
</tr>
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</table>

### Size class and particle diameter (mm)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>0.000 - 0.061</th>
<th>0.060 - 0.16</th>
<th>0.160 - 0.31</th>
<th>0.310 - 0.63</th>
<th>0.630 - 1.25</th>
<th>1.250 - 2.0</th>
<th>2.000 - 2.57</th>
<th>2.570 - 5.52</th>
<th>5.520 - 10.00</th>
<th>10.000 - 15.00</th>
<th>15.000 - 30.00</th>
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<tbody>
<tr>
<td>O</td>
<td>A</td>
<td>48</td>
<td>37</td>
<td>15</td>
<td>5.52</td>
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<td>14.24</td>
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</tr>
<tr>
<td>Bw</td>
<td>28</td>
<td>52</td>
<td>20</td>
<td>0.57</td>
<td>2.34</td>
<td>9.43</td>
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<td>5.73</td>
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<tr>
<td>0-5</td>
<td>A</td>
<td>33</td>
<td>51</td>
<td>16</td>
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<tr>
<td>5-10</td>
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<td>10</td>
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<td>7.71</td>
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<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>0.000 - 0.061</th>
<th>0.060 - 0.16</th>
<th>0.160 - 0.31</th>
<th>0.310 - 0.63</th>
<th>0.630 - 1.25</th>
<th>1.250 - 2.0</th>
<th>2.000 - 2.57</th>
<th>2.570 - 5.52</th>
<th>5.520 - 10.00</th>
<th>10.000 - 15.00</th>
<th>15.000 - 30.00</th>
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<tr>
<td>5-10</td>
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<td>29.21</td>
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<td>4.67</td>
<td>7.33</td>
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<td>35%</td>
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<td>10-15</td>
<td>Bw</td>
<td>1.82</td>
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<td>22.54</td>
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<td>4.66</td>
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<td>33-46</td>
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<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Carbon (organic)</th>
<th>Organic Matter</th>
<th>Percent Moisture (water)</th>
<th>pH</th>
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<tbody>
<tr>
<td>0-5</td>
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<td>24.84</td>
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<td>5.3</td>
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<td>5-10</td>
<td>Bw</td>
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<td>17.79</td>
<td>37</td>
<td>$$$</td>
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<tr>
<td>10-15</td>
<td>Bw</td>
<td>7.79</td>
<td>13.29</td>
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<td>$$$</td>
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<tr>
<td>33-46</td>
<td>Bw</td>
<td>5.69</td>
<td>9.79</td>
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</table>

$ $$$ = no data collected
Soil No.: S-3  
Classification: Typic Udivitrand  
Location: Multnomah County, Oregon  
T1S R6E Sec15 SW1/4 of NW1/4  
South side of the reservoir, near the dam there are three main streams, this is located just east of the middle stream  
Topography: Elevation 330 meters (1080 feet), 9° slope, aspect S17E  
Drainage: Well Drained  
Vegetation: Hemlock & Douglas fir (100 years), sparse undergrowth: ferns and moss  
Parent Material: Grande Ronde (basalts and pyroclastics)  
Sampled by: Doann Hamilton and Daryl Wienke, July 15, 1993  
Comments: Root Disturbance: 1% (dispersed)  
Stoniness: Stony at 10% (two large 0.5 meters, 1.5 feet)  
Basalt here is highly weathered with epidote, bank showed sediment units below this site, depth stopped by a rock  

Horizon Characteristics

### O
0-7.5 cm (0-3 in.) Dark Brown (7.5YR 3/3) (wet), Dark Yellowish Brown (10YR 4/6) (dry); sandy loam; weak fine subangular blocky; non sticky and slightly plastic (wet); abrupt smooth boundary.

### Bw1
7.5-40.5 cm (3-16 in.) Dark Brown (7.5YR 3/4), Yellowish Brown (10YR 5/6) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); gradual wavy boundary.

### Bw2
40.5-56 cm (16-22+ in.) Dark Reddish Brown (5YR 3/4) (wet), Brownish Yellow (10YR 6/6) (dry); silt loam; weak fine subangular blocky; slightly sticky and plastic (wet).

<table>
<thead>
<tr>
<th>Size class and particle diameter (mm)</th>
<th>% Total</th>
<th>% Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (cm)</td>
<td></td>
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<table>
<thead>
<tr>
<th>O</th>
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<tbody>
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<td>0-5</td>
<td>57</td>
<td>9</td>
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<tr>
<td>0.063-0.004</td>
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**Horizon Characteristics continued**

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<th>Size class and particle diameter (mm)</th>
<th>% Total</th>
<th>% Coarse fragments</th>
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<tbody>
<tr>
<td>Depth (cm)</td>
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<th>Organic Matter</th>
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<tr>
<td>Organic Matter</td>
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<td></td>
</tr>
<tr>
<td>Percent Moisture</td>
<td>(water)</td>
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§§§§ = no data collected
Soil No.: S-4  
Classification: none given  
Location: Multnomah County, Oregon  
T1S R6E Sec15 SW1/4 of NW1/4  
South side of the reservoir, near the dam there are three main streams  
this is located just east of the middle stream (at rivers edge just below S-3)  
Topography: Elevation 320 meters (1050 feet)  
Drainage:  
Parent Material: Grande Ronde (basalts and pyroclastics)  
Sampled by: Deann Hamilton and Daryl Wienke, July 15, 1993  
Comments: Sample of sediment exposed at the lake shore bank

**Characteristics**

**Bank Sample** Reddish Brown (5YR 4/4) (wet), Brownish Yellow (10YR 6/6) (dry); silt loam, weak subangular blocky, slightly sticky and slightly plastic.

<table>
<thead>
<tr>
<th></th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>V. Coarse</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
<th>V. Fine</th>
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<tbody>
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<td>0.063 -</td>
<td>&lt;0.004</td>
<td>2 - 1</td>
<td>1 - 0.5</td>
<td>0.5 -</td>
<td>0.25 -</td>
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<td>0.004</td>
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<td></td>
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<tr>
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<td>51</td>
<td>12</td>
<td>0.34</td>
<td>2.23</td>
<td>11.99</td>
<td>14.49</td>
<td>7.95</td>
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<th></th>
<th>% Sand</th>
<th>% Silt</th>
<th>% Clay</th>
<th>% Coarse</th>
<th>% Medium</th>
<th>% Fine</th>
<th>% V. Fine</th>
<th>% Stones</th>
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<tbody>
<tr>
<td>Depth</td>
<td>(0.063 -</td>
<td>(0.031 -</td>
<td>(0.016 -</td>
<td>(0.008 -</td>
<td>(0.004 - &lt;0.002</td>
<td>&gt;2mm throughout</td>
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<tr>
<td>(cm)</td>
<td>Horizon</td>
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<td>0.016</td>
<td>0.008</td>
<td>0.004</td>
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<td>0.20</td>
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<tr>
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<th>Organic Carbon</th>
<th>Organic Matter</th>
<th>Percent Moisture</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>(cm) Horizon</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| bank sample | 1.02 | 1.75 | 4.0 | $$$

$\text{$$$} = \text{no data collected}$
Soil No.: S-5
Classification: Typic Udvitrand
Location: Multnomah County, Oregon
T1S R6E Sec16 NW1/4 of NE1/4
South side of the reservoir, west of the log boom, around the bend
Topography: Elevation 330 meters (1080 feet), 23° slope, aspect S7E
Drainage: Well Drained
Vegetation: Hemlock & Douglas fir (50 years), sparse undergrowth: ferns and moss
Parent Material: Grande Ronde (basalts and pyroclastics)
Sampled by: Doann Hamilton and Daryl Wiebke, July 14, 1993
Comments: Root Disturbance: 5% mostly at the top
Stoniness: Gravelly at 10%
A and BW contact have a white mold
Did not sample BW

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Very Dusky Brown (2.5YR 2.5/2) (wet), Dark Yellowish-Brown (10YR 4/6) (dry), silt loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet); abrupt smooth boundary.</td>
</tr>
<tr>
<td>Bw</td>
<td>Dark Reddish Brown (5YR 3/3) (wet); sandy loam (field); weak fine subangular blocky; non sticky and non plastic (wet).</td>
</tr>
<tr>
<td>R</td>
<td>226 cm (89 in.) (hand augered).</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>% Sand</th>
<th>% Silt</th>
<th>% Clay</th>
<th>V. Coarse</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
<th>V. Fine</th>
</tr>
</thead>
<tbody>
<tr>
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<td>A</td>
<td>31</td>
<td>57</td>
<td>12</td>
<td>5.01</td>
<td>3.46</td>
<td>8.10</td>
<td>8.34</td>
<td>6.09</td>
</tr>
<tr>
<td>7.5-12.5</td>
<td>A</td>
<td>33</td>
<td>55</td>
<td>12</td>
<td>4.91</td>
<td>2.40</td>
<td>8.16</td>
<td>9.26</td>
<td>7.27</td>
</tr>
<tr>
<td>12.5-15</td>
<td>A</td>
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<td>55</td>
<td>10</td>
<td>6.68</td>
<td>4.33</td>
<td>8.64</td>
<td>8.97</td>
<td>6.38</td>
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<table>
<thead>
<tr>
<th>Size class and particle diameter (mm) continued</th>
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<tbody>
<tr>
<td>Depth (cm)</td>
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<tr>
<td>------------</td>
</tr>
<tr>
<td>0-7.5</td>
</tr>
<tr>
<td>7.5-12.5</td>
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<tr>
<td>12.5-15</td>
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<table>
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<th>Organic Carbon</th>
<th>Matter</th>
<th>Moisture (water)</th>
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<td>12.83</td>
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<td>12.5-15</td>
<td>A</td>
<td>6.66</td>
<td>11.46</td>
<td>3.0</td>
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</table>

---
Soil No.: S-6
Classification: Typic Udivitrand
Location: Multnomah County, Oregon
T1S R6E Sec15 NE1/4 of NE1/4
South side of the reservoir, west of the log boom, before bend
Topography: Elevation 330 meters (1080 feet), 13° slope, aspect N43E
Drainage: Well Drained
Vegetation: Hemlock & Douglas fir (35-40 years), moderate underbrush sticker bush, ferns, some brittle shrub, some young hardwoods
Parent Material: Grande Ronde (basalts and pyroclastics)
Sampled by: Doann Hamilton and Daryl Wieneke, July 14, 1993
Comments: Root Disturbance: 25%
Stoniness: Cobbly at 50% average 2.5-12.5 cm (1-5 inches) one large 0.6 meters (2 feet) too large of rocks to sample well

<table>
<thead>
<tr>
<th>Horizon Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 13-0 cm(5-0 in.)</td>
</tr>
<tr>
<td>A 0-15 cm (0-6 in.) Dark Reddish Brown (5YR 3/3) (wet), Dark Brown-Brown (7.5YR 4/3) (dry); sandy loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet); gradual wavy boundary.</td>
</tr>
<tr>
<td>Bw 15-61+ cm (6-24+ in.) Reddish Brown (5YR 4/4) (wet), Strong Brown (7.5YR 4/6) (dry); silt loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size class and particle diameter (mm)</th>
<th>Size class and particle diameter (mm) continued</th>
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<tbody>
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<td>Depth (cm)</td>
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</tr>
<tr>
<td>% Total</td>
<td>Sand</td>
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<td>(0.063</td>
</tr>
<tr>
<td>0-6</td>
<td>A</td>
</tr>
<tr>
<td>6-11.5</td>
<td>A</td>
</tr>
<tr>
<td>48-61</td>
<td>Bw</td>
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<tr>
<td>6-11.5</td>
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<tr>
<td>48-61</td>
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</tbody>
</table>

$\text{(((}}$ no data collected
Soil No.: S-7  
Classification: Typic Udiflirtand  
Location: Multnomah County, Oregon  
T1S R6E Sec 14 NE1/4 of NW1/4  
South side of the reservoir, east of the log boom, west of North Fork  
Topography: Elevation 330 meters (1080 feet), 0° slope  
Drainage: Well Drained  
Vegetation: Hemlock & Douglas fir (200 years), some cedar, moderate underbrush a lot of moss in the trees, vine maple  
Parent Material: Grande Ronde (basalts and pyroclastics)  
Sampled by: Doann Hamilton and Daryl Wieneke, July 12, 1993  
Comments: Root Disturbance: 2-3% mostly at the top  
Stoniness: Gravelly at 5% average 2.5 cm (one inch)  
On a flat above a very steep bank (possible on top a basalt flow) a lot of sand with rounded rock on bottom.  
(Possible fire area 1950-1959)

Horizon Characteristics:
- **O**: 7.5-0 cm (3-0 in.)  
  Dark Reddish Brown (5YR 3/3) (wet), Brown-Dark Brown (7.5YR 4/4) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); roots; clear wavy boundary.
- **A**: 0-7.5 cm (0-3 in.)  
  Dark Reddish Brown (5YR 3/3) (wet), Brown-Dark Brown (7.5YR 4/4) (dry); loam; weak fine subangular blocky; non sticky and slightly plastic (wet); abrupt smooth boundary.
- **Bw1**: 7.5-38 cm (3-15 in.)  
  Dark Reddish Brown (2.5YR 3/3) (wet), Yellowish Brown (10YR 5/6) (dry); silt loam; weak fine subangular blocky; non sticky and slightly plastic (wet); abrupt smooth boundary.
- **Bw2**: 38-73.5 cm (15-29 in.)  
  Strong Brown (7.5YR 4/6) (wet), Strong Brown (7.5YR 5/8) (dry); sandy loam; weak fine subangular blocky; non sticky and non plastic (wet).
- **R**: 73.5 cm (29 in.)

### Size class and particle diameter (mm)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>% Sand</th>
<th>% Silt</th>
<th>% Clay</th>
<th>% V. Coarse</th>
<th>% Coarse</th>
<th>% Medium</th>
<th>% Fine</th>
<th>% V. Fine</th>
<th>% Coarse fragments</th>
<th>% Organic Matter</th>
<th>% Moisture (water)</th>
<th>% Organic Carbon</th>
<th>% Organic Matter</th>
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<tr>
<td>0-7.5</td>
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<td>4.63</td>
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<td>-</td>
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<td>20.67</td>
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<td>12.5-17.5</td>
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<td>1.72</td>
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<td>23-25.5</td>
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<td>-</td>
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<td>-</td>
<td>21.31</td>
<td>21.69</td>
<td>5</td>
<td>15.33</td>
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### Size class and particle diameter (mm) continued

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<th>Depth (cm)</th>
<th>Horizon</th>
<th>% Silt</th>
<th>% Clay</th>
<th>% V. Fine</th>
<th>% Coarse</th>
<th>% Medium</th>
<th>% Fine</th>
<th>% Coarse fragments</th>
<th>% Organic Matter</th>
<th>% Moisture (water)</th>
<th>% Organic Carbon</th>
<th>% Organic Matter</th>
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<td>2.46</td>
<td>2.46</td>
<td>17.35</td>
<td>5</td>
<td>22.13</td>
<td>37</td>
<td>12.87</td>
</tr>
<tr>
<td>12.5-17.5</td>
<td>Bw1</td>
<td>17.00</td>
<td>20.46</td>
<td>15.53</td>
<td>4.24</td>
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<td>2.64</td>
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<tr>
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<td>21.46</td>
<td>20.72</td>
<td>5.62</td>
<td>4.36</td>
<td>5.00</td>
<td>2.40</td>
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<td>25.22</td>
<td>16.22</td>
</tr>
<tr>
<td>23-25.5</td>
<td>Bw1</td>
<td>12.00</td>
<td>21.31</td>
<td>14.69</td>
<td>4.42</td>
<td>3.18</td>
<td>4.42</td>
<td>4.20</td>
<td>5</td>
<td>21.69</td>
<td>21.31</td>
<td>15.53</td>
</tr>
<tr>
<td>66-73.5</td>
<td>Bw2</td>
<td>24.71</td>
<td>8.34</td>
<td>6.95</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>25.74</td>
<td>5</td>
<td>21.31</td>
<td>21.69</td>
<td>15.33</td>
</tr>
</tbody>
</table>

### Chemical Analysis

- **Depth (cm)**: 0-7.5
- **Horizon**: A
- **Organic Matter**: 35
- **Carbon**: 35
- **Moisture (water)**: 35

---

### Additional Notes
- **Soil Profile**: Typic Udiflirtand
- **Location**: Multnomah County, Oregon
- **Sampling**: Doann Hamilton and Daryl Wieneke, July 12, 1993
- **Comments**: Root Disturbance: 2-3% mostly at the top, Stoniness: Gravelly at 5% average 2.5 cm (one inch), clear wavy boundary.
**Soil No.: S-8**  
**Classification:** Typic Ud Ivirand  
**Location:** Multnomah County, Oregon  
T1S R6E Sec11 SE1/4 of SE1/4  
South side of the reservoir, east of the log boom, up Fir Creek  
**Topography:** Elevation 330 meters (1080 feet), 13° slope, aspect S29W

**Drainage:** Well Drained  

**Vegetation:** Hemlock & Douglas fir (75 years), moderate underbrush ferns, moss, huckleberry, Oregon grape  

**Parent Material:** Grande Ronde (basalts and pyroclastics)

**Sampled by:** Doann Hamilton and Daryl Wieneke, July 14, 1993

**Comments:** Root Disturbance: 2% mostly at the top  
StoneH: Gravelly at <1% at top only  
A and BW contact have a white mold

(Possible fires of 1940-1949 and 1950-1959)

---

**Horizon Characteristics**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-8</td>
<td>A</td>
<td>0-8 cm (0-3 in.) Dark Brown (7.5YR 3/3) (wet), Dark Brown-Brown (7.5YR 4/4) (dry); loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet); abrupt smooth boundary.</td>
</tr>
<tr>
<td>8-11.5</td>
<td>Bw1</td>
<td>8-11.5 cm (3-32 in.) Strong Brown (7.5YR 4/6) (wet), Yellowish Brown (10YR 5/6) (dry); silt loam; weak fine subangular blocky; slightly sticky and slightly plastic (wet); gradual wavy boundary.</td>
</tr>
<tr>
<td>11.5-16.5</td>
<td>Bw1</td>
<td>11.5-16.5 cm (4-6 in.) Dark Brown (7.5YR 4/4) (wet), Brownish Yellow (10YR 6/6) (dry); silt loam; weak fine subangular blocky; sticky and plastic (wet).</td>
</tr>
<tr>
<td>130</td>
<td></td>
<td>R 130 cm (51 in.) (hand augered).</td>
</tr>
</tbody>
</table>

---

**Size class and particle diameter (mm)**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Size class and particle diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-8</td>
<td>A</td>
<td>Sand 41 (0.063), Silt 48 (0.004), Clay 11 (2-1), V. Coarse 9.92 (0.004), Coarse 4.44 (0.015), Medium 8.48 (0.015), Fine 9.70 (0.125), V. Fine 8.45 (0.125).</td>
</tr>
<tr>
<td>8-11.5</td>
<td>Bw1</td>
<td>8-11.5 cm (3-32 in.) Sand 34 (0.063), Silt 52 (0.004), Clay 14 (2-1), V. Coarse 7.33 (0.004), Coarse 3.37 (0.015), Medium 7.82 (0.015), Fine 8.43 (0.125), V. Fine 6.65 (0.125).</td>
</tr>
<tr>
<td>11.5-16.5</td>
<td>Bw1</td>
<td>11.5-16.5 cm (4-6 in.) Sand 20 (0.063), Silt 58 (0.004), Clay 22 (2-1), V. Coarse 0.93 (0.004), Coarse 1.45 (0.015), Medium 5.76 (0.015), Fine 7.06 (0.125), V. Fine 4.80 (0.125).</td>
</tr>
<tr>
<td>86-94</td>
<td>Bw2</td>
<td>86-94 cm (33-35 in.) Sand 28 (0.063), Silt 51 (0.004), Clay 21 (2-1), V. Coarse 3.35 (0.004), Coarse 2.59 (0.015), Medium 7.72 (0.015), Fine 8.41 (0.125), V. Fine 6.37 (0.125).</td>
</tr>
</tbody>
</table>

---

**Organic Carbon, Organic Matter, Percent Moisture (water), pH**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Organic Carbon</th>
<th>Organic Matter</th>
<th>Percent Moisture (water)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-8</td>
<td>A</td>
<td>9.19</td>
<td>15.81</td>
<td>39</td>
<td>5</td>
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<tr>
<td>8-11.5</td>
<td>Bw1</td>
<td>7.19</td>
<td>12.37</td>
<td>36</td>
<td>$\text{$$$}$</td>
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<tr>
<td>11.5-12.5</td>
<td>Bw1</td>
<td>5.90</td>
<td>10.15</td>
<td>30</td>
<td>$\text{$$$}$</td>
</tr>
<tr>
<td>12.5-16.5</td>
<td>Bw1</td>
<td>4.51</td>
<td>7.75</td>
<td>33</td>
<td>$\text{$$$}$</td>
</tr>
<tr>
<td>86-94</td>
<td>Bw2</td>
<td>1.74</td>
<td>2.99</td>
<td>36</td>
<td>$\text{$$$}$</td>
</tr>
</tbody>
</table>

$\text{$$$}$ = no data collected
Soil No.: S-9  
Classification: Typic Ud.ivitrand  
Location: Multnomah County, Oregon  

T1S R6E Sec11 SE1/4 of SE1/4  
South side of the reservoir, east of the log boom, east of Fir Creek  

Topography: Elevation 330 meters (1080 feet), 0° slope  

Drainage: Well Drained  

Vegetation: Hemlock & Douglas fir (200 years) (sparse), moderate underbrush a lot of sticker bushes, fens, huckleberry, vine maple  

Parent Material: Grande Ronde (basalts and pyroclastics)  

Sampled by: Doann Hamilton and Daryl Wiencek, July 12, 1993  

Comments: Root Disturbance: 10-15% mostly at the top  

Stoniness: 0%  

flat on top of steep possible on top of a flow  

(Possible fire area 1940-1949 and 1950-1959)  

--- Size class and particle diameter (mm) continued ---  

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Organic Carbon</th>
<th>Matter</th>
<th>Percent</th>
<th>pH</th>
<th>Coarse fragments</th>
<th>percent</th>
<th>% stones</th>
<th>&lt;2mm thoroughout</th>
<th>% Organic</th>
<th>Percent</th>
<th>Moisture (water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9</td>
<td>A</td>
<td>9.93</td>
<td>17.09</td>
<td>52</td>
<td>5.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.93</td>
<td>17.09</td>
<td>52</td>
</tr>
<tr>
<td>5-9</td>
<td>Bw1</td>
<td>8.89</td>
<td>15.29</td>
<td>51</td>
<td>$$$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.89</td>
<td>15.29</td>
<td>51</td>
</tr>
<tr>
<td>9-12.5</td>
<td>Bw1</td>
<td>6.87</td>
<td>11.82</td>
<td>48</td>
<td>$$$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.87</td>
<td>11.82</td>
<td>48</td>
</tr>
<tr>
<td>15-140</td>
<td>Bw2</td>
<td>1.73</td>
<td>2.97</td>
<td>46</td>
<td>$$$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.73</td>
<td>2.97</td>
<td>46</td>
</tr>
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</table>

$\text{\$\$\$\$} = \text{no data collected}$
Soil No.: S-10  
Classification: none given  
Location: Multnomah County, Oregon  
T1S R6E Sec12 SE1/4 of SW1/4  
South side of the reservoir, far east end past island near main steam  
Topography: Elevation 330 meters (1080 feet)  
Drainage: Well Drained  
Vegetation: Hemlock & Douglas fir (100-150 years), a lot of underbrush: ferns salmon berry, huckleberry  
Parent Material: Grande Ronde (basalts and pyroclastics)  
Sampled by: Deann Hamilton and Daryl Wieneke, July 12, 1993  
Comments: Stoniness: Stony at 75%  
Too many rocks and can't get around the steep terrain to get a good sample  
Sampled only the A approx. 10 cm (4 inches) down  
(possible fire area 10-2-70)  

Horizon Characteristics  
A 0-10 cm (0-4 in.) Dark Reddish Brown (5YR 2.5/2) (wet), Strong Brown (7.5YR 4/6) (dry); sandy loam; weak fine subangular blocky; non sticky and slightly plastic (wet).  
R 76 cm (30 in.) (hand augered)  

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>A</th>
<th>V. Coarse</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Medium</th>
<th>Fine</th>
<th>V. Fine</th>
<th>Coarse fragments</th>
<th>Organic Carbon</th>
<th>Organic Matter</th>
<th>Percent</th>
<th>pH</th>
<th>Moisture (water)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>A</td>
<td>50</td>
<td>44</td>
<td>6</td>
<td>6.73</td>
<td>5.07</td>
<td>10.89</td>
<td>13.69</td>
<td>13.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>A</th>
<th>V. Coarse</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Medium</th>
<th>Fine</th>
<th>V. Fine</th>
<th>Coarse fragments</th>
<th>Organic Carbon</th>
<th>Organic Matter</th>
<th>Percent</th>
<th>pH</th>
<th>Moisture (water)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>A</td>
<td>14.99</td>
<td>19.94</td>
<td>9.06</td>
<td>1.00</td>
<td>3.00</td>
<td>2.00</td>
<td>19.90</td>
<td>stony</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tbody>
</table>
APPENDIX I

SOIL SITE DESCRIPTION - TABULAR FORM
Table 11: Field and lab analysis on north side soil pits.

<table>
<thead>
<tr>
<th>Site</th>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Boundary</th>
<th>Parent material</th>
<th>Structure</th>
<th>Moisture</th>
<th>Soil Color</th>
<th>Soil Color</th>
<th>Plasticity</th>
<th>Wet Consistence</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-1</td>
<td>O</td>
<td>7.5-0</td>
<td></td>
<td>Frenchman Springs</td>
<td>10 degrees</td>
<td>wfsbk</td>
<td>5%</td>
<td>5YR 3/4</td>
<td>non plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>0-7.5</td>
<td></td>
<td>10 degrees</td>
<td>wfsbk</td>
<td>5%</td>
<td>5YR 3/4</td>
<td>non plastic</td>
<td>slightly sticky</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bw1</td>
<td>7.5-30</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>5%</td>
<td>5YR 3/4</td>
<td>slightly plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw2</td>
<td>30-63.5+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>5%</td>
<td>10YR 4/4</td>
<td>non plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td>N-2</td>
<td>O</td>
<td>15-0</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>71%</td>
<td>10YR 4/6</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>0-10</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>41%</td>
<td>5YR 3/4</td>
<td>non plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw1</td>
<td>10-33</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>38%</td>
<td>10YR 3/4</td>
<td>non plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw2</td>
<td>33-66-+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>34%</td>
<td>5YR 4/6</td>
<td>non plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td>N-3</td>
<td>O</td>
<td>2.5-0</td>
<td></td>
<td>Grande Ronde</td>
<td>diffuse</td>
<td>wfsbk</td>
<td>44%</td>
<td>5YR 3/4</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>A1</td>
<td>0-18</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>39%</td>
<td>2.5YR 2.5/2</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>18-53+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>36%</td>
<td>5YR 3/4</td>
<td>slightly plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td>N-4</td>
<td>O</td>
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<td>wfsbk</td>
<td>66%</td>
<td>5YR 3/4</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>0-2.5</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>39%</td>
<td>2.5YR 2.5/2</td>
<td>non plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>B/A</td>
<td>2.5-17.5</td>
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<td>Grande Ronde</td>
<td>gradual</td>
<td>wfsbk</td>
<td>36%</td>
<td>5YR 3/4</td>
<td>slightly plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw1</td>
<td>17.5-66+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>33%</td>
<td>10YR 4/4</td>
<td>non plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw2</td>
<td>66-94+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>34%</td>
<td>7.5YR 4/6</td>
<td>non plastic</td>
<td>slightly plastic</td>
</tr>
<tr>
<td>N-5</td>
<td>O</td>
<td>12.5-0</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>44%</td>
<td>5YR 3/4</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>0-15</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>44%</td>
<td>5YR 3/4</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>Bw1</td>
<td>15-38+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>43%</td>
<td>5YR 4/4</td>
<td>slightly plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
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<td>38-60+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>39%</td>
<td>5YR 4/4</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td>N-7</td>
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<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>43%</td>
<td>5YR 4/4</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>A1</td>
<td>0-30.5</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>43%</td>
<td>5YR 4/4</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>30.5-43+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>36%</td>
<td>7.5YR 3/4</td>
<td>non plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw1</td>
<td>43-58.8+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>34%</td>
<td>7.5YR 4/4</td>
<td>slightly plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw2</td>
<td>58.8-94+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>34%</td>
<td>7.5YR 4/4</td>
<td>slightly plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td>N-8</td>
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<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>35%</td>
<td>5.5YR 3/4</td>
<td>slightly plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>0-10</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>35%</td>
<td>5.5YR 3/4</td>
<td>slightly plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw1</td>
<td>10-56</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>31%</td>
<td>5YR 4/4</td>
<td>slightly plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw2</td>
<td>56-73.5+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>30%</td>
<td>7.5YR 5/3</td>
<td>non plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td>N-9</td>
<td>O</td>
<td>2.5-0</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>33%</td>
<td>5.5YR 3/4</td>
<td>slightly plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>0-5</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>33%</td>
<td>10YR 3/4</td>
<td>non plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td></td>
<td>Bw1</td>
<td>5-56</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>33%</td>
<td>10YR 4/6</td>
<td>slightly plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td></td>
<td>Inclusion</td>
<td>43-56</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>35%</td>
<td>10YR 4/6, 2.5YR 4/6</td>
<td>slightly plastic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bw2</td>
<td>56-71+</td>
<td></td>
<td>Grande Ronde</td>
<td>abrupt</td>
<td>wfsbk</td>
<td>34%</td>
<td>10YR 4/6</td>
<td>plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td>Site</td>
<td>Horizon</td>
<td>Depth (cm)</td>
<td>Boundary Conditions</td>
<td>Parent material</td>
<td>Structure</td>
<td>Moisture</td>
<td>pH</td>
<td>Soil Color Wet (#)</td>
<td>Soil Color Dry (#)</td>
<td>Plasticity</td>
</tr>
<tr>
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<td>-----------------</td>
<td>-----------</td>
<td>----------</td>
<td>----</td>
<td>-------------------</td>
<td>-------------------</td>
<td>------------</td>
</tr>
<tr>
<td>N-10</td>
<td>O</td>
<td>5-0</td>
<td>$\text{weak fine sub-angular blocky}$</td>
<td>$\text{Frenchman Springs}$</td>
<td>$\text{N}=$</td>
<td>$\text{66%}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td>0-6</td>
<td>abrupt wavy, 7 degrees</td>
<td>$\text{wfsbk}$</td>
<td>$\text{47%}$</td>
<td>$\text{5S5}$</td>
<td>$\text{5YR 2.5/1}$</td>
<td>$\text{10YR 4/4}$</td>
<td>slightly plastic</td>
<td>non sticky</td>
</tr>
<tr>
<td>Bw1</td>
<td></td>
<td>6-25</td>
<td>gradual wavy</td>
<td>$\text{wfsbk}$</td>
<td>$\text{33%}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{7.5YR 3/4, 2.5YR 5/8}$</td>
<td>$\text{10YR 6/6}$</td>
<td>slightly plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td>Bw2</td>
<td></td>
<td>25-51+</td>
<td></td>
<td>$\text{wfsbk}$</td>
<td>$\text{34%}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{10YR 5/6}$</td>
<td>$\text{10YR 7/6}$</td>
<td>plastic</td>
<td>slightly sticky</td>
</tr>
<tr>
<td>N-11</td>
<td></td>
<td>$\text{140 cm}$</td>
<td>Grande Ronde</td>
<td>$\text{wfsbk}$</td>
<td>$\text{68S}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5YR 3/2}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
</tr>
<tr>
<td>N-12</td>
<td>O</td>
<td>13-0</td>
<td>Rhododendron Form.</td>
<td>$\text{wfsbk}$</td>
<td>$\text{74%}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5YR 3/2}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td>0-38</td>
<td>abrupt sharp, flat</td>
<td>$\text{wfsbk}$</td>
<td>$\text{68S}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5YR 3/2}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
</tr>
<tr>
<td>A2</td>
<td></td>
<td>38-48+</td>
<td>Ground Water = 38 cm</td>
<td>$\text{wfsbk}$</td>
<td>$\text{66S}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5YR 3/2}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
<td>$\text{5S6S}$</td>
</tr>
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</table>

(wfsbk = weak fine sub-angular blocky, $\text{N}=$ no data available, abrupt = < 2.5 cm (one inch), clear = 2.5 - 6 cm (1-2.5 inches), gradual = 6-12.5 cm (2.5-5 inches), diffuse = > 12.5 cm (5 inches), smooth = boundary is parallel, wavy = pockets are wider than their depth, irregular = pockets are deeper than their width, broken = parts of the horizon are unconnected to other parts, non sticky - after release of pressure, practically no soil material adheres to thumb or finger, slightly sticky - after pressure, soil material adheres to both thumb and finger but comes off one or the other rather cleanly. It is not appreciably stretched when the digits are separated, very sticky - after pressure, soil materials adheres strongly to both thumb and forefinger and is decidedly stretched when they are separated. (#) = colors by Munsell's Soil color charts (1990) (all definitions are as described in USDA Soil Conservation Service Agriculture Handbook #436, Soil Survey Staff, 1975)
Table 12: Field and lab analysis on south side soil pits.

<table>
<thead>
<tr>
<th>Site</th>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Boundary Conditions</th>
<th>Parent Material</th>
<th>Structure</th>
<th>Moisture</th>
<th>pH</th>
<th>Soil Color</th>
<th>Soil Color Plasticity</th>
<th>Wet Consistence</th>
<th>Dry Consistence</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>O</td>
<td>5-0</td>
<td>Grande Ronde</td>
<td>Abrupt smooth</td>
<td>3 degrees</td>
<td>wfsbk</td>
<td>68%</td>
<td>5.55</td>
<td>5YR 3/2</td>
<td>10YR 3/2</td>
<td>Slightly Plastic</td>
</tr>
<tr>
<td>A</td>
<td>0-5</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>25%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw1</td>
<td>5-58</td>
<td>Gradual wavy</td>
<td>wfsbk</td>
<td>35%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw2</td>
<td>59-79+</td>
<td></td>
<td>wfsbk</td>
<td>35%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-2</td>
<td>O</td>
<td>13-0</td>
<td>Grande Ronde</td>
<td>Abrupt smooth</td>
<td>6 degrees</td>
<td>wfsbk</td>
<td>58%</td>
<td>5.15</td>
<td>5YR 3/2</td>
<td>10YR 3/2</td>
<td>Slightly Plastic</td>
</tr>
<tr>
<td>A</td>
<td>0-5</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>32%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw</td>
<td>5-51+</td>
<td></td>
<td>wfsbk</td>
<td>37%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-3</td>
<td>O</td>
<td>15-0</td>
<td>Grande Ronde</td>
<td>Abrupt smooth</td>
<td>6 degrees</td>
<td>wfsbk</td>
<td>59%</td>
<td>5.75</td>
<td>7YR 3/4</td>
<td>10YR 3/4</td>
<td>Slightly Plastic</td>
</tr>
<tr>
<td>A</td>
<td>0-5</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>55%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Bw1</td>
<td>7-8-40</td>
<td>Gradual wavy</td>
<td>wfsbk</td>
<td>31%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw2</td>
<td>40-5-6+</td>
<td></td>
<td>wfsbk</td>
<td>32%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-4</td>
<td>O</td>
<td>10-0</td>
<td>Grande Ronde</td>
<td>Abrupt smooth</td>
<td>23 degrees</td>
<td>wfsbk</td>
<td>54%</td>
<td>5.15</td>
<td>5YR 3/2</td>
<td>10YR 3/2</td>
<td>Slightly Plastic</td>
</tr>
<tr>
<td>A</td>
<td>0-5</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>34%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw1</td>
<td>15-48+</td>
<td>Abrupt smooth</td>
<td>wfsbk</td>
<td>34%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-6</td>
<td>O</td>
<td>13-0</td>
<td>Grande Ronde</td>
<td>Abrupt smooth</td>
<td>13 degrees</td>
<td>wfsbk</td>
<td>59%</td>
<td>5.25</td>
<td>5YR 3/3</td>
<td>10YR 3/4</td>
<td>Slightly Plastic</td>
</tr>
<tr>
<td>A</td>
<td>0-15</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>47%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rw1</td>
<td>15-47+</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>40%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Bw1</td>
<td>7-5-0</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>64%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw2</td>
<td>38-73+</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>54%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-7</td>
<td>O</td>
<td>10-0</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>36%</td>
<td>5YR 3/4</td>
<td>7YR 4/6</td>
<td>Slightly Plastic</td>
<td>Non Plastic</td>
<td>Non Plastic</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0-7.5</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>43%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Bw1</td>
<td>38-53+</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>36%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw2</td>
<td>38-53+</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>54%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-8</td>
<td>O</td>
<td>10-0</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>41%</td>
<td>7YR 4/6</td>
<td>7YR 5/8</td>
<td>Slightly Plastic</td>
<td>Non Plastic</td>
<td>Non Plastic</td>
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</tr>
<tr>
<td>A</td>
<td>0-8</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>36%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Bw1</td>
<td>3-81</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>45%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
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</tr>
<tr>
<td>Bw2</td>
<td>56-69+</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>50%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>S-9</td>
<td>O</td>
<td>13-0</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>46%</td>
<td>10YR 5/6</td>
<td>10YR 6/8</td>
<td>Slightly Plastic</td>
<td>Plastic</td>
<td>Slightly Plastic</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0-5</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>52%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Bw1</td>
<td>5-56</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>50%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
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<td>Bw2</td>
<td>56-69+</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>46%</td>
<td>Plastic</td>
<td>Slightly</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>S-10</td>
<td>O</td>
<td>0-10</td>
<td>Abrupt smooth</td>
<td>Grande Ronde</td>
<td>39%</td>
<td>5YR 2/5</td>
<td>7YR 4/6</td>
<td>Slightly Plastic</td>
<td>Non Plastic</td>
<td>Non Plastic</td>
<td></td>
</tr>
</tbody>
</table>

See Table 11 for the definitions and descriptions
(all definitions are as described in USDA Soil Conservation Service Agriculture Handbook #436, Soil Survey Staff, 1975)
Table 13: Grain-size analysis on north side soil pits (\#).

<table>
<thead>
<tr>
<th>Site Horizon</th>
<th>% stones (Ø)</th>
<th>%&gt;2mm</th>
<th>%0.063-0.004</th>
<th>%&lt;0.004</th>
<th>Texture</th>
<th>Carbon (%)</th>
<th>Organic matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-1 O</td>
<td>0%</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>loam</td>
<td>14.50</td>
<td>24.95</td>
</tr>
<tr>
<td>A</td>
<td>11.59%</td>
<td>42</td>
<td>48</td>
<td>10</td>
<td>loam</td>
<td>14.50</td>
<td>24.95</td>
</tr>
<tr>
<td>Bw1</td>
<td>19.78%</td>
<td>32</td>
<td>53</td>
<td>15</td>
<td>silt loam</td>
<td>9.06</td>
<td>15.59</td>
</tr>
<tr>
<td>Bw2</td>
<td>5.39%</td>
<td>25</td>
<td>57</td>
<td>18</td>
<td>silt loam</td>
<td>2.40</td>
<td>4.73</td>
</tr>
<tr>
<td>N-2 O</td>
<td>0%</td>
<td>$$$$</td>
<td>$$$$</td>
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<tr>
<td>A</td>
<td>17.17%</td>
<td>46</td>
<td>42</td>
<td>12</td>
<td>loam</td>
<td>9.48</td>
<td>16.30</td>
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<tr>
<td>Bw1</td>
<td>16.93%</td>
<td>43</td>
<td>47</td>
<td>10</td>
<td>loam</td>
<td>7.23</td>
<td>12.43</td>
</tr>
<tr>
<td>Bw2</td>
<td>0.64%</td>
<td>22</td>
<td>58</td>
<td>20</td>
<td>silt loam</td>
<td>0.63</td>
<td>1.17</td>
</tr>
<tr>
<td>N-3 O</td>
<td>Cobbley 7%</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
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<td>$$$$</td>
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</tr>
<tr>
<td>A</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
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<td>$$$$</td>
<td>$$$$</td>
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<tr>
<td>N-4 O</td>
<td>0%</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
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<td>$$$$</td>
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</tr>
<tr>
<td>A</td>
<td>26.78%</td>
<td>37</td>
<td>51</td>
<td>12</td>
<td>silt loam</td>
<td>17.44</td>
<td>29.99</td>
</tr>
<tr>
<td>B/A</td>
<td>15.58%</td>
<td>25</td>
<td>53</td>
<td>12</td>
<td>silt loam</td>
<td>9.90</td>
<td>17.02</td>
</tr>
<tr>
<td>Bw1</td>
<td>12.43%</td>
<td>32</td>
<td>53</td>
<td>15</td>
<td>silt loam</td>
<td>5.00</td>
<td>8.60</td>
</tr>
<tr>
<td>Bw2</td>
<td>1.37%</td>
<td>31</td>
<td>57</td>
<td>12</td>
<td>silt loam</td>
<td>0.71</td>
<td>1.23</td>
</tr>
<tr>
<td>N-5</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
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</tr>
<tr>
<td>A</td>
<td>15.50%</td>
<td>29</td>
<td>61</td>
<td>10</td>
<td>silt loam</td>
<td>13.18</td>
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</tr>
<tr>
<td>Bw1</td>
<td>17.78%</td>
<td>32</td>
<td>52</td>
<td>16</td>
<td>silt loam</td>
<td>6.81</td>
<td>11.71</td>
</tr>
<tr>
<td>N-7 O</td>
<td>0%</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
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<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
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<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
</tr>
<tr>
<td>N-8 O</td>
<td>0%</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
</tr>
<tr>
<td>A</td>
<td>29.81%</td>
<td>37</td>
<td>46</td>
<td>17</td>
<td>loam</td>
<td>9.74</td>
<td>16.75</td>
</tr>
<tr>
<td>Bw1</td>
<td>20.60%</td>
<td>40</td>
<td>43</td>
<td>17</td>
<td>loam</td>
<td>5.56</td>
<td>9.57</td>
</tr>
<tr>
<td>Bw2</td>
<td>0.42%</td>
<td>76</td>
<td>20</td>
<td>4</td>
<td>loamy sand</td>
<td>0.76</td>
<td>1.30</td>
</tr>
<tr>
<td>N-9 O</td>
<td>0%</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
</tr>
<tr>
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<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
</tr>
<tr>
<td>Bw1</td>
<td>26.77%</td>
<td>38</td>
<td>45</td>
<td>17</td>
<td>loam</td>
<td>9.12</td>
<td>15.69</td>
</tr>
<tr>
<td>N/A</td>
<td>34.83%</td>
<td>38</td>
<td>47</td>
<td>15</td>
<td>loam</td>
<td>4.90</td>
<td>7.38</td>
</tr>
<tr>
<td>Bw2</td>
<td>15.84%</td>
<td>33</td>
<td>53</td>
<td>14</td>
<td>silt loam</td>
<td>1.11</td>
<td>1.91</td>
</tr>
<tr>
<td>N-10 C</td>
<td>0%</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
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<td>A</td>
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<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
</tr>
<tr>
<td>Bw1</td>
<td>16.74%</td>
<td>38</td>
<td>54</td>
<td>8</td>
<td>silt loam</td>
<td>12.00</td>
<td>20.66</td>
</tr>
<tr>
<td>Bw2</td>
<td>9.76%</td>
<td>40</td>
<td>47</td>
<td>13</td>
<td>loam</td>
<td>3.73</td>
<td>6.42</td>
</tr>
<tr>
<td>N-11 O</td>
<td>Stony 50%</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
<td>$$$$</td>
</tr>
<tr>
<td>A1</td>
<td>$$$$</td>
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<td>A2</td>
<td>$$$$</td>
<td>$$$$</td>
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</tbody>
</table>

# = grain size analysis performed by hydrometer using a modified method of Day, 1965
Ø = the percentage of coarse fragments greater than 2.5 cm (one inch) found throughout the soil pit
\% = % organic carbon was performed by titration using Walkely-Black method (Soil Conservation Service, 1972)
$$$$ = data not available
Gravelly = 2.5-7.5 cm (1-3 inches)
Cobblely = 7.5-25.5 cm (3-10 inches)
Stony = greater than 25.5 cm (10 inches)

(all definitions are as described in USDA Soil Conservation Service Agriculture Handbook #436, Soil Survey Staff, 1975)
Table 14: Grain-size analysis on south side soil pits (#).

<table>
<thead>
<tr>
<th>Site</th>
<th>Horizon</th>
<th>% stones (G)</th>
<th>% sand</th>
<th>% silt</th>
<th>% clay</th>
<th>Texture</th>
<th>% organic carbon (T)</th>
<th>% organic matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>O</td>
<td>Cobbly 2%</td>
<td>6666</td>
<td>6666</td>
<td></td>
<td></td>
<td>6666</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24.48%</td>
<td>40</td>
<td>43</td>
<td></td>
<td>7; sandy loam</td>
<td>22.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11.63%</td>
<td>25</td>
<td>56</td>
<td></td>
<td>19; silt loam</td>
<td>7.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.09%</td>
<td>24</td>
<td>60</td>
<td></td>
<td>16; silt loam</td>
<td>2.75</td>
</tr>
<tr>
<td>S-2</td>
<td>O</td>
<td>Cobbly 35%</td>
<td>6666</td>
<td>6666</td>
<td></td>
<td></td>
<td>6666</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45.37%</td>
<td>48</td>
<td>37</td>
<td></td>
<td>15; loam</td>
<td>14.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.40%</td>
<td>36</td>
<td>48</td>
<td></td>
<td>16; silt loam</td>
<td>7.96</td>
</tr>
<tr>
<td>S-3</td>
<td>O</td>
<td>Stony 10%</td>
<td>6666</td>
<td>6666</td>
<td></td>
<td></td>
<td>6666</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23.06%</td>
<td>52</td>
<td>36</td>
<td></td>
<td>12; sandy loam</td>
<td>11.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13.44%</td>
<td>47</td>
<td>40</td>
<td></td>
<td>13; loam</td>
<td>8.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.14%</td>
<td>24</td>
<td>61</td>
<td></td>
<td>15; silt loam</td>
<td>2.34</td>
</tr>
<tr>
<td>S-4</td>
<td>O</td>
<td>Gravelly 10%</td>
<td>6666</td>
<td>6666</td>
<td></td>
<td></td>
<td>6666</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>26.70%</td>
<td>33</td>
<td>56</td>
<td></td>
<td>11; silt loam</td>
<td>9.06</td>
</tr>
<tr>
<td>S-5</td>
<td>O</td>
<td>Gravelly 5%</td>
<td>6666</td>
<td>6666</td>
<td></td>
<td></td>
<td>6666</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>31.52%</td>
<td>46</td>
<td>48</td>
<td></td>
<td>6; sandy loam</td>
<td>12.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20.43%</td>
<td>38</td>
<td>57</td>
<td></td>
<td>5; silt loam</td>
<td>5.35</td>
</tr>
<tr>
<td>S-6</td>
<td>O</td>
<td>Gravelly &lt;1%</td>
<td>6666</td>
<td>6666</td>
<td></td>
<td></td>
<td>6666</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24.65%</td>
<td>41</td>
<td>48</td>
<td></td>
<td>11; loam</td>
<td>9.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17.03%</td>
<td>28</td>
<td>55</td>
<td></td>
<td>17; silt loam</td>
<td>5.87</td>
</tr>
<tr>
<td>S-7</td>
<td>O</td>
<td>Gravelly 5%</td>
<td>6666</td>
<td>6666</td>
<td></td>
<td></td>
<td>6666</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12.87%</td>
<td>28</td>
<td>51</td>
<td></td>
<td>21; silt loam</td>
<td>1.74</td>
</tr>
<tr>
<td>S-8</td>
<td>O</td>
<td>Gravelly &lt;1%</td>
<td>6666</td>
<td>6666</td>
<td></td>
<td></td>
<td>6666</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16.96%</td>
<td>34</td>
<td>58</td>
<td></td>
<td>8; silt loam</td>
<td>9.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16.28%</td>
<td>28</td>
<td>64</td>
<td></td>
<td>8; silt loam</td>
<td>7.86</td>
</tr>
<tr>
<td>S-9</td>
<td>O</td>
<td>Gravelly 7%</td>
<td>6666</td>
<td>6666</td>
<td></td>
<td></td>
<td>6666</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22.30%</td>
<td>50</td>
<td>44</td>
<td></td>
<td>6; sandy loam</td>
<td>22.30</td>
</tr>
</tbody>
</table>

§ = grain size analysis performed by hydrometer using a modified method of Day, 1965
G = the percentage of coarse fragments greater than 2.5 cm (one inch) found throughout the soil pit
T = % organic carbon was performed by titration using Walkely-Black method (Soil Conservation Service, 1972)
§§§§ = data not available
Gravelly = 2.5-7.5 cm (1-3 inches)
Cobbly = 7.5-25.5 cm (3-10 inches)
Stony = greater than 25.5 cm (10 inches)
(all definitions are as described in USDA Soil Conservation Service Agriculture Handbook #436, Soil Survey Staff, 1975)
APPENDIX J

CS-137 RESULTS - SOIL SAMPLES
Table J1: Results of Cs-137 analysis on N-4 and S-7.
Table also includes results of additional nuclei analyzed along with Cs-137.

<table>
<thead>
<tr>
<th>Sample: N-4</th>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Cs-137 Counting</th>
<th>Ac-228 Counting</th>
<th>K-40 Counting</th>
<th>Bi-214 Counting</th>
<th>Th-232 Counting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>pCi/g</td>
<td>Uncertainty</td>
<td>pCi/g</td>
<td>Uncertainty</td>
<td>pCi/g</td>
</tr>
<tr>
<td>0-2.5</td>
<td>A</td>
<td>0.71</td>
<td>2.75%</td>
<td>0.45</td>
<td>11.40%</td>
<td>12.03</td>
<td>2.14%</td>
</tr>
<tr>
<td>2.5-10</td>
<td>B/A</td>
<td>0.13</td>
<td>8.88%</td>
<td>0.48</td>
<td>8.53%</td>
<td>10.33</td>
<td>1.53%</td>
</tr>
<tr>
<td>10-14</td>
<td>B/A</td>
<td>0.11</td>
<td>8.66%</td>
<td>0.43</td>
<td>8.74%</td>
<td>11.01</td>
<td>1.54%</td>
</tr>
<tr>
<td>14-17.5</td>
<td>B/A</td>
<td>&lt; 0.01</td>
<td></td>
<td></td>
<td>0.47</td>
<td>5.32%</td>
<td>1.39%</td>
</tr>
<tr>
<td>17.5-23</td>
<td>Bw1</td>
<td>0.05</td>
<td>24.17%</td>
<td>0.55</td>
<td>8.57%</td>
<td>10.70</td>
<td>2.39%</td>
</tr>
<tr>
<td>23-25.5</td>
<td>Bw1</td>
<td>0.03</td>
<td>23.90%</td>
<td>0.53</td>
<td>9.38%</td>
<td>10.89</td>
<td>1.47%</td>
</tr>
<tr>
<td>25.5-30.5</td>
<td>Bw1</td>
<td>0.05</td>
<td>26.70%</td>
<td>0.50</td>
<td>8.12%</td>
<td>10.66</td>
<td>1.50%</td>
</tr>
<tr>
<td>66-94</td>
<td>Bw2</td>
<td>&lt; 0.01</td>
<td></td>
<td></td>
<td>0.48</td>
<td>7.34%</td>
<td>1.32%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample: S-7</th>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Cs-137 Counting</th>
<th>Ac-228 Counting</th>
<th>K-40 Counting</th>
<th>Bi-214 Counting</th>
<th>Th-232 Counting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>pCi/g</td>
<td>Uncertainty</td>
<td>pCi/g</td>
<td>Uncertainty</td>
<td>pCi/g</td>
</tr>
<tr>
<td>0-7.5</td>
<td>A</td>
<td>0.19</td>
<td>12.08%</td>
<td>0.54</td>
<td>12.97%</td>
<td>11.75</td>
<td>2.80%</td>
</tr>
<tr>
<td>7.5-12.5</td>
<td>Bw1</td>
<td>0.07</td>
<td>18.79%</td>
<td>0.54</td>
<td>10.77%</td>
<td>11.55</td>
<td>2.01%</td>
</tr>
<tr>
<td>12.5-17.5</td>
<td>Bw1</td>
<td>0.05</td>
<td>13.21%</td>
<td>0.46</td>
<td>11.17%</td>
<td>10.86</td>
<td>1.77%</td>
</tr>
<tr>
<td>17.5-23</td>
<td>Bw1</td>
<td>&lt; 0.01</td>
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<td></td>
<td>0.46</td>
<td>11.04%</td>
<td>2.02%</td>
</tr>
<tr>
<td>23-25.5</td>
<td>Bw1</td>
<td>0.06</td>
<td>23.45%</td>
<td>0.44</td>
<td>8.21%</td>
<td>10.43</td>
<td>1.90%</td>
</tr>
<tr>
<td>66-73.5</td>
<td>Bw2</td>
<td>0.01</td>
<td>42.06%</td>
<td>0.36</td>
<td>10.25%</td>
<td>9.64</td>
<td>1.39%</td>
</tr>
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</table>
## Table J2: Cs-137 analysis normalized to amount of clay.

<table>
<thead>
<tr>
<th>Sample: N-4</th>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Cs-137 pCi/g soil</th>
<th>Counting Uncertainty % clay</th>
<th>Start Wt. (grams)</th>
<th>Amount of clay (grams)</th>
<th>gram of clay pCi per</th>
<th>Amount of clay (grams)</th>
<th>gram of clay pCi per</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2.5</td>
<td>A</td>
<td>0.71</td>
<td>2.75%</td>
<td>12%</td>
<td>308.1</td>
<td>36.97</td>
<td>26.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5-10</td>
<td>B/A</td>
<td>0.13</td>
<td>5.88%</td>
<td>12%</td>
<td>362.6</td>
<td>43.51</td>
<td>5.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-14</td>
<td>B/A</td>
<td>0.11</td>
<td>8.66%</td>
<td>14%</td>
<td>350.3</td>
<td>49.04</td>
<td>5.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14-17.5</td>
<td>B/A</td>
<td>&lt; 0.01</td>
<td>11%</td>
<td>12%</td>
<td>355.1</td>
<td>39.06</td>
<td>&lt; 0.345</td>
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</tr>
<tr>
<td>17.5-23</td>
<td>Bw1</td>
<td>0.05</td>
<td>24.17%</td>
<td>15%</td>
<td>361.9</td>
<td>54.28</td>
<td>2.86</td>
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<td>23-25.5</td>
<td>Bw1</td>
<td>0.03</td>
<td>23.90%</td>
<td>15%</td>
<td>360.5</td>
<td>54.08</td>
<td>1.75</td>
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</tr>
<tr>
<td>25.5-30.5</td>
<td>Bw1</td>
<td>0.05</td>
<td>26.70%</td>
<td>15%</td>
<td>390.9</td>
<td>58.64</td>
<td>2.76</td>
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</tr>
<tr>
<td>86-94</td>
<td>Bw2</td>
<td>&lt; 0.01</td>
<td>12%</td>
<td>9%</td>
<td>388.6</td>
<td>46.06</td>
<td>&lt; 0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample: S-7</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-7.5</td>
<td>A</td>
<td>0.19</td>
<td>12.08%</td>
<td>9%</td>
<td>309.8</td>
<td>27.88</td>
<td>5.30</td>
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<td></td>
</tr>
<tr>
<td>7.5-12.5</td>
<td>Bw1</td>
<td>0.07</td>
<td>18.79%</td>
<td>8%</td>
<td>327.6</td>
<td>26.21</td>
<td>1.93</td>
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<tr>
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<td>9%</td>
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<td>15%</td>
<td>9%</td>
<td>33.4</td>
<td>5.01</td>
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<tr>
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<td>1%</td>
<td>355.3</td>
<td>3.55</td>
<td>0.05</td>
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</table>
Figure J1: Cs-137 distribution, samples N-4 and S-7.
Figure J2: Cs-137 distribution per gram of clay, samples N-4 and S-7.
APPENDIX K

DIFFERENCING MAP
Figure K2: Shaded Differencing Map

Shaded Area Represents The Cut Regions

1000'
APPENDIX L

ISOPACH -- TREE-STUMP ANALYSIS
Figure L1: Sediment Cut or Fill Determined from Tree-Stump Analysis

Contours are not enclosed where data is unavailable.

Shaded Area Represents The Cut Regions.

Stream drainage was added from the 1924 pre-impoundment map.
Bear Creek

Original Bull Run River channel

Dam

Log Boom

Small side channels

Sediment thickness (volume):
- 16.8 cm (11,605 m³)
- 14.2 cm (41,411 m³)
- 0 cm
- 30.7 cm (22,811 m³)
- 25.1 cm (9,174 m³)

Figure L2: Tree-stump analysis divisions in far western quarter.
Sediment thickness (volume):

- 12.2 cm (19,960 m³)
- 18.5 cm (29,743 m³)
- 0 cm
- 17.0 cm (10,140 m³)
- 21.3 cm (15,768 m³)

3716 square meters

Figure L3: Tree-stump analysis divisions in middle western quarter.
Old Bull Run
River channel

Small side channel

3716 square meters

Sediment thickness (volume):

- 9.7 cm (8,258 m³)
- 23.9 cm (11,565 m³)
- 0 cm
- 0 cm (steep cliff walls)
- 9.7 cm (2,874 m³)

Figure L4: Tree-stump analysis divisions in middle eastern quarter.
Figure L5: Tree-stump analysis divisions in far eastern quarter.
Figure M1: Simplified bar graphs of the core logs.
Figure M1 continued
Figure M1 continued
APPENDIX N

X-RADIOGRAPHS OF CORES
Figure N1: Contact print of X-radiograph Core 38-37c.

Core 38-37c

Re-mixed material

A

E2

M

E1

B

Pre-impoundment

[--------]

2.54 cm = 1 inch
Core 5-9c (A)
[top 4 cm (1.5 inches) are not shown]

Re-mixed material

Figure N2: Contact print of X-radiograph Core 5-9c.
Core 5-9c (B)
[bottom 22cm (8.7 inches) are not shown]

Figure N2 continued
Core 3-11c (A)
[top 2cm (0.8 inches) are not shown]

Re-mixed material

Figure N3: Contact print of X-radiograph Core 3-11c.
Core 3-11c (B)
[bottom 12cm (4.7 inches) are not shown]

Dewatering cracks

2.54 cm = 1 inch

Figure N3 continued
Figure N4: Contact print of X-radiograph Core 35-5cb.
Figure N5: Contact print of X-radiograph Core 40-6c.

2.54 cm = 1 inch
APPENDIX O

BULK DENSITY - CORES
Table 01: Bulk density calculations for core 3-11c

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Bulk density wet (g/cm³)</th>
<th>Bulk density dry (g/cm³)</th>
<th>ID (*)</th>
<th>Average bulk density for each layer wet</th>
<th>Average bulk density for each layer dry</th>
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<td>+ or - 0.08</td>
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<td>+ or - 0.07</td>
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<td>sd + or -</td>
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<td>0.19</td>
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</tr>
</tbody>
</table>

*ID refers to the different layers location within the core:
A = after, E2 = the second event, M = middle layer,
E1 = first event, and B = before the events.
Figure O1: Core 3-11c Bulk Density

Bulk Density (g/cm³)

Depth (cm)

Wet
Dry
Table O2: Bulk density calculations for core 5-9c

<table>
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<tr>
<th>Depth (cm)</th>
<th>Bulk density wet (g/cm³)</th>
<th>Bulk density dry (g/cm³)</th>
<th>ID (*)</th>
<th>Average bulk density for each layer</th>
<th>Average bulk density for each layer</th>
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<td>+ or - 0.11</td>
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* ID refers to the different layers location within the core:
  A = after, E2 = the second event, M = middle layer,
  E1 = first event, and B = before the events.
Figure Q2: Core 5-9c Bulk Density
<table>
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<th>Depth (cm)</th>
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* = ID refers to the different layers location within the core:
A = after, E2 = the second event, M = middle layer,
E1 = first event, and B = before the events.
Table O4: Bulk density calculations for core 9-1c.

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<th>Depth (cm)</th>
<th>Bulk density wet (g/cm³)</th>
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<th>Average bulk density for each layer</th>
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<td>0.48</td>
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<td>20-22</td>
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^ = ID refers to the different layers location within the core:
A = after, E2 = the second event, M = middle layer,
E1 = first event, and B = before the events.
APPENDIX P

GRAIN-SIZE ANALYSIS
BAG SAMPLES
Table P1: Grain-size analysis of bagged samples. Separated into east and west ends of the reservoir.

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- Gravelly Sand
- Slightly Gravely Mud
- Slightly Gravely Sandy Mud
- Slightly Gravely Muddy Sand
- Gravelly Muddy Sand
- Gravely Muddy Sand
- Slightly Gravely Muddy Sand
- Gravelly Muddy Sand
Figure P1: Overall grain-size distribution in bagged samples.
Figure P1 continued
Table P2: Grain-size analysis of bagged samples arranged by elevation.

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Figure P2: Bag Samples - Gravel, Sand, & Mud Vertical Distribution

Elevation (meters)

Percent

Gravel
Sand
Mud

310 305 300 295 290 285 280 275 270 265
APPENDIX Q

GRAIN-SIZE ANALYSIS
CORE SAMPLES
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<th>Clay</th>
<th>Coarse Med.</th>
<th>Fine</th>
<th>V.Fine</th>
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Table Q1: Grain-size analysis of core samples, east end.
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**W. Average**<br>0.1 | 4 | 96 | 0.1 | 4 | 82 | 14 | 0.1 | 4 | 9 | 10 | 41 | 22 | 14 | Slightly Gravelly Mud | 11.29 | 45.57 |

**sd ± of -**<br>0.3 | 4 | 4 | 4 | 0.3 | 4 | 4 | 30 | 0.3 | 4 | 4 | 5 | 3.9 | 5.4 | 6.2 | 5.1 | 4.58 | 20.47 |

**Total**<br>0.3 | 10 | 90 | 0.3 | 10 | 79 | 10 | 0.3 | 10 | 18 | 15 | 32 | 14 | 10 | Slightly Gravelly Mud | 10.96 | 44.42 |

**sd ± of -**<br>1.6 | 10 | 3 | 10 | 9.1 | 3.7 | 1.6 | 10 | 3 | 8.9 | 5.2 | 10.1 | 7.5 | 3.7 | Slightly Gravelly Sandy Mud | 4.14 | 16.3 |
Table Q3: Average grain-size for the different layers.

These averages are separated into samples representing east and west-end.

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<th>Gravel</th>
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<th>Clay</th>
<th>Gravel</th>
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Figure Q1: Grain-size distribution within Before layer.
Figure Q2: Grain-size distribution within E1 layer.
Figure Q3: Grain-size distribution within Middle layer.
Figure Q4: Grain-size distribution within E2 layer.
Figure Q5: Grain-size distribution within After layer.
Figure Q6: Grain-size distribution Overall.
Figure Q6 continued
Table Q4: Grain-size analysis of each layer arranged by elevation.

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<td>2 6 6 45 26 14</td>
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<tr>
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<td>1 99</td>
<td>0.00</td>
<td>1 84 15</td>
<td>0.00</td>
<td>1 8 11 43 22 15</td>
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<td>3 97</td>
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<td>3 83 14</td>
<td>0.00</td>
<td>3 12 15 42 14 14</td>
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<td>6 95</td>
<td>0.00</td>
<td>6 81 14</td>
<td>0.00</td>
<td>6 4 11 44 22 14</td>
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<td>1 99</td>
<td>0.00</td>
<td>1 81 18</td>
<td>0.00</td>
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<td>13 87</td>
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<td>4 6 9 39 26 16</td>
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<td>0.00</td>
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<td>0.00</td>
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<td>2 5 6 42 27 16</td>
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<td>15 8 7 39 19 14</td>
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Table 4 continued
Figure Q7: Sand & Mud Vertical Distribution - Before

- •-Sand
- o-Mud

Elevation (meters)

Percent

310 305 300 295 290 285 280 275 270
Figure Q8: Sand & Mud Vertical Distribution - E1

- Sand
- Mud
Figure Q9: Sand & Mud Vertical Distribution
- Middle
Figure Q10: Sand & Mud Vertical Distribution

- E2

Elevation (meters)
Figure Q11: Sand & Mud Vertical Distribution
- After
Figure Q12: Sand & Mud Vertical Distribution
- Overall
APPENDIX R

GRAIN-SIZE
INDIVIDUAL CORE SAMPLES
Figure R1. Comparison of each layer in Core 3-11c.
Figure R2. Comparison of each layer in Core 5-9c.
Figure R3. Comparison of each layer in Core 8-40cb.
Figure R4. Comparison of each layer in Core 9-1c.
Figure R5. Comparison of each layer in Core 10-39c.
Figure R6: Comparison of each layer in Core 13-33c.
Figure R7: Comparison of each layer in Core 24-8c.
Figure R8: Comparison of each layer in Core 37-15c.
APPENDIX S

CS-137 ANALYSIS
CORE SAMPLES
Table S1: Cs-137 analysis of selected core tube samples.
Also includes results of additional nuclei analyzed along with Cs-137.

<table>
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<tr>
<th>Sample (cm)</th>
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<th>K-40 Counting</th>
<th>Bi-214 Counting</th>
<th>Th-232 Counting</th>
<th>Uncertainty</th>
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<td>&lt; 0.69</td>
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<td>84-85c</td>
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<td>7.07</td>
<td>14.91%</td>
<td>358.73</td>
<td>0.75%</td>
<td>3.71</td>
<td>10.20%</td>
</tr>
<tr>
<td>89-95c</td>
<td>Before &lt; 0.28</td>
<td>7.07</td>
<td>14.91%</td>
<td>358.73</td>
<td>0.75%</td>
<td>3.71</td>
<td>10.20%</td>
</tr>
<tr>
<td>94-95c</td>
<td>Before &lt; 0.28</td>
<td>7.07</td>
<td>14.91%</td>
<td>358.73</td>
<td>0.75%</td>
<td>3.71</td>
<td>10.20%</td>
</tr>
<tr>
<td>104-105c</td>
<td>Before &lt; 0.28</td>
<td>7.07</td>
<td>14.91%</td>
<td>358.73</td>
<td>0.75%</td>
<td>3.71</td>
<td>10.20%</td>
</tr>
</tbody>
</table>
Figure S1: Cs-137 distribution in Core 8-40cb. Not all depths within the core are represented.
Figure S2: Cs-137 distribution in Core 9-1c. Not all depths within the core are represented.
Figure S3: Detailed log of core 8-40cb showing location for Cs-137 sampling.
Figure S4: Detailed log of core 9-1c showing location for Cs-137 sampling.
Table S2: Cs-137 normalized to amount of clay.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Cs-137 pCi/gram</th>
<th>Counting</th>
<th>% Clay</th>
<th>Sample Wt (gram)</th>
<th>Amount of Clay (gram)</th>
<th>pCi per gram</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-11c</td>
<td>20-21</td>
<td>E2</td>
<td>1.37</td>
<td>22.96%</td>
<td>7%</td>
<td>7.167</td>
<td>0.5017</td>
<td>0.69</td>
</tr>
<tr>
<td>33-34</td>
<td>E1</td>
<td>1.72</td>
<td>15.27%</td>
<td>7%</td>
<td>14.284</td>
<td>0.9999</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td>5-9c</td>
<td>18-19</td>
<td>E2</td>
<td>0.72</td>
<td>30.72%</td>
<td>8%</td>
<td>7.329</td>
<td>0.5863</td>
<td>0.42</td>
</tr>
<tr>
<td>23-24</td>
<td>Middle</td>
<td>1.84</td>
<td>21.31%</td>
<td>6%</td>
<td>9.143</td>
<td>0.5486</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>28-29</td>
<td>E1</td>
<td>1.58</td>
<td>24.22%</td>
<td>6%</td>
<td>7.131</td>
<td>0.4279</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>8-40cb</td>
<td>15-16</td>
<td>After</td>
<td>&lt; 0.73</td>
<td>8%</td>
<td>7.922</td>
<td>0.6338</td>
<td>&lt; 0.46</td>
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</tr>
<tr>
<td>19-20</td>
<td>E2</td>
<td>1.28</td>
<td>18.02%</td>
<td>8%</td>
<td>8.774</td>
<td>0.7019</td>
<td>1.10</td>
<td></td>
</tr>
<tr>
<td>21-22</td>
<td>Middle</td>
<td>1.57</td>
<td>18.00%</td>
<td>8%</td>
<td>16.984</td>
<td>1.359</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>28-29</td>
<td>Middle</td>
<td>0.89</td>
<td>19.76%</td>
<td>8%</td>
<td>16.984</td>
<td>1.359</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>32-33</td>
<td>Middle</td>
<td>1.20</td>
<td>19.74%</td>
<td>8%</td>
<td>10.374</td>
<td>0.8299</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>36-37</td>
<td>Middle</td>
<td>1.62</td>
<td>22.14%</td>
<td>8%</td>
<td>9.076</td>
<td>0.7261</td>
<td>1.18</td>
<td></td>
</tr>
<tr>
<td>38-39</td>
<td>Middle</td>
<td>1.76</td>
<td>19.03%</td>
<td>8%</td>
<td>7.930</td>
<td>0.6344</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td>45-46</td>
<td>E1</td>
<td>1.59</td>
<td>22.82%</td>
<td>11%</td>
<td>7.549</td>
<td>0.8304</td>
<td>1.32</td>
<td></td>
</tr>
<tr>
<td>47-48</td>
<td>Before</td>
<td>1.78</td>
<td>14.85%</td>
<td>8%</td>
<td>7.591</td>
<td>0.6073</td>
<td>1.08</td>
<td></td>
</tr>
<tr>
<td>50-51</td>
<td>Before</td>
<td>0.83</td>
<td>21.47%</td>
<td>8%</td>
<td>7.220</td>
<td>0.5776</td>
<td>0.48</td>
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</tr>
<tr>
<td>54-55</td>
<td>Before</td>
<td>1.57</td>
<td>35.32%</td>
<td>8%</td>
<td>5.147</td>
<td>0.4118</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>57-58</td>
<td>Before</td>
<td>1.14</td>
<td>25.86%</td>
<td>8%</td>
<td>6.676</td>
<td>0.5341</td>
<td>0.61</td>
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</tr>
<tr>
<td>59-60</td>
<td>Before</td>
<td>0.86</td>
<td>37.94%</td>
<td>8%</td>
<td>5.153</td>
<td>0.4122</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>60-61</td>
<td>Before</td>
<td>0.84</td>
<td>31.16%</td>
<td>8%</td>
<td>5.977</td>
<td>0.4782</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>61-62</td>
<td>Before</td>
<td>&lt; 0.23</td>
<td>8%</td>
<td>6.063</td>
<td>0.4850</td>
<td>&lt; 0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65-66</td>
<td>Before</td>
<td>&lt; 0.255</td>
<td>8%</td>
<td>6.715</td>
<td>0.5372</td>
<td>&lt; 0.14</td>
<td></td>
<td></td>
</tr>
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Table S2 continued

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Cs-137</th>
<th>Counting</th>
<th>% Clay</th>
<th>Sample Wt. of Clay (gram)</th>
<th>Amount pCi per gram of clay</th>
<th>pCi per gram</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-1c</td>
<td>13-14</td>
<td>After</td>
<td>1.21</td>
<td>21.61%</td>
<td>6%</td>
<td>5.580</td>
<td>0.3348</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>20-21</td>
<td>E2</td>
<td>1.36</td>
<td>29.37%</td>
<td>13%</td>
<td>6.279</td>
<td>0.8163</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>24-25</td>
<td>E2</td>
<td>1.27</td>
<td>16.91%</td>
<td>13%</td>
<td>5.286</td>
<td>0.6872</td>
<td>0.87</td>
</tr>
<tr>
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<td>25-26</td>
<td>Middle</td>
<td>1.86</td>
<td>25.63%</td>
<td>6%</td>
<td>4.777</td>
<td>0.2866</td>
<td>0.53</td>
</tr>
<tr>
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<td>27-28</td>
<td>Middle</td>
<td>2.21</td>
<td>11.83%</td>
<td>6%</td>
<td>4.559</td>
<td>0.2735</td>
<td>0.61</td>
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<td>31-32</td>
<td>Middle</td>
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<td>24.83%</td>
<td>6%</td>
<td>8.711</td>
<td>0.5227</td>
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<td>40-41</td>
<td>Middle</td>
<td>1.67</td>
<td>14.16%</td>
<td>6%</td>
<td>7.182</td>
<td>0.4309</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>47-48</td>
<td>Middle</td>
<td>1.19</td>
<td>26.64%</td>
<td>6%</td>
<td>7.549</td>
<td>0.4529</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>53-54</td>
<td>Middle</td>
<td>1.07</td>
<td>23.49%</td>
<td>13%</td>
<td>6.354</td>
<td>0.8260</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>56-57</td>
<td>E1</td>
<td>&lt; 0.43</td>
<td>13%</td>
<td>6.051</td>
<td>0.7866</td>
<td>&lt; 0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>57-58</td>
<td>Before</td>
<td>2.36</td>
<td>23.95%</td>
<td>8%</td>
<td>6.013</td>
<td>0.4810</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>59-60</td>
<td>Before</td>
<td>0.85</td>
<td>23.54%</td>
<td>8%</td>
<td>10.895</td>
<td>0.8716</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>63-64</td>
<td>Before</td>
<td>1.56</td>
<td>17.17%</td>
<td>8%</td>
<td>9.890</td>
<td>0.7912</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>67-68</td>
<td>Before</td>
<td>1.80</td>
<td>15.10%</td>
<td>8%</td>
<td>6.732</td>
<td>0.5385</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>70-71</td>
<td>Before</td>
<td>1.64</td>
<td>21.75%</td>
<td>8%</td>
<td>7.438</td>
<td>0.5950</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>75-76</td>
<td>Before</td>
<td>1.13</td>
<td>22.41%</td>
<td>8%</td>
<td>7.528</td>
<td>0.6022</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>80-81</td>
<td>Before</td>
<td>0.84</td>
<td>25.20%</td>
<td>8%</td>
<td>6.278</td>
<td>0.6622</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>82-83</td>
<td>Before</td>
<td>1.12</td>
<td>22.83%</td>
<td>8%</td>
<td>7.002</td>
<td>0.5602</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>83-84</td>
<td>Before</td>
<td>0.96</td>
<td>28.25%</td>
<td>8%</td>
<td>6.434</td>
<td>0.5147</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>84-85</td>
<td>Before</td>
<td>&lt; 0.19</td>
<td>8%</td>
<td>7.355</td>
<td>0.5884</td>
<td>&lt; 0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>95-97</td>
<td>Pre-impound</td>
<td>&lt; 0.098</td>
<td></td>
<td></td>
<td>8.741</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 13-33c | 4-5        | E2          | 1.74   | 16.53%   | 10%    | 7.362                      | 0.7362                      | 1.28          |
|        | 9-10       | E1          | 1.85   | 18.90%   | 10%    | 7.371                      | 0.7371                      | 1.36          |
|        | 11-12      | Before      | 1.88   | 17.18%   | 12%    | 5.952                      | 0.7142                      | 1.34          |
| 24-8c  | 6-7        | Middle      | 1.15   | 15.42%   | 10%    | 8.903                      | 0.8903                      | 1.03          |
|        | 11-12      | Before      | 0.96   | 33.32%   | 15%    | 6.201                      | 0.6201                      | 0.59          |
| 37-15c | 3-3.5      | Middle      | 2.31   | 18.42%   | 13%    | 5.763                      | 0.7492                      | 1.73          |
|        | 4-5        | Before      | < 0.28 | 12%      | 8.271  | 0.9925                     | < 0.27                      |              |
|        | 5-6        | Before      | < 0.27 | 12%      | 6.926  | 0.8311                     | < 0.23                      |              |
Figure S5: Distribution of Cs-137 per gram clay in core 8-40cb. Not all depths within the core are represented.
Figure S6: Distribution of Cs-137 per gram clay in core 9-1c. Not all depths within the core are represented.
APPENDIX T

ISOPACH COMBINED VOLUMES
Figure T1: Combined isopach divisions in far western quarter.

Sediment thickness (volume):
- 15-30 cm (15,826 m³)
- 0-15 cm (22,028 m³)
- 0-10 cm (2,429 m³)
- 0 cm
- 15-30 cm (8,341 m³)

Bear Creek
Log Boom
Dam

Original Bull Run River channel
Small side channels

3716 square meters
Sediment thickness (volume)

- 0-15 cm (12,475 m³)
- 15-30 cm (3,657 m³)
- 15-30 cm (8,020 m³)
- 10-20 cm (9,053 m³)
- 15-30 cm (16,895 m³)

Figure T2: Combined isopach divisions in middle western quarter.
Sediment thickness (volume):

- 7.5-20 cm (11,871 m³)
- 15-30 cm (11,121 m³)
- 15-30 cm (7,378 m³)
- 0 cm (steep cliff walls)
- 0-15 cm (2,246 m³)

3716 square meters

Figure T3: Combined isopach divisions in middle eastern quarter.
Figure T4: Combined isopach divisions in far eastern quarter.
APPENDIX U

TURBIDITY READINGS
Table U1: Turbidity reading at Station 59-2.
Yearly and monthly averages listed highest to lowest.

<table>
<thead>
<tr>
<th>Year</th>
<th>Months Observed</th>
<th>Year Average (NTU)</th>
<th>Month</th>
<th>Monthly Average (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>all</td>
<td>0.71</td>
<td>12</td>
<td>0.88</td>
</tr>
<tr>
<td>1977</td>
<td>only May-Dec.</td>
<td>0.63</td>
<td>11</td>
<td>0.69</td>
</tr>
<tr>
<td>1981</td>
<td>all except Sept.</td>
<td>0.59</td>
<td>10</td>
<td>0.64</td>
</tr>
<tr>
<td>1987</td>
<td>all except Jan.</td>
<td>0.55</td>
<td>1</td>
<td>0.57</td>
</tr>
<tr>
<td>1982</td>
<td>all</td>
<td>0.54</td>
<td>2</td>
<td>0.55</td>
</tr>
<tr>
<td>1986</td>
<td>all</td>
<td>0.44</td>
<td>9</td>
<td>0.49</td>
</tr>
<tr>
<td>1980</td>
<td>all</td>
<td>0.39</td>
<td>8</td>
<td>0.43</td>
</tr>
<tr>
<td>1984</td>
<td>all</td>
<td>0.39</td>
<td>3</td>
<td>0.42</td>
</tr>
<tr>
<td>1985</td>
<td>all except Feb. &amp; Dec.</td>
<td>0.39</td>
<td>4</td>
<td>0.30</td>
</tr>
<tr>
<td>1988</td>
<td>all</td>
<td>0.37</td>
<td>7</td>
<td>0.29</td>
</tr>
<tr>
<td>1978</td>
<td>all</td>
<td>0.36</td>
<td>5</td>
<td>0.28</td>
</tr>
<tr>
<td>1983</td>
<td>all</td>
<td>0.34</td>
<td>6</td>
<td>0.27</td>
</tr>
<tr>
<td>1989</td>
<td>all except Oct., Nov., &amp; Dec.</td>
<td>0.33</td>
<td></td>
<td></td>
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</table>
Figure U1: Turbidity Distribution 59-2

Turbidity (NTU) vs. Depth (meters)
Table U2: Turbidity readings at Station 59-1. Yearly and monthly averages listed highest to lowest.

<table>
<thead>
<tr>
<th>Year</th>
<th>Months Observed</th>
<th>Year Average (NTU)</th>
<th>Month</th>
<th>Monthly Average (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>only June-Dec.</td>
<td>0.73</td>
<td>11</td>
<td>0.88</td>
</tr>
<tr>
<td>1981</td>
<td>all</td>
<td>0.65</td>
<td>12</td>
<td>0.79</td>
</tr>
<tr>
<td>1979</td>
<td>all</td>
<td>0.65</td>
<td>10</td>
<td>0.71</td>
</tr>
<tr>
<td>1987</td>
<td>all</td>
<td>0.64</td>
<td>2</td>
<td>0.65</td>
</tr>
<tr>
<td>1982</td>
<td>all</td>
<td>0.59</td>
<td>9</td>
<td>0.59</td>
</tr>
<tr>
<td>1986</td>
<td>all</td>
<td>0.57</td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td>1977</td>
<td>all</td>
<td>0.52</td>
<td>3</td>
<td>0.46</td>
</tr>
<tr>
<td>1980</td>
<td>all</td>
<td>0.40</td>
<td>8</td>
<td>0.34</td>
</tr>
<tr>
<td>1984</td>
<td>all</td>
<td>0.39</td>
<td>4</td>
<td>0.31</td>
</tr>
<tr>
<td>1978</td>
<td>all</td>
<td>0.38</td>
<td>6</td>
<td>0.28</td>
</tr>
<tr>
<td>1983</td>
<td>all except Feb., Nov., &amp; Dec.</td>
<td>0.36</td>
<td>5</td>
<td>0.27</td>
</tr>
<tr>
<td>1985</td>
<td>all</td>
<td>0.36</td>
<td>7</td>
<td>0.26</td>
</tr>
<tr>
<td>1988</td>
<td>all</td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>only Jan.-Sept.</td>
<td>0.29</td>
<td></td>
<td></td>
</tr>
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</table>
Figure U2: Turbidity Distribution 59-1
Table U3: Turbidity readings at Station 59-0.
Yearly and monthly averages listed highest to lowest.

<table>
<thead>
<tr>
<th>Year</th>
<th>Months Observed</th>
<th>Year Average (NTU)</th>
<th>Month</th>
<th>Monthly Average (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
<td>2.59</td>
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<tr>
<td>1966</td>
<td>all</td>
<td>5.32</td>
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<td>2.53</td>
</tr>
<tr>
<td>1967</td>
<td>all</td>
<td>3.38</td>
<td>11</td>
<td>2.32</td>
</tr>
<tr>
<td>1968</td>
<td>all</td>
<td>1.96</td>
<td>12</td>
<td>2.12</td>
</tr>
<tr>
<td>1969</td>
<td>all</td>
<td>0.77</td>
<td>8</td>
<td>1.19</td>
</tr>
<tr>
<td>1970</td>
<td>all</td>
<td>0.70</td>
<td>3</td>
<td>0.99</td>
</tr>
<tr>
<td>1973</td>
<td>only Jan.-Sept.</td>
<td>0.69</td>
<td>7</td>
<td>0.93</td>
</tr>
<tr>
<td>1975</td>
<td>all</td>
<td>0.61</td>
<td>6</td>
<td>0.80</td>
</tr>
<tr>
<td>1981</td>
<td>all</td>
<td>0.54</td>
<td>5</td>
<td>0.80</td>
</tr>
<tr>
<td>1979</td>
<td>all except Oct. &amp; Nov.</td>
<td>0.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>all</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1978</td>
<td>all</td>
<td>0.36</td>
<td></td>
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Figure U3: Turbidity Distribution 59-0
Figure U4: Station 59-1
January Turbidity Distribution

Turbidity (NTU)

Depth (meters)
Figure U5: Station 59-1
February Turbidity Distribution
Figure U6: Station 59-1
March Turbidity Distribution
Figure U7: Station 59-1
April Turbidity Distribution
Figure U8: Station 59-1
May Turbidity Distribution
Figure U9: Station 59-1
June Turbidity Distribution

Turbidity (NTU)

Depth (meters)
Figure U10: Station 59-1
July Turbidity Distribution
Figure U11: Station 59-1
August Turbidity Distribution

Turbidity (NTU)

Depth (meters)
Figure U12: Station 59-1
September Turbidity Distribution

Turbidity (NTU) vs. Depth (meters)
Figure U13: Station 59-1
October Turbidity Distribution
Figure U14: Station 59-1
November Turbidity Distribution
Figure U15: Station 59-1
December Turbidity Distribution

Turbidity (NTU)

Depth (meters)