GEOLOGIC HAZARDS

OF THE

BULL RUN WATERSHED

MULTNOMAH AND CLACKAMAS

COUNTIES, OREGON

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST

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#### **BULLETIN 82**

# GEOLOGIC HAZARDS OF THE BULL RUN WATERSHED, MULTNOMAH AND CLACKAMAS COUNTIES, OREGON

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1974

#### FOREWORD

For the past several years, the Department of Geology and Mineral Industries has been conducting field investigations in areas of the State where there are problems of land stability. During the winter of 1972 a small landslide on the North Fork of the Bull Run River in the Western Cascades introduced a large volume of red clay and silt into Portland's main reservoir. The City's water supply was discolored by the clayey material for several weeks after the event.

Recognizing the need for long-range direction in management, the U.S. Forest Service and the City of Portland Bureau of Water Works initiated a comprehensive 2-year investigation in 1973, of which this study is a part. Geologic data will be used to maintain or improve water quality, to determine the types of land use the region can realistically sustain, to minimize the effect of unavoidable geologic hazards, and to avert geologic disasters.

This bulletin, covering the entire Bull Run Watershed, provides the necessary basic information plotted on a series of geologic and hazards maps together with the explanatory text. Geologic processes and their related hazards must be considered in developing proper and intelligent land use plans. It is the purpose of this report to provide that kind of information.

R. E. Corcoran State Geologist

March 1974

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# GEOLOGIC HAZARDS OF THE BULL RUN WATERSHED MULTNOMAH AND CLACKAMAS COUNTIES, OREGON

#### INTRODUCTION

#### Purpose

The Bull Run Watershed constitutes the sole source of pure water for the Portland metropolitan area. The system of streams and the lakes, both natural and man made, which make up the watershed are administered by the City of Portland Bureau of Water Works. The natural setting of the area is such that it is well-suited for the production of high-quality water (Figure 1).

The Bull Run Watershed also lies within the bounds of the Mount Hood National Forest. Potential for timber production is excellent (Figure 2); logging and all other management activities are administered by the Forest Service of the U.S. Department of Agriculture.

Recognizing the need for long-range direction in management, the U.S. Forest Service and the City of Portland Bureau of Water Works initiated a comprehensive 2-year investigation in 1973, of which this geologic study is a part. Geologic data will be used to maintain or improve water quality, to determine the types of land use the region can realistically sustain, to minimize the effect of unavoidable geologic hazards, and to avert geologic disasters.

In creating a comprehensive land-use plan, geologic data will be combined with additional information from a variety of fields of specialization including engineering, geography, biology, hydrology, forestry, ecology, fisheries, wildlife management, zoology, economics, and bacteriology. Funding for the geologic investigation totaled \$18,000, of which \$9,000 was provided by Federal programs. The remaining \$9,000 was provided in salaries by the Oregon Department of Geology and Mineral Industries.

#### Previous Work

The Bull Run Watershed is lacking in significant mineral wealth and has been subject to restricted access for over 40 years. Geologic mapping has been limited primarily to topical investigations related to water management. Bull Run Dam No. 2 was the subject of numerous engineering geology studies by Shannon and Wilson (1958a, 1958b, 1963), Ruff (1957), and Schlicker (1961). The Ditch Camp slide near the community of Bull Run was investigated by Shannon and Wilson (1965) and Stevens and Thompson (1965). The 1971 slide into the North Fork of the Bull Run River was studied by Dames and Moore (1972a, 1972b, 1973) and Patterson (1973).

Perhaps the earliest geologic investigation in the watershed was a study of the origin of Bull Run Lake by Williams (1920). Parts of the report are quoted in a report on a dam site investigation at Bull Run Lake by Shannon and Wilson (1961). More recently the western part of the watershed was included in a small-scale map of the Western Cascades by Peck and others (1964). Wise (1969) included the east-ernmost parts of the watershed in a generalized geologic map of the Mount Hood area.

#### Sources of Information

The accompanying geologic and hazards maps are based primarily on field mapping, aerial photo interpretation, and topographic map interpretations by the author. Also helpful in developing the text were data from numerous published and unpublished reports and discussions with appropriate personnel from the City of Portland Bureau of Water Works, the U.S. Forest Service, and various consulting firms.

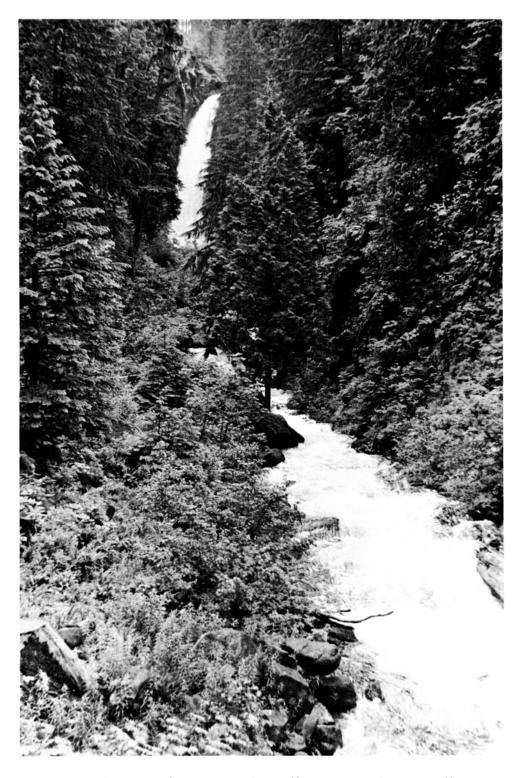


Figure 1. The natural setting of the Bull Run Watershed is well suited to the production of abundant high-quality water. Photo shows Falls Creek after a heavy rain.

#### Acknowledgments

The author greatly appreciates the cooperation and help given by many individuals and organizations in the preparation of this report. Special thanks is expressed to Peter V. Patterson of the U.S. Forest Service for his many helpful suggestions and assistance in the field. Vernon R. McLean, also of the U.S. Forest Service, provided the base maps.

Michael J. Walker of the City of Portland Bureau of Water Works assisted in the administrative aspects of the early stages of the study. William M. Elliott, of the same bureau, supplied the author with numerous unpublished reports and made many helpful and timely suggestions. This assistance is greatly appreciated. G. E. Paulson of the City of Portland Bureau of Water Works supplied turbidity data. The frequent assistance of George Palmer, a consultant supplied by Perron Partnership of Portland, was instrumental in coordinating this study with related investigations in the watershed.

The author also wishes to express appreciation to the staff members of the Oregon Department of Geology and Mineral Industries for their help in preparing this report. Photography and preparation of prints were by Greg Paul, summer employee and student at Portland State University. Ruth Pavlat typed the manuscript. Margaret L. Steere and Carol S. Brookhyser edited and prepared the manuscript for publication. Steven R. Renoud and William H. Pokorny did the drafting and cartography. Special thanks is extended to Herbert G. Schlicker for his informative discussions, particularly in regard to the section on geologic hazards.



Figure 2. High quality of virgin timber near the Headworks is typical of much of the watershed.

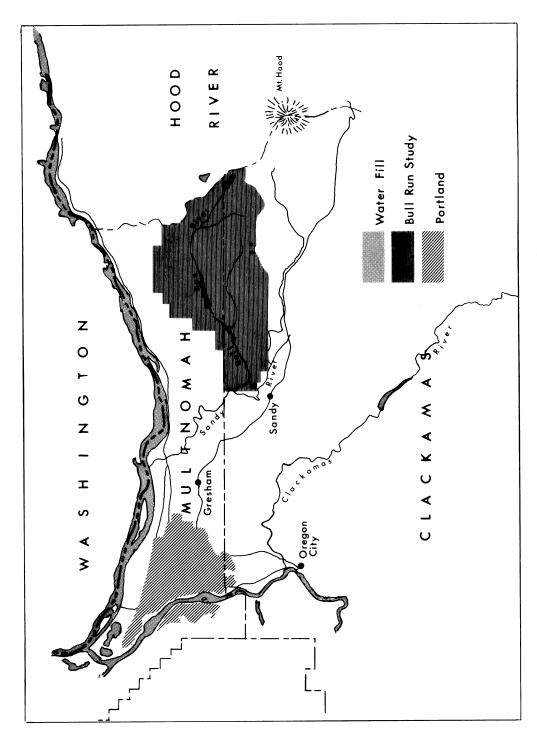


Figure 3. Location map of the Bull Run Watershed.

#### **GEOGRAPHY**

#### Location and Extent of Area

The watershed of the Bull Run River lies in the Western Cascades of northwestern Oregon between Mount Hood and Portland (Figure 3). Geographic features surrounding the watershed include Larch Mountain on the north, Lolo Pass on the east, the Little Sandy River on the south, and the Sandy River on the west. Total extent of the study area is approximately 150 square miles.

The watershed occupies the intersection of the Cherryville, Bridal Veil, Bonneville Dam, and Mount Hood No. 2 15' quadrangles. Access to the general area is provided by U.S. Highway 26 on the south and Interstate 80N along the Columbia River. Numerous county roads pass within a mile or so of the watershed. Admittance to the watershed area is limited to those on official business.

#### Climate and Vegetation

The climate of the Bull Run Watershed is controlled primarily by moist cyclonic storms moving east-ward from the Pacific Ocean in the winter and by dry high pressure air masses in the summer. Mean monthly temperatures for the Headworks at Bull Run Dam No. 2 are given in Figure 4. Daily maximum temperature exceeds 90°F at the Headworks 8 times a year, and a minimum below 32°F is recorded 64 times a year.

Annual precipitation varies from 86 inches at the Headworks to 190 inches at the North Fork Reservoir. As shown in Figure 5, winters are wet and summers are dry. Snowfall is light and temporary at the Headworks but remains until spring at the higher elevations.

The most common confiers in the watershed are Douglas-fir (Pseudotsuga menziesii), Western hemlock (Tsuga heterophylla), Western redcedar (Thuja plicata), and Grand fir (Abies grandis). The most common hardwood trees are Red alder and Bigleaf maple. Shrub species include Vine maple and Red huckleberry. Understory vegetation includes sword fern and Oxalis. Dense fast-growing forests dominate the lower elevations where particularly large trees were not uncommon prior to logging (Figure 2). At higher elevations trees are smaller and include more hardy varieties, such as Noble fir (Abies procera).

#### Topography

The Bull Run River extends westerly for approximately 30 miles from its headwaters near Bull Run Lake to its confluence with the Sandy River 2 miles northwest of the community of Bull Run. Flowing into the Bull Run River from the north are a series of short, high-gradient streams including Bear Creek, Cougar Creek, Log Creek, Falls Creek (Figure 1), West Branch, and the North Fork of the Bull Run River. Streams entering the Bull Run River from the south are longer and lower in gradient. They include the Little Sandy River, the South Fork of the Bull Run River, Fir Creek, and Blazed Alder Creek.

Highest point in the watershed is Hiyu Mountain (elevation 4,600 feet) overlooking Bull Run Lake. Other peaks in the eastern park of the watershed with elevations greater than 4,000 feet include Burnt Peak (4,419 feet), Hickman Butte (4,385 feet), and Blazed Alder Butte (4,258 feet). Big Bend Mountain near the center of the watershed has an elevation of 4,017 feet. The elevation of the Headworks is 748 feet.

The topographic features of the Bull Run Watershed are the products of a complex series of geomorphic processes. Pliocene volcanism formed the west-tilting lava plain into which the Bull Run River and its tributaries have become incised. In the upper reaches, Pleistocene glaciation scoured out numerous small flat-bottomed U-shaped valleys including those of Bull Run Lake, Blue Lake, and Hickman Creek.

To the west at lower elevations, exposures of resistant Columbia River Basalt in the valley of the Bull Run River have retarded downcutting. Concurrently, backwasting of the softer breccias of the Rhododendron Formation, which occupies the valley walls, has produced a series of massive landslides with steep headscarps. The result is a U-shaped valley for which a glacial origin is commonly interpreted. It is doubtful, however, that glaciation proceeded below elevations of 2,000 or 2,500 feet (Figures 6 and 7). This interpretation is consistent with glacial distributions presented by Crandell (1967) for the area.

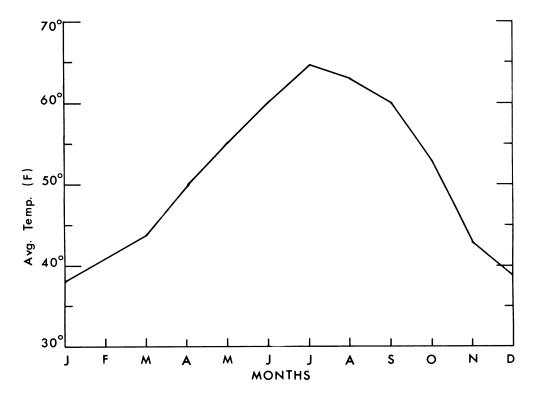


Figure 4. Mean monthly temperature at the Headworks.

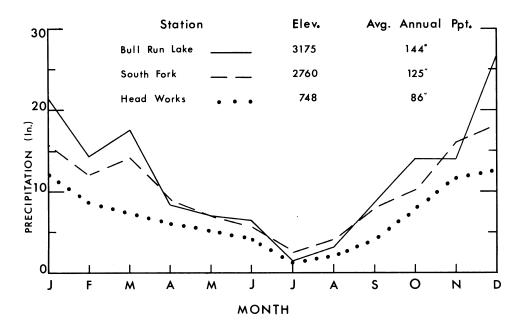


Figure 5. Precipitation for three stations in the Bull Run Watershed.



Figure 6. The upper valley of the Bull Run River is probably not of glacial origin.



Figure 7. Looking westward down Bedrock Creek from a point near the eastern edge of the watershed.

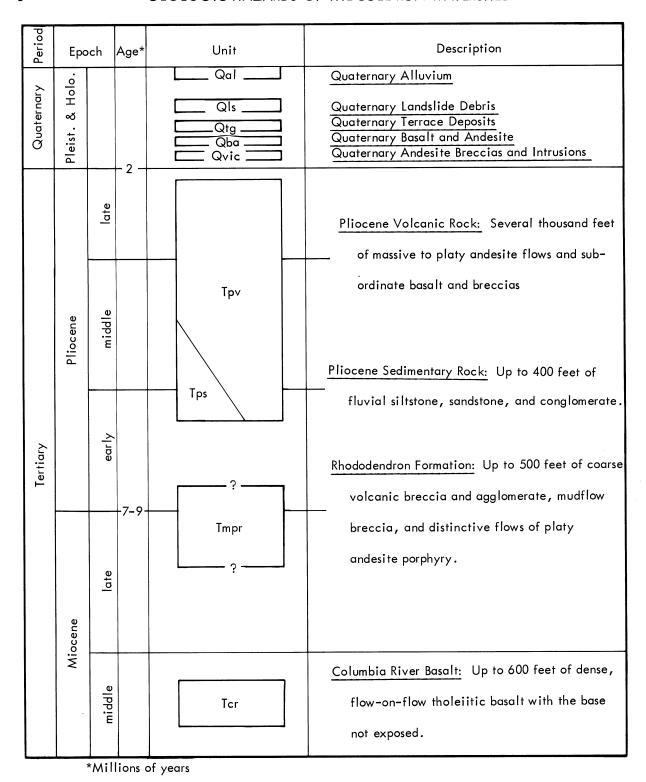


Figure 8. Stratigraphic time chart for the Bull Run Watershed area.

#### Geologic Units

Volcanic rocks ranging in age from middle Miocene to Quaternary underlie the project area (Figure 8). They include the upper part of the middle Miocene Columbia River Basalt (base not exposed), the late Miocene to early Pliocene Rhododendron Formation (500 feet), and Pliocene to Quaternary flow rock and subordinate breccias. Near the community of Bull Run, the Pliocene volcanic rock appears to pass westward into Pliocene sedimentary rock equivalent to the Troutdale Formation and Sandy River Mudstone of Trimble (1963). Mantling the bedrock units locally is a variety of unconsolidated surficial units including alluvium, terrace gravels, and landslide debris.

#### Columbia River Basalt (Tcr)

Russell (1893) first used the term Columbia lava in central Washington and modified the term to Columbia River lava in a later study in Idaho (Russell, 1901a, 1901b). The unit was restricted to lavas of post–John Day and pre-Mascall (late Miocene) age in central Oregon by Merriam (1901).

Waters (1961) subdivided the unit into two formations, the Picture Gorge Formation and the overlying Yakima Basalt. Peck and others (1964) traced the Yakima Basalt into western Oregon, and Waters (1973) described Yakima Basalt flows in the Columbia River Gorge immediately north of the project area. Wise (1969) described exposures of Yakima Basalt in the Cascade Range near Mount Hood. On the basis of geochemistry, Nathan and Fruchter (1974) demonstrate the presence of Columbia River Basalt in the Clackamas River drainage.

The Columbia River Basalt forms the floor of the Bull Run Valley from a point near Bull Run Lake downstream to a point midway between the Headworks and the community of Bull Run. Relatively recent downcutting by the Bull Run River has exposed as much as 600 feet of the unit, but the base is not visible. Exposures of Columbia River Basalt also extend up many of the major tributaries including Blazed Alder Creek and the North Fork of the Bull Run River (Figure 9).

The Columbia River Basalt consists of a series of subaerial flows of dense, tholeiitic basalt (Figure 10). Coarse columnar jointing is widespread (Figure 11). Geochemically the rock corresponds to the Yakima Basalt (Wise, 1969). Pillow structures, vesicular basalt, and relatively soft basalt exposures are common high in the section. Breccias of basaltic glass are present in the valley of the North Fork of the Bull Run River. For a distance of 5 miles along the north shore of the Bull Run River between Bull Run Dam No. 1 and the North Fork of the Bull Run River, fresh diktytaxitic rock is included in the Columbia River Basalt. An interbed 30 feet thick of arkosic sandstone and siltstone underlies these exposures in the vicinity of the boathouse. Attempts to map the sedimentary rock as a separate rock unit were not successful.

Weathering produces brown loamy soils of varying thickness. Lateritic horizons are absent on the present surfaces of weathering, and they are absent in the stratigraphic section as well. It is inferred that rapid uplift and erosion in the area of the present-day Bull Run River precluded the development of thick residual soils in late Miocene times.

Radiometric age dates from various localities in the Northwest indicate an age of approximately 15 million years for the Yakima Basalt unit of the Columbia River Basalt. In view of recent trends to shift the Mio-Pliocene boundary upward in the time scale (Berggren, 1973; Turner, 1970), this age is best regarded as middle Miocene. The Columbia River Basalt is unconformable over the Eagle Creek Formation in the Columbia River Gorge and is unconformable beneath the Rhododendron Formation.

#### Rhododendron Formation (Tmpr)

Barnes and Butler (1930) applied the term Rhododendron Formation to a series of post-Columbia River Basalt "agglomerates and conglomerates" in the Mount Hood area. Hodge (1933) formally described the



Figure 9. Columbia River Basalt is well exposed at the mouth of the North Fork of the Bull Run River (sec. 11, T. 1 S., R. 6 E.).



Figure 10. Much of the Columbia River Basalt is dark, dense, fresh, and coarsely jointed (sec. 25, T. 1 S., R. 5 E.).

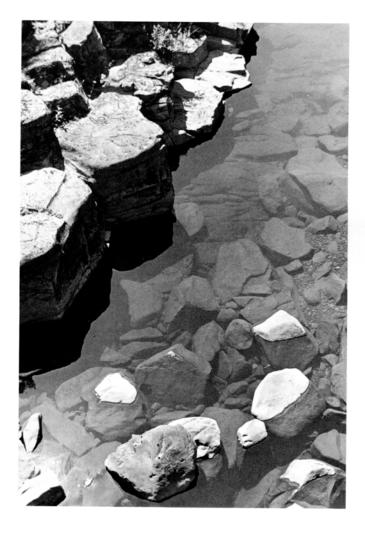
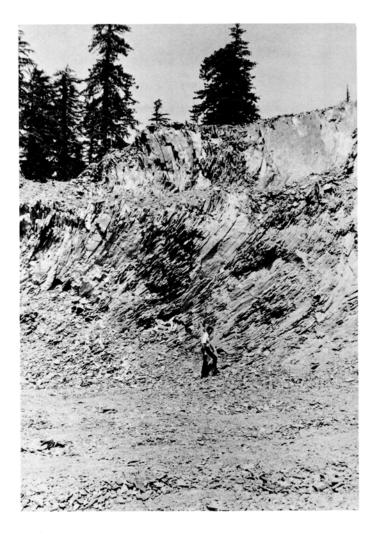


Figure 11. Columnar jointing is common in the Columbia River Basalt (Larson's Bridge, sec. 4, T. 1 S., R. 5 E.).

Figure 12. Firmly cemented breccias of the Rhododendron Formation form steep canyons in the lower Bull Run drainage.







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Figure 13. Pods of red colloidal clay in the Rhododendron Formation are particularly hazardous in terms of turbidity (near Fir Creek, sec. 13, T. 1 S., R. 6 E.).

Figure 14. Platy flow rock of the Rhodo-dendron Formation is quarried for road metal (sec. 10, T. 1 S., R. 6 E.).



Figure 16. Large hazy crystals of plagioclase are abundant in the platy andesites of the Rhododendron Formation.



Figure 15. The platiness of the Rhododendron andesites is a product of cooling; its orientation is not related to regional structure (sec. 10, T. 1 S., R. 6 E.).

unit in print. The Rhododendron Formation was included in the Sardine Formation by Peck and others (1964). Near the type section of Zig Zag Mountain (south of the study area) the unit is 1,400 feet thick (Wise, 1969).

The Rhododendron Formation crops out along the valley walls of the Bull Run River and its major tributaries in the western two-thirds of the Bull Run Watershed (Figure 12). Maximum thickness is approximately 500 feet. The unit thins abruptly to extinction east of Fir Creek and the North Fork of the Bull Run River. Possibly the unit represents localized volcanic accumulations in late Miocene topographic lows. Wise (1969) interprets analogous settings for other exposures of the Rhododendron Formation in the Mount Hood area.

In the Bull Run Watershed, the Rhododendron Formation is composed of several hundred feet of indurated Clarno-like mudflows and volcanic breccias downstream from the Headworks, approximately 500 feet of volcanic breccia and agglomerate near Bull Run Reservoir No. 1, and several hundred feet of varicolored pyroclastics (Figure 13) and platy andesite porphyry (Figures 14, 15, 16) along the North Fork of the Bull Run River. The breccias of the Rhododendron Formation are primarily andesitic in composition. Pumice is exposed locally. Up to 150 feet of massive sandy tuffs and poorly sorted tuffaceous sandstones near the confluence of Cedar Creek and the South Fork of the Bull Run River are assigned to the Rhododendron Formation.

The Rhododendron unconformably overlies west-dipping middle Miocene Columbia River Basalt and underlies west-dipping Pliocene sedimentary rock and Pliocene volcanic rock. Wise (1969) reports a radiometric age of 7± 2 million years for the lower part of the unit at Lost Creek, and an age of 5.8 million years for rocks overlying the unit at Lolo Pass, immediately east of the Bull Run Watershed.

Near Molalla, 25 miles to the southwest, beds underlying the Rhododendron Formation have yielded late Miocene leaves (Jack A. Wolfe, written communication, 1971) and radiometric age dates of 12.1 ± 1.0 million years, 12.2 ± 0.6 million years (John D. Obradovich, written communication, 1971), and 10.8 million years (Evernden and others, 1964). Although Wise (1969) refers the Rhododendron Formation to the Clarendonian, data provided by Evernden and others (1964) and Evernden and Evernden (1970) indicate equivalence with the Hemphillian. In view of the above data and the continuing discussion regarding the Mio-Pliocene boundary, a late Miocene to early Pliocene age is tentatively assigned to the Rhododendron Formation.

#### Pliocene sedimentary rock (Tps)

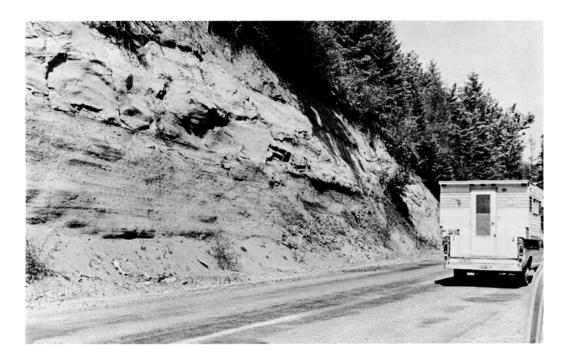
The Pliocene sedimentary rock unit consists of up to 400 feet of fluvial conglomerate, sandstone, and siltstone overlying the Rhododendron Formation in the bluffs overlooking the Bull Run River downstream from the Little Sandy River. It is equivalent to the Troutdale Formation of Hodge (1933, 1938) and the Troutdale Formation and Sandy River Mudstone of Trimble (1963).

Buff, clayey siltstones comprise the lower half of the unit, and beds of sandstone and conglomerate make up the upper half of the section (Figure 17). Quartzite pebbles are abundant in one of the conglomeratic interbeds. Large blocks of subangular basalt and sandstone interbeds composed of grains of basaltic glass high in the section indicate partial derivation of the unit from local eruptive sources (Pliocene volcanic rock). Massive failures are developed on the clayey lower part of the unit. The coarser upper parts of the unit are characterized by steeper slopes and talus.

Stratigraphic position above the Rhododendron Formation and beneath Pliocene volcanic rock indicates an early to possibly middle Pliocene age for the Pliocene sedimentary rock. Early Pliocene leaves have been recovered from equivalent strata in the region (Hodge, 1938; Trimble, 1963). Derivation of much of the unit from neighboring volcanic rock indicates age equivalence with part of the Pliocene volcanic rock unit.

#### Pliocene and Quaternary volcanic rocks (Tpv, Qvic, Qba)

Flows of andesite and subordinate basalt comprise the mountains and plains which overlook the valley of the Bull Run River. The unit occupies 80 percent of the study area and exceeds several thousand feet in thickness in the eastern part of the watershed. Stevens (1964) applied the term Cascades Andesite Formation to the unit. Wise (1969) demonstrated a predominately Pliocene age for these and equivalent rocks in the Mount Hood area.





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Figure 17. Bedded sandstone of fluvial origin makes up much of the upper part of the Pliocene sedimentary rock (sec. 32, T. 1 S., R. 5 E.).

Figure 18. Coarse, vertical plates characterize the Pliocene volcanic rock south and west of Bull Run Lake.



Figure 19. Pliocene volcanic rock overlooking the South Fork consists of dense columnar flow rock and vesicular basalt (sec. 31, T. 2 S., R. 5 E.).



Figure 20. Biscuit structures are common near Log Creek at the base of the Pliocene volcanic rock (sec. 11, T. 1 S., R. 7 E.).

Three subunits are recognized in this report: Pliocene volcanic rock, Quaternary volcanic and intrusive complex, and Quaternary basalt and andesite.

The Pliocene volcanic rock (Tpv) consists of massive to platy flows of andesite, subordinate thin massive flows of basalt, and minor volcanic breccias (Figures 18-23). It constitutes the bulk of the Pliocene to Quaternary volcanic rock unit. Basalt flows are reported in the eastern part of the watershed (Wise, 1969) and on the ridges overlooking the Bull Run River near Aims. At the latter locality, the flows are inflated in places and may be equivalent to the Boring Lava of Trimble (1963) in the Portland area. Wise (1969) reports an age of 5.8 million years for rocks at Lolo Pass herein assigned to the Pliocene volcanic rock subunit. On the basis of regional studies, Wise (1969) inferred a total age range of 2 to 7 million years for rocks assigned to the Pliocene volcanic rock unit. Exposures in the Bull Run Watershed are not adequate to determine conformity or unconformity of the Pliocene volcanic rock over the Rhododendron Formation.

Thick breccias of hornblende andesite and associated intrusions near Blazed Alder Butte (Figure 24) are assigned a Quaternary age by Wise (1969) and are treated as a Quaternary volcanic and intrusive complex (Qvic) in this report. The breccias are probably the isolated remnant of a once fairly contiguous volcanic sequence which was erupted from what is now Clear Fork Butte (Wise, 1969). Thunder Rock, a large uninterrupted monolith (500 vertical feet) of nonbrecciated andesite porphyry with minor flanking conglomerate and sandstone is also of probable intrusive origin. Thick, coarse breccias of andesite porphyry make up much of Blazed Alder Butte. Because the unit intrudes late Pliocene strata, it is assigned a Quaternary age (Wise, 1969).

Relatively young volcanic landforms (Qba) include cinder cones at Walker Prairie and West Aschoff Butte (Figure 25) and a series of flows of basaltic andesite at the lower end of Bull Run Lake. Excellent exposures in roadcuts and in the channel leading out of Bull Run Lake indicate that volcanic rock is the dominant lithology in that area (Figure 26). Previously the elevated valley bottom was interpreted as glacial moraine on the basis of scattered surficial morainal material near Bull Run Lake (Shannon and Wilson, 1961).

#### Surficial deposits (Qtg, Qls, Qal)

Overlying the stratigraphic units in several of the major valleys are localized deposits of unconsolidated surficial Quaternary alluvium (Qal), terrace material (Qtg) (Figure 27), landslide debris (Qls), glaciofluvial outwash (Figures 28 and 29), and moraine. Generally, accumulations of Quaternary alluvium are too small to be mapped. Deposits of sand and gravel along the Sandy River downstream from the community of Bull Run are mapped, however.

Numerous elevated terraces are developed in the western part of the watershed. Elevations vary considerably among the terraces, and more than one period of valley widening (followed by downcutting) is indicated. Deposits on the terraces consist of gravel and sand (Qtg), some of which may be of glaciofluvial origin. Small unmapped deposits of terrace material are exposed farther upstream on the valley wall and on the flat valley bottom near the Headworks. Unmapped patches of morainal material overlie Quaternary basalt (Qba) at the lower end of Bull Run Lake.

Along the major streams throughout much of the lower half of the watershed, a series of massive landslides of Quaternary age have produced large accumulations of landslide debris (Qls). The deposits may exceed 100 feet in thickness and completely obscure the bedrock geology. In places, as at Bull Run Dam No. 2, flow rock assigned to one of the youngest stratigraphic units (Tpv) has been transported downslope to directly overly the oldest stratigraphic unit (Tcr). In the eastern part of the watershed, talus debris is not differentiated from the underlying bedrock.



Figure 21. (Upper left) Weathering produces tightly interlocking clasts in the Pliocene volcanic rock; note massive flow rock above it.

Figure 22. (Upper right) Spheroidal weathering results in rounded clasts in breccias of Pliocene volcanic rock.



Figure 23. (Left) Many of the weathered agglomerates and breccias of the Pliocene volcanic rock resemble glacial till.



Figure 24. The Thunder Rock monolith consists of coarse-grained andesite and is surrounded by coarse breccias and clastics; it may be a Quaternary volcanic neck or plug.

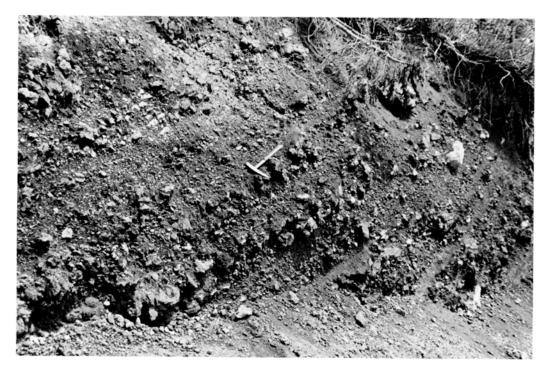


Figure 25. West Aschoff Butte is a Quaternary volcanic cone composed primarily of bedded cinders.



Figure 26. Rubbly regolith overlying intracanyon flow rock at Bull Run Lake bears no resemblance to glacial till, for which it is sometimes mistaken.



Figure 27. Patches of terrace material overlie Columbia River Basalt at Bull Run Reservoir No. 2.



Figure 28. Unmapped glacial outwash along Cedar Creek consists of scattered rounded boulders in a sedimentary matrix.



Figure 29. Glacial outwash contains rounded boulders; close examination reveals several types of rock unlike deeply weathered flow rock (Figure 23).

#### Structure

Distribution of rock units and measured attitudes indicate a gentle tilting of bedrock to the west in the Bull Run Watershed. Pliocene sedimentary rocks crop out only in the west. Rhododendron outcrops are present in the west and central parts of the drainage. The upper surface of the Columbia River Basalt rises eastward from an elevation of 750 feet near the Headworks to an elevation of 3,000 feet near Bull Run Lake. Dips in the Columbia River Basalt, Pliocene sedimentary rock, and Pliocene volcanic rock are 0° to 5° westerly. Deformation is gentle and relatively recent.

Regionally the upper surface of the Columbia River Basalt has undergone broad folding and possibly faulting since middle Miocene times. The elevation of the upper surface is 1,000 feet below sea level in the Tualatin Valley (Schlicker and Deacon, 1967) and 3,000 feet above sea level at Nicolai Ridge near Astoria. Folding of the Columbia River Basalt is well-displayed in the Columbia River Gorge (Waters, 1973) north of the study area. To the south in the Sandy River drainage, the upper surface is exposed at an elevation of 1,400 feet (Wise, 1969).

Detailed mapping in the Bull Run Watershed in this study and reconnaissance mapping and radiometric age determinations by Wise (1969) suggest a post-Columbia River Basalt age for all rocks in the Mount Hood area not assigned to that unit. The northernmost part of the Cascade Range in Oregon is best viewed as an accumulation of Pliocene and Quaternary volcanic rock resting upon the regionally deformed upper surface of the Columbia River Basalt.

Faults are mappable displacements of rock units and are recognized on the basis of displaced beds, topographic lineations, termination of structures, zones of alteration, or by the presence of breccia, slickensides, or gouge. Using this concept, no significant faults were identified in the Bull Run Watershed. Although vegetation, talus, and massive landslides obscure much of the bedrock geology, no major faults are believed to be present in the area.

A variety of evidence (Balsillie and Benson, 1971) suggests the presence of a large regional fault trending northwesterly through Portland to the west. Seismic activity in the area is well documented (Berg and Baker, 1963; Dehlinger and others, 1963), and it is possible that the structure trends southeasterly to pass within approximately 20 miles of the Bull Run Watershed (Schmela and Palmer, 1972). Approximately 25 miles northeast of the watershed, Waters (1973) maps a north-trending fault zone termed the Hood River Fault Zone (Figure 30).

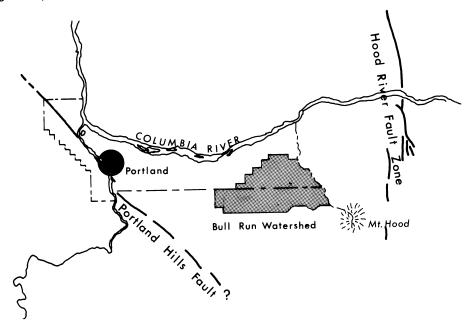


Figure 30. Regional faults near the Bull Run Watershed.

## ENGINEERING PROPERTIES OF GEOLOGIC UNITS

The various stratigraphic and surficial geologic units in the Bull Run Watershed display a wide range of engineering properties. In many places weathering and degradational processes are interacting with the rocks to produce a variety of geologic hazards. These are depicted on the geologic hazards map. In other areas where hazards have not developed, the properties of the rocks are still a major concern. As man continues to modify the terrain and to influence natural processes, it is imperative that his activities be keyed to the geologic conditions.

#### Columbia River Basalt (Tcr)

The Columbia River Basalt consists of dense flow-on-flow basalt. It occupies the valley bottom of the Bull Run River and parts of its major tributaries including Blazed Alder Creek and the North Fork of the Bull Run River. The unit is resistant to weathering and erodes to form steep canyon walls. Soil consists of reddish brown silt with varying amounts of clay and is present in thicknesses of less than a foot to approximately 15 feet on gentle slopes and horizontal surfaces. Bedrock is commonly exposed on steeper slopes. Hazards associated with the unit include local rockfall and thin-skinned sloughing of soil material on steep slopes.

Excavation in the Columbia River Basalt requires blasting. In areas where interbeds of sediment are present and steep slopes are developed (80 to 90 percent), blasting may initiate thin skinned slides of soil material downslope. Such a slide near "the boathouse" at Bull Run Reservoir No. 1 was generated in an area of thick vegetation and abundant bedrock outcrops. The blast loosened the sediments, which slid downslope; the loss of support to the overlying basalt caused it to slide downslope also. Preliminary geologic investigations gave no hint of the potential hazard. In analogous situations in the future, detailed soil investigations on the steeper slopes may be needed to properly assess the potential for sliding.

Rockfall is a constant source of danger at the base of steep slopes, especially in areas of recent excavation. In the Falls Creek area, the presence of pillow structures and associated alteration of the basalt contributes further to hazard potential. The abundant joints and inhomogeneity of the flows result in numerous rockfalls during and after moderate to heavy rains. Rockfall constitutes a greater hazard to safety than it does to stability.

Under most circumstances, cuts in Columbia River Basalt are stable. Care should be exercised, however, to assure that such cuts do not undermine less stable material upslope, such as parts of the Rhododendron Formation. Fill material placed on moderate to steep slopes will not be stable and is not recommended.

The Columbia River Basalt is a "tight" unit of low permeability. Runoff is high and water retention is low. In areas of thick talus and moderate to steep slope, streams are widely spaced and runoff occurs a few feet beneath the ground surface. Road construction which cuts through the talus must be designed to accommodate the subsurface runoff.

Because the Columbia River Basalt is firm and stable, it provides a good foundation for dams. Its low permeability and lack of structural deformation make it highly suitable for reservoir containment. Bull Run Dam No. 1 is a concrete structure situated in Columbia River Basalt terrain. Bull Run Dam No. 2 is an earthfill structure situated on an area of massive sliding. The valleys of the upper Bull Run River and Blazed Alder Creek may offer adequate sites for future dam construction.

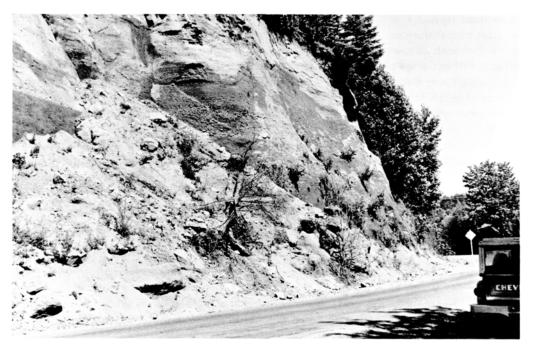
#### Rhododendron Formation (Tmpr)

Hard volcanic breccias and mudflows assigned to the Rhododendron Formation form steep cliffs along the lower Bull Run and Sandy Rivers (Figure 31). Farther upstream where cementation is incomplete and downcutting is less prominent in the unit, the breccias are associated with thick talus deposits and massive landslides. Locally in the north central parts of the watershed, flows of platy andesite porphyry form distinct knobs and ridges.



Figure 31. Cribbing supports the access road in steeply sloping Rhododendron terrain near the west gate (sec. 5, T. 1 S., R. 5 E.).

Figure 32. Blockfall is typical along steep slopes cut into the upper part of the Pliocene sedimentary rock.



The thickness of soil and unconsolidated material varies considerably as a function of parent rock type, degree of cementation, and local setting. Massive landslide deposits between the community of Bull Run and Bull Run Dam No. 1 may exceed 100 feet in thickness. These are discussed in a later section. Thick accumulations of unconsolidated debris mantle the middle slopes of the Bull Run Valley where massive slides are not developed. Commonly debris from younger units upslope has become incorporated in the debris derived from the Rhododendron Formation. Excavations in this material and in the poorly cemented to uncemented parent breccias are generally not difficult. Oversteepening should be avoided, however. Pockets of pyroclastic and fumarolic red clay in the breccias are particularly prone to failure. Quarry operations in the platy flow rock require some blasting. The platy quality promotes fracturing, and very little subsequent treatment is required even for use as road metal.

With the exception of the hard, well-cemented breccias in the lower reaches of the watershed, the breccias of the Rhododendron Formation are characterized by moderate to high permeability. Numerous springs are evident in roadcuts after heavy rains.

Significantly, many of the conduits leading from the Bull Run Reservoirs westward out of the watershed are founded on rocks assigned to the Rhododendron Formation. Stability of the footings varies considerably. In areas where the breccias are well cemented and form horizontal landforms, no hazards are present. In areas of moderate slope and mass movement, the possibility exists for serious disruption of Portland's water supply. Specific localities are discussed in a later section.

In terms of water quality, the most critical feature of the Rhododendron Formation is the widespread distribution of red clay pods in the breccias (see North Fork slide in Geologic Hazards section). These are particularly prevalent on both sides of the Bull Run River in the middle reaches of the watershed. When the clay becomes incorporated in the surface water, it can easily degrade the water quality of the entire watershed downstream (see Turbidity in Geologic Hazards section). Preliminary calculations suggest that only a few tens of cubic yards of red clay were involved in the discoloration associated with the North Fork slide of 1972. It is imperative that all planned or incidental modifications of runoff in the watershed be designed to prevent the introduction of red clay into the streams. Care should be exercised in locally modifying stream channels for both temporary and permanent purposes (e.g., road construction). Projects which alter stream flow, such as small dams, should also be evaluated in terms of possible water contamination from introduction of red clay into surface water.

#### Pliocene sedimentary rock (Tps)

Exposures of Pliocene sedimentary rock are restricted to the westernmost part of the watershed where the unit forms most of the slopes overlooking the Bull Run River. The conglomerate and sandstone, which dominate the upper part of the section, are moderately stable and stand in fairly steep slopes. The underlying clayey silt is prone to failure, and slides developed in it commonly undercut the overlying beds.

Soil and unconsolidated debris vary in thickness as a function of slope, rock type, and local conditions. Slide material is over 40 feet thick at the Ditch Camp slide (see Geologic Hazards). On the Aims grade, conglomerates and sandstones form bare vertical slopes along creeks but are mantled with talus and slide debris from 1 to 30 feet thick on undissected slopes. Much of the slide debris is derived from the overlying Pliocene volcanic rock (Tpv). Steep cuts locally produce blockfall (Figure 32).

Excavation is relatively easy in the Pliocene sedimentary rock unit, but all projects should be preceded by adequate engineering studies. A county road widening project immediately south of the Bull Run Bridge removed enough of the toe of an old landslide to reinitiate movement (see Ditch Camp slide in Geologic Hazards section). Conduits leading to Portland through the slide area were temporarily out of service.

Construction of large permanent structures in terrain underlain by the Pliocene sedimentary rock unit requires proper engineering. If additional conduits are to be built, it is imperative that the potential for sliding be considered in preliminary route planning as well as the actual design.

## Pliocene and Quaternary volcanic rock (Tpv, Qvic, Qba)

Pliocene and Quaternary volcanic rock underlies 80 percent of the Bull Run Watershed. Rock types are diverse and include flow rock, breccias, and intrusive rock. The Pliocene volcanic rock (Tpv) is the dominant subunit and consists primarily of massive to platy andesitic flows.



Figure 33. Talus is common on the steeper slopes of the upper Bull Run Watershed (Pliocene volcanic rock, sec. 19, T. 1 S., R. 8 E.).



Figure 34. Care must be exercised to assure that roadcuts in talus are not too steep. Note that the thick forest cover probably obscured the talus prior to road construction.

Deep weathering produces thick soils on horizontal to gently sloping surfaces, especially in the southwestern part of the watershed. Permeability and water retention are high. Scattered breccias also retain much of the precipitation. In the eastern part of the watershed, rapid downcutting and glacial erosion have produced steep slopes which now are mantled with thick talus (Figures 33 and 34). Infiltration is high.

Much runoff occurs a few feet beneath the ground surface in the talus and must be properly accommodated in roadcuts and other excavations (Figure 35). Large cuts in the talus may tend to work their way upslope as the hillside returns to stable conditions. Oversteepening and overloading must be avoided (Figure 36). Some large operations in well-packed talus, however, appear stable. A notable example is the quarry operation 2 miles downstream from Bull Run Lake.

In the northwestern part of the watershed, upland slopes are gentle to moderate and stream gradients are steep. Soil cover is moderate to thin. Runoff is extremely high in some of the stream valleys. Undercutting of the Pliocene volcanic rock along the lower Bull Run River near Dodge Park has produced talus and blockfall in places.

Flows of basalt and andesite (Qba) are exposed in roadcuts and in the weir at the lower end of Bull Run Lake. Permeability of this volcanic accumulation is very high. The stream leaving Bull Run Lake enters the ground through a series of sinks a short distance from the lake to emerge again farther down-canyon half a mile from the lake. Scattered morainal material on the volcanic pile has led to a mistaken identification of the entire unit as terminal moraine in previous reports (Shannon and Wilson, 1961).

In places, the breccias of the Pliocene volcanic rock are bound by a red clay-like material similar in some respects to the red colloidal clay of the Rhododendron Formation. The clay does not form distinct pods, however, and it apparently does not stay in suspension. During the North Fork slide disaster of 1972, water continuing downstream from Pliocene volcanic rock terrain was not significantly discolored even though much of the red clay at the Boody (North Fork Reservoir) spillway upstream had been eroded. In contrast, water leaving the slide area in Rhododendron Formation pyroclastic material discolored Portland's entire water supply for weeks. In view of the poor exposures in the watershed, however, the possibility remains that pods of colloidal clay lie undetected in the Pliocene volcanic rock unit (Tpv).

Several types of quarry stone are available from the Pliocene and Quaternary volcanic rock. Platy andesite immediately west of Bull Run Lake is quarried for road metal. Blocky talus on the north side of the Bull Run River in the eastern parts of the watershed could conceivably be used as riprap. Large riprap used to redirect the flow of the North Fork of the Bull Run River after the 1972 slide was taken from gentle talus-like slopes near the Boody Reservoir. The gentle angle of repose of these slopes suggests a possible residual origin as opposed to rockfall.

#### Surficial deposits (Qtg, Qls, Qal)

A variety of unconsolidated surficial deposits overlies the bedrock units in places. Most significant are the terrace gravels (Qtg) and landslide debris (Qls) in the lower reaches of the watershed. Quaternary alluvium (Qal) is mapped near Dodge Park and small patches of unmapped morainal material are present in some of the eastern glacial valleys.

The terraces are composed of gravel and are relatively unweathered. Soils are thin. Runoff is low owing to the high permeability and the very gentle slopes. The location of the deposits is such that they are not significant to most aspects of watershed management. Generally the terraces are stable enough to support aqueducts, pipelines, and similar structure.

The Quaternary landslide debris (Qls) may exceed 100 feet in thickness and poses serious problems in terms of stability. Drainage is commonly poor and irregular. Continual readjustments are to be expected within the slide areas, and excavations for all purposes should be adequately engineered beforehand. The heterogeneity of the slide material presents additional problems even in areas of low slope. At Bull Run Dam No. 2, cave-ins occurred at excavations for the spillway plunge pool. Tunnels through the slide material may fail. Hazards associated with Quaternary landslide debris (Qls) are discussed in more detail under Geologic Hazards.



Figure 36. Road fills on steep slopes of talus will fail if the slope is overloaded (sec. 27, T. 1 S., R. 7 E.).



Figure 35. Roadcuts in talus commonly intersect subsurface drainage.

## GEOLOGIC HAZARDS

Geologic hazards in the Bull Run Watershed fall under two main categories -- tectonic and degradational. Tectonic hazards are produced by volcanism and earthquakes; degradational hazards are the product of slow but persistent weathering and erosion of the land surface and are the more significant in the area of this study.

## Degradational Hazards

Degradational processes in the Bull Run Watershed have produced two major geologic hazards: (1) massive landslides, both prehistoric and recent, and (2) detrimental runoff.

Various degradational processes have carved out the present landforms and are important factors in all surficial geologic hazards. Stream erosion has produced moderate to steep slopes along all of the major canyons. As these hillsides have evolved, massive landslides have developed in the western parts of the watershed. Talus (see Engineering Properties of Geologic Units) is widespread in the steep, formerly glaciated valleys of the eastern end of the watershed. Various elements of climate, permeability, and slope contribute to an important class of hazards associated with runoff.

Proper understanding of hazards in a specific area requires an appreciation of regional processes as well as local conditions. For instance, knowledge of regional climate, past stream behavior, and rock distribution are needed to assess the precise nature of massive landslides in the lower Bull Run Watershed. Such knowledge is also useful in determining the relative stability of other areas that are not subject to actual sliding at the present time.

Anticipated future activities of man in the watershed include dam construction, road construction, and logging. Such projects can influence slope stability, runoff, and siltation. Information in this section will be useful in determining the extent to which these and other activities should be allowed; it will aid preliminary engineering investigations and help develop a meaningful program of stream monitoring.

## Massive landslides

Description: Areas of massive landsliding are characterized by a variety of topographic features. Basically the downslope movement of material disrupts the terrain so that the ground surface is irregular to hummocky and the drainage is deranged. Springs, swampy areas, and sag ponds are common. Outcrops are rare and scattered and generally consist of broken rock delivered from higher on the slope.

Viewing the slide as a whole, the slope is gentle relative to the intact surrounding terrain. Where depth of failure is relatively great, the headscarp bounding the upper edge of the slide is commonly concave. For particularly large slides, such as those lining the lower valley of the Bull Run River, depth of failure is probably greater than 100 feet. Mapping of bedrock geology is not possible in these areas, and a surficial unit, Quaternary landslide debris (Qls), is shown on the geologic map.

Distribution and cause: The massive landslide failures in the western half of the Bull Run Watershed are most common in moderately sloping terrain underlain by poorly cemented breccias of the Rhododendron Formation and in Pliocene sedimentary rock (Tps). Scattered breccias of the Pliocene volcanic rock unit (Tpv) are not actively involved in deep massive failures. Well-cemented parts of the Rhododendron breccias form nearly vertical canyon walls in the lower Little Sandy and Bull Run valleys and likewise are not involved in significant sliding.

Other factors in addition to rock type that contribute to massive failure are oversteepening of slopes by stream or river erosion, the presence of groundwater, a moist climate, and deep penetration of chemical weathering. Scouring by glacial floodwaters may have contributed to the oversteepening of the slopes. It is doubtful, however, that glacial erosion was a factor.

Moraine, cirques, steep U-shaped valleys and other glacial features are not present below an elevation of 2,000 feet anywhere in the watershed. The relatively gentle U-shaped profile of the valley of the lower Bull Run River is solely a product of lithology. The flat valley floor is underlain by hard, massive Columbia River Basalt; the gentle middle slopes are underlain by incompetent Rhododendron breccias; and the steeper upper slopes are underlain by more resistant flow rock of the Pliocene volcanic rock unit (Tpv).

Massive landslides line the valley of the Bull Run River from Bull Run Reservoir No. 2 downstream to its confluence with the Sandy River near Dodge Park. Massive failures also are present in the lower reaches of the South Fork of the Bull Run River; much of the sliding there involves rock rather than soil or clay. The slides along the North Fork of the Bull Run River occur in pyroclastic rocks of the Rhododen-dron Formation.

Man's activities: The stability characteristics of massive landslide terrain are very important to man's activities even in regions where slides are presently inactive. Potential problems include general instability and differential settling, caving, piping of water, reactivation of old slides, and generation of new slides. Persons involved in land management or in the design or construction of dams, roads, conduits, and other permanent or large structures should be aware of the slide potential and soil conditions. For example, a knowledge of the foundation and reservoir characteristics of Bull Run Dam No. 2 was a factor in the choice of a broad-based earthfill dam for that site.

Studies from other areas show that road construction can easily upset the delicate stability of land-slide areas and can even cause slides in previously stable areas. During a study period, slumps and earth-flows along road right-of-ways in the H. J. Andrews Experimental Forest in the Western Cascades accounted for 65 percent of all mass movement (Dyrness, 1967). Factors instrumental in sliding included upslope failure, fill failure, and modified drainage. However, conditions in much of the Bull Run Watershed are not as extreme as those in the H. J. Andrews Experimental Forest.

Slope loading by large fills increases the weight of the soil mantle below the road; on steep or saturated slopes sliding may result. Undercutting on the uphill side of the road will initiate new slides or reactivate old ones if the excavation oversteepens the slope. Interception of surface runoff and shallow ground water by the road may encourage saturation. The resulting increased pore pressure in the soil mantle favors sliding.

Introduction of soil materials directly into streams by sliding or indirectly by erosion of slide areas can greatly increase turbidity and reduce water quality in a watershed. In areas of critical stability where water quality is a concern, road construction should be accompanied by adequate engineering studies. Serious problem areas should be avoided. Road design should accommodate potential hazards elsewhere. Fills should be minimized; oversteepening should be avoided; and adequate provisions should be made to monitor and handle runoff. This includes regular surveillance to assure that culverts are not clogged with debris.

Little detailed work has been done to relate actual logging operations to mass movement processes. It is generally accepted, however, that transpiration by trees removes considerable quantities of water from the soil and thus inhibits sliding. Root systems also effectively bind the soil (Bishop and Stevens, 1964). Landslides along the North Fork of the Ogden River in Utah resulted from the loss of mechanical support by root systems of trees after logging (Croft and Adams, 1950).

There is no simple cause and effect relationship between logging and mass movement, however. Regions cited above are generally more extreme than the Bull Run Watershed in terms of steepness of slopes, rock type, and slide potential. Specific sites of potential future logging must be evaluated on an individual basis. Blanket statements comparing entire watersheds are seldom justified. In many places where slides are a threat, selective logging, aerial logging, and other techniques can be used to maintain stability.

Stability of the conduits (Figure 37) and aqueducts leading through the lower reaches of the Bull Run River to Portland is of prime concern. In places where the conduits rest on massive landslides, damage has occurred in the past and may occur in the future (see Ditch Camp Slide in Geologic Hazards section). Footings for the aqueducts at river crossings rest on solid bedrock and are stable.

Although landslide debris (Qls) surrounds the Headworks area, the footings for the aqueducts there are founded on stable Columbia River Basalt bedrock (Figure 38), which was exposed by stream erosion after sliding occurred. Downstream at Larsons Bridge (sec. 34) the bridge footings are also placed on Columbia River Basalt (Figure 39).

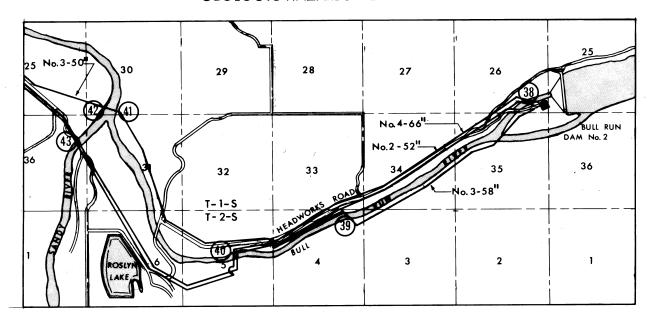


Figure 37. Aqueduct stream crossings and conduits, lower Bull Run drainage; circled numbers refer to figures in text.

At Bowman's Bridge, a short distance downstream from the confluence of the Bull Run and Little Sandy Rivers (center sec. 5), aqueduct footings are rooted in firm, stable, breccias of the Rhododendron Formation (Figure 40). In contrast to most Rhododendron breccias elsewhere, the breccias in this area are well-cemented. At Camp Namanu, 3 miles downstream on the Sandy River, the east footing of an aqueduct crossing also rests firmly on stable well-cemented breccias of the Rhododendron Formation (Figure 41). The west footing is founded in bouldery Quaternary alluvium (Figure 42).

At Dodge Park, a highway bridge and an aqueduct are founded on Pliocene sedimentary rock on the north bank of the Sandy River (Figure 43). Under severe flood conditions the unit could be eroded, thus undercutting the footings. At present, pilings protect the cliff. Also a bridge pier placed against the riverbank a short distance downstream retards stream-bank erosion at the crossings.

North Fork slide: Collectively, adverse geologic, topographic, and hydrologic conditions along the North Fork of the Bull Run River are the most extreme in the entire Bull Run Watershed in terms of slide potential. On January 20, 1972, the North Fork began delivering extremely turbid waters to Bull Run Reservoir No. 1; the slide was found 1 3/4 miles upstream from the mouth of the North Fork (Figures 44 and 45). The water supply for the City of Portland was discolored for several weeks.

At the site of the slide (Figures 44 and 45), agglomerates, fine-grained pyroclastics, and flow rock of the Rhododendron Formation form thick deposits of landslide debris (Qls) overlying intact bedrock of the Columbia River Basalt (Figures 46–49). In places, Pliocene volcanic rock (Tpv) is involved in the sliding. The pyroclastic parts of the Rhododendron Formation include pods of varicolored clay of fumarolic or volcanic origin. The red clays which quickly go into colloidal solution caused the pronounced turbidity of the North Fork in the winter of 1972. Possibly only a few tens of yards of this material were needed to discolor Portland's water supply.

The valley of the North Fork of the Bull Run River is steep-sided and the gradient is moderate (1 percent). Both factors contribute to rapid runoff. In recent years, clear-cutting operations in the basin have removed a small percentage of the protective vegetation, possibly contributing to the runoff potential during times of rapid snowmelt.

The North Fork of the Bull Run River originates in a region of gently sloping upland meadows. Run-off originating on the meadows is impounded behind a low dam to form the Boody Reservoir. It is probable

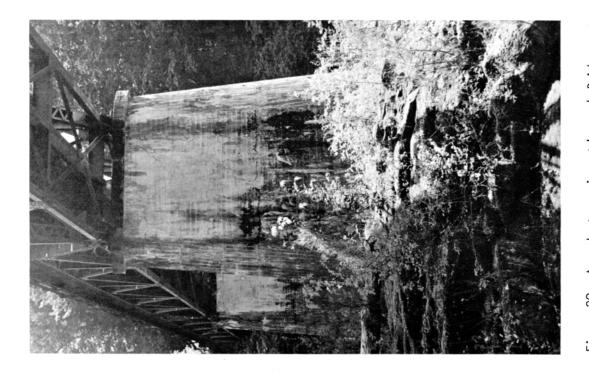


Figure 39. Aqueduct crossing at Larson's Bridge rests on stable Columbia River Basalt.



Figure 38. Aqueduct crossing at the Headworks rests on stable Columbia River Basalt.



Figure 40. Aqueduct crossing at Bowman's

Bridge (sec. 5, T. 1 S., R. 5 E.) rests
on firmly cemented breccias of the
Rhododendron Formation.

Figure 41. East end of the aqueduct crossing downstream from Dodge Park rests firmly on well-cemented Rhododendron breccias.

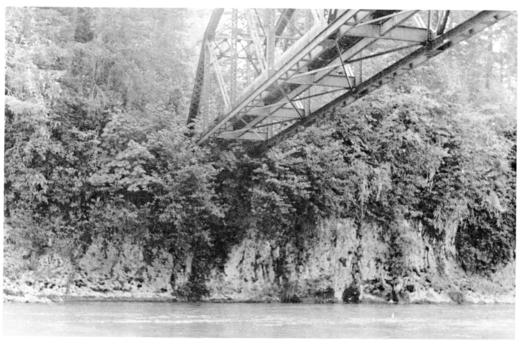




Figure 42. West end of aqueduct crossing downstream from Dodge Park is founded on alluvial gravels.

Figure 43. Looking north at highway and aqueduct crossings at Dodge Park.



that melt waters and flood waters surging from the reservoir were instrumental in initiating movement on the North Fork Slide on January 20, 1972 (see Runoff in Geologic Hazards section).

The course of the North Fork of the Bull Run River meanders greatly at the site of the North Fork slide. The sharp curves promote slides by encouraging stream-bank erosion. The North Fork slide of 1972 was caused when high runoff eroded into the stream banks on the outer edges of stream curves and oversteepened the slopes. High turbidity resulted when colloidal red clays slid into the stream and went into suspension.

The size, topographic development, and general setting of the North Fork slide area indicate that mass movement has been occurring in the region for thousands of years. The climate, steep slopes, and unique rock types, including pods of red clay, are fundamental to the slide process. Activities of man, including construction of the Boody Reservoir and possibly clear-cutting, are also significant because they may constitute trigger mechanisms for individual slides.

The impact of the North Fork slide area on man derives not from the presence of the slide itself, but rather from the turbid waters the slide generates. Corrective measures on the slide area were made for the purpose of preserving the quality of Portland's water supply.

On-site examination of sliding at the North Fork slide area in the winter of 1972 revealed that the stream had shifted position and was actively undercutting soft pyroclastic material. Corrective measures included: (1) rerouting the stream to its previous location; (2) placing riprap in the stream channel and along the stream banks (Figure 50); (3) removing bedrock constrictions immediately downstream from the slide area to improve flow characteristics; (4) removing or sectioning all logs in the stream bed to minimize the danger of log jams; and (5) constructing an overflow channel to relieve the main channel during high flooding (Figure 45a). According to figures provided by Dames and Moore (1972b), 22,980 cubic yards of unsuitable material was hauled out of the slide area and 13,642 yards of replacement material was hauled in for the overflow channel diversion structure, diversion channel armor rock, main channel armor rock, and riprap. An additional 13,608 cubic yards of rock was used in the construction of the access road.

Analyses by personnel of the U.S. Geological Survey indicate that a surge flow of 9,800 cfs passed down the North Fork of the Bull Run River on January 20, 1972 (see Runoff). Independent evidence substantiating a tremendous flow at this date includes significant growth of the delta at the mouth of the North Fork, scars in trees where boulders hurled by the flood waters ripped bark from the trees, driftwood in tree branches, and the magnitude of the slide area (see Rapid Runoff).

The number of trees uprooted by the slide and the flood waters was so great that preliminary reports attributed the flooding to log jams (Dames and Moore, 1972a). The magnitude of the flood contrasts markedly with other recorded floods on the North Fork (Table 2).

Corrective measures to date are not sufficient to handle runoff equivalent to that calculated for the flood of January 20, 1972. Structures are designed for a flow of only 2,700 cfs. It is recommended that all necessary measures be taken to prevent surge floods from developing upstream at the Boody Reservoir. Close surveillance, redesign, or actual removal of the impoundment structure may be required.

Riprap and armor rock placed in and along the North Fork may not be sufficient to handle smaller floods of natural origin. Many of the naturally occurring boulders in the stream immediately upstream from the slide area are as large as many of the boulders in the riprap (Figure 50). Moreover, small floods in the winter of 1973 rearranged some of the riprap along the streambank. More detailed assessment of the riprap should be made; grouting may be required. Also, much more riprap may be required, especially along the west bank of the diversion channel (Figures 51 and 52). Removal of logs from the stream channel upstream and modification of drainage on the slide areas will not significantly alter slide potential at the North Fork slide.

Ditch Camp slide: The Ditch Camp slide is situated along the southern bank of the Bull Run River immediately southwest of the community of Bull Run (Figure 53). Sliding was first noted at the locality approximately 80 years ago when a few tens of thousands of dollars worth of repairs were required on conduit No. 1 (no longer used). Similar sliding above the Portland General Electric Power facility immediately downstream necessitated deep excavations to place the penstocks beneath the surface of sliding. Owing to poorly engineered road construction and to exceptionally heavy rains in December 1964 and January 1965, the ground surface dropped 15 feet under conduit No. 2. During restoration the conduit was out of service for several weeks.

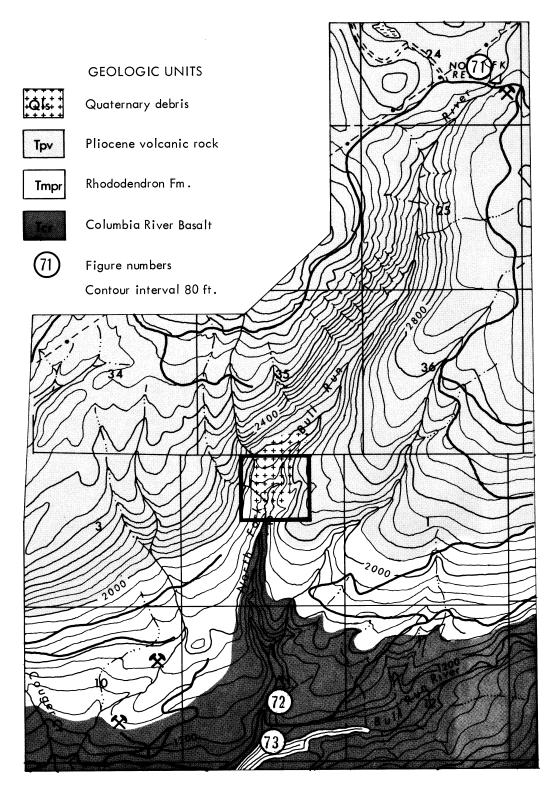


Figure 44. Regional setting of the North Fork slide. Boxed area shown in Figure 45a.

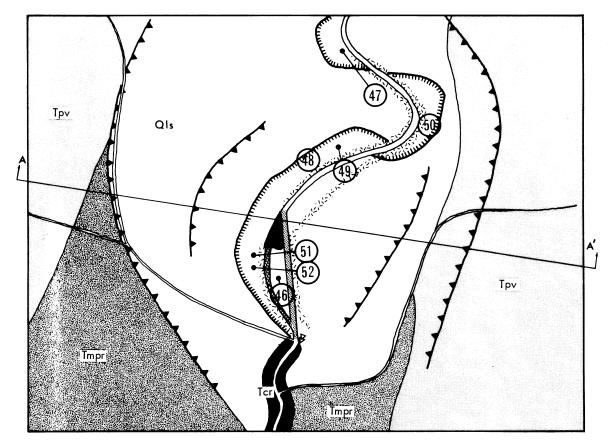


Figure 45a. Local setting of the North Fork slide.

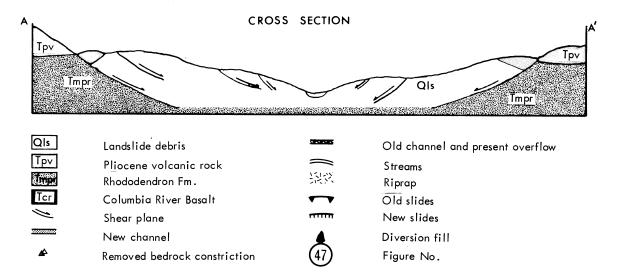


Figure 45b. Cross section of the North Fork slide.



Figure 46. View of part of the North Fork slide looking upstream.



Figure 47. The northernmost part of the North Fork slide area; note that some of the rounded boulders in the creek are as large as much of the riprap.



Figure 48. View of part of the North Fork slide area looking downstream; truck is in same position as in Figure 46.



Figure 49. A flow of Pliocene hypersthene andesite, with baked zone to the right and abundant vesicles on the left, has been greatly rotated by massive landsliding at the North Fork slide area.



Figure 50. Coarse riprap has been placed along the east bank of the North Fork to prevent stream-bank erosion at the North Fork slide.

Figure 51. Material continues to slough
off the slopes oversteepened by streambank erosion during the North Fork
flood of January 1972.





Figure 52. Material sloughing over the riprap into the overflow channel is abundant enough to pose turbidity problems.

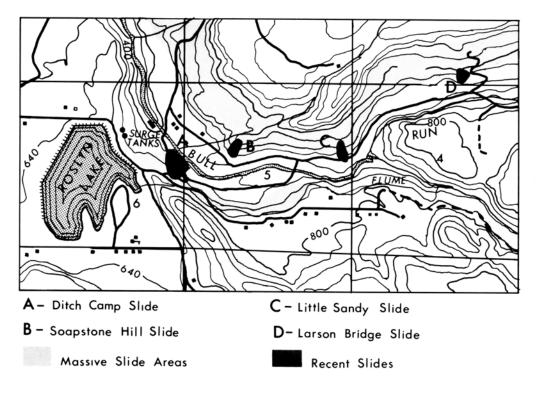


Figure 53. Location of active slides in the lower Bull Run drainage.

Natural factors causing sliding at the Ditch Camp site include moist climate, moderate slopes, and unfavorable bedrock. The Pliocene sedimentary rock (Tps) in which the slide is developed consists of sand-stone and conglomerate high on the slope and clayey siltstone or mudstone low in the section (Figure 54). Penetrative weathering and high pore pressures along the contact between the clay and the sandstone has produced a zone of failure above which friable coarse-grained clastics are undercut and below which slow moving earthflow is developed. The mantle of slide debris is approximately 40 to 45 feet thick (Shannon and Wilson, 1965).

The slide area is characterized by scattered springs and irregular topography. Occasional tension cracks were noted after the 1965 slide (Shannon and Wilson, 1965). A short distance downstream, gradual movement at the rate of 1 inch every 4 years was noted immediately upslope from the Portland General Electric Power Plant (Shannon and Wilson, 1965). Geologically the slide is mature; erosion no longer removes material from the toe.

County road construction prior to movement in 1965 included excavation of a 30-foot-wide cut along the toe of the slide. In places the cut bank was 10 feet high. Removal of this material decreased friction along the shear plane and reinitiated sliding. Possible modification of drainage by a road located near the headscarp of the slide may have been a secondary factor in sliding. It is doubtful that erosion by local streams in the slide area contribute measurably to slide potential.

Approximately 6 to 8 feet of ballast was placed on the toe of the slide to arrest movement. Among other recommendations was the enhancement of drainage to lower the winter water table. Because movement on the Ditch Camp slide has not been completely eliminated (Figures 55 and 56), further corrective measures are necessary. Interruption of water supply to Portland provided by conduits 2 and 4 could have dire consequences. It is recommended that qualified personnel make a detailed engineering investigation of the Ditch Camp slide to evaluate possible future damage to the conduits through settling or sliding and to recommend corrective measures.

Soapstone Hill slide: The Soapstone Hill slide is located approximately half a mile southeast of the community of Bull Run on the north side of the Bull Run River (Figure 53). Slopes are moderately steep. The slide occurs in Pliocene sedimentary rock and is analogous to the Ditch Camp slide. Moist climate and the abundance of clay-rich material low on the slope cause the instability of the rock (Figure 54).

Activity on the slide in 1965 disturbed an area 150 feet wide at the base and extending upslope to a point midway between the road and the pipeline (Shannon and Wilson, 1965). The road is situated out of the slide area and rests on nearly horizontal bedrock. Possible damage to the road by future sliding will be limited to local burial by debris sliding downhill. In 1965 approximately 1,500 to 3,000 cubic yards of material, some of which reached the road, was dislocated.

The significance of the slide rests in the fact that older parts of it probably extend upslope beyond conduit No. 3. Shannon and Wilson (1965) note that disturbed ground extends slightly beyond the pipeline. In future years, if slide debris is periodically removed from the road, the toe of the slide will be effectively diminished. The resulting decrease of friction along the shear plane could reinitiate movement on the presently stable parts of the slide upslope.

In view of the potential impact of possible future sliding, it is recommended that the Soapstone Hill area be studied in detail by qualified engineering personnel. If it is determined that the three buttresses which now stabilize the slide are not adequate, additional corrective measures should be taken.

Little Sandy River slide: The Little Sandy River slide is located between the access road and conduit No. 4 approximately one mile east of the community of Bull Run (Figure 53). Immediately to the south, the Little Sandy River flows into the Bull Run River. A metal retaining wall and rock backfill mark the precise location of the slide.

Although local geology is obscured by vegetation, soil cover, and the road, the road and the metal retaining wall appear to be founded in bedrock of the Rhododendron Formation (Shannon and Wilson, 1965). Regional mapping indicates that the Pliocene sedimentary rock unit (Tps) is very thin. Soil material suggests the presence of clayey and sandy interbeds of that unit, however (Sandy River Mudstone of Shannon and Wilson, 1965). Steep slopes are the dominant factor in the sliding and the slides are shallow (Figure 54).

The potential impact of possible future sliding is minimal. The road is situated below the slide area and is stable; material delivered to the road by slides upslope can easily be removed. The pipeline situated upslope from the slide is not endangered (Shannon and Wilson, 1965).

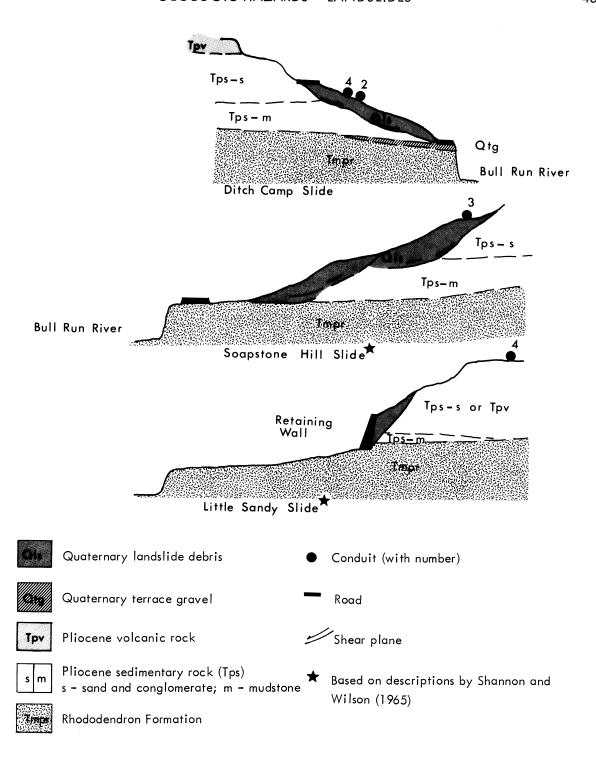


Figure 54. Diagrammatic cross sections of recent slides in the lower Bull Run drainage.



Figure 55. The headscarp of the Ditch Camp slide crosses the main access road.



Figure 56. Continued settling or movement at the Ditch Camp slide has bowed conduit No. 4.

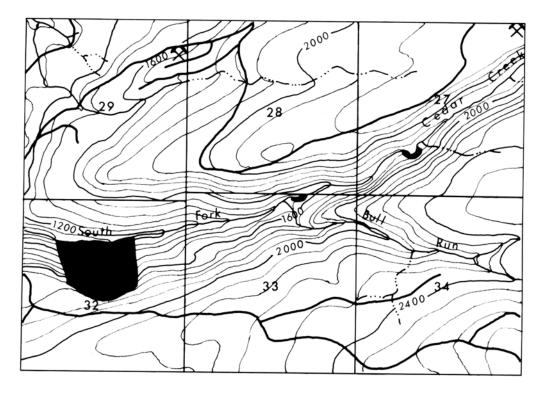


Figure 57. Slide areas in the South Fork drainage (shaded pattern).



Figure 58. Massive rock failure near Sugar Loaf Mountain near Lolo Pass. Similar sliding, now obscured by timber, has occurred along the South Fork.

Boathouse slide: The boathouse slide is located midway between the boatshouse and the mouth of Bear Creek on the north bank of Bull Run Reservoir No. 1. The slide is shallow and is situated on steep slopes (90 percent). Sliding was initiated by blasting related to road construction in the autumn of 1973.

Bedrock of the lower elevations along the reservoir consists of Columbia River Basalt. This unit is well exposed in the abutments of Bull Run Dam No. 1 immediately downstream. In the slide area, approximately 30 feet of sand and clayey sand is exposed directly above the basalt. In fresh roadcuts along the access road, vesicular to slightly inflated basaltic flow rock is exposed above the sedimentary strata. Identity of the flow rock is uncertain. It is tentatively included in the Columbia River Basalt in this report. Locally inflated Columbia River Basalt is exposed in logging roads upslope and laterally to the east and west

The significance of the slide rests in the implications it holds for other areas of similar geologic setting in the watershed. Prior to sliding, the site was characterized by a cover of numerous trees and brush growing on a steeply sloping reddish brown soil mantle in a region mapped as Columbia River Basalt. The presence of a sedimentary interbed was not suspected. Likewise no outcrops were available to suggest the presence of inflated flow rock.

Blasting mobilized the sedimentary rock, which in turn undercut the flow rock upslope. It is recommended that blasting be kept to a minimum near areas of steep slope. Soil studies on the slopes might be of use in identifying potential unstable horizons. Although thin-skinned slides generally will not affect water quality, they are significant from the standpoint of safety.

Larson's Bridge slide: The Larson's Bridge slide is located upslope from Larson's Bridge, one mile upstream from the confluence of the Bull Run and Little Sandy Rivers (Figure 53). It is situated in a region of landslide topography and was activated in 1955 by excavations related to the placing of conduit No. 4. According to William A. Liggett, City of Portland Bureau of Water Works, slow movement on the slide after burial of conduit No. 4 gradually crushed the pipeline. Corrective measures included removing much of the upslope load on the slide by leveling the slope. There has been no subsequent movement, and the slide is considered inactive. No engineering studies were conducted prior to excavation of the pipeline. Experience at the Larson's Bridge slide locality points out the need for engineering investigations prior to excavations or construction in areas of landslide topography.

South Fork slides: Aerial photographs, stream patterns, and field inspection reveal the presence of three slide areas in the drainage basin of the South Fork of the Bull Run River (Figure 57). Landslide topography is indicated on the geologic hazards map in areas immediately upstream from the confluence of Cedar Creek and the South Fork of the Bull Run River.

Sliding on the south bank of the South Fork in section 32 has produced a pronounced headscarp on the upper slopes. Thick colluvium obscures the bedrock geology, but regional mapping indicates the presence of Rhododendron Formation in the subsurface. The slide is dominated by rock fragments and reddishbrown loamy soil material (Figure 58). No colloidal red clay is involved and stream-bank erosion is not excessive. During periods of high streamflow, the slide area may contribute to the turbidity of the South Fork of the Bull Run River. In view of the large size of the landslide area and the minimal impact on turbidity, no specific or corrective actions are required.

Three steep slides are present on the south bank of Cedar Creek immediately upstream from the confluence of the South Fork of the Bull Run River. They average 50 to 100 feet in width and extend upslope similar distances. The slide material consists of reddish-brown loamy soil and boulders. There is no red colloidal clay similar to that involved in the North Fork Slide.

A log jam on the north bank of Cedar Creek diverts the stream against the south bank. Initial diversion probably occurred during times of high flow, but the stream is now entrenched in its new channel and continues to flow along the south bank even during times of low flow. Undercutting of steep colluvial slopes initiated the slides. Massive landslide topography is not developed upslope as at the North Fork slide.

Potential impact of the slides lies in the turbidity they may contribute to the South Fork of the Bull Run River, one of the more turbid streams in the watershed in recent years. The slides have probably been contributing debris to Cedar Creek for several years. In the absence of detailed data it can be assumed that future turbidity will approximate that of past years.

Removal of the log jam would reduce stream-bank erosion in times of high flow and would minimize turbidity. Further corrective actions on the scale of those employed at the North Fork slide would not be realistic. The overall setting and slide potentials of the two areas are considerably different. If further sliding should reveal the presence of pods of red colloidal clay, however, further corrective measures will be required.

One mile upstream from the confluence of the South Fork of the Bull Run River and Cedar Creek, in section 27, the course of Cedar Creek makes a sharp turn in the form of a semi-circle. Material on the north bank of the creek inside the bend is rocky, flat-lying, and stable and presents no threats to water quality. Stream-bank erosion in the future on the south bank could contribute to stream turbidity. Field examination revealed no active slides of significance at the present time, however. Log jams that develop in the area should be removed.

Headworks landslide area: The Headworks landslide area is situated on the north bank of the Bull Run River at the Headworks and Bull Run Dam No. 2 approximately 5 miles upstream from the community of Bull Run (Figure 59a). The slide is not mentioned in early studies regarding dam construction (Stevens and Thompson, 1957; Ruff, 1957) and was not fully appreciated until the later stages of construction (Schlicker, 1961; J. E. Sceva, written communication to L. A. Stanley, 1961). Understanding of the highly variable soil conditions at the site, however, was apparently sufficient to assure the construction of a safe structure. Shannon and Wilson (1963) document the coordination of on-site engineering investigations with the various stages of construction.

The landslide mass covers approximately 0.7 square miles. It is composed primarily of Rhododendron material which has slid downslope from the north, leaving a large concave headscarp or scar along the crest-line overlooking the valley. Within the slide mass, blocks of flow rock assigned to the Pliocene volcanic rock (Tpv) have moved downward several hundred feet (Figure 59b).

In the valley the landslide debris is characterized by irregular topography and irregular drainage (Figure 60). Sceva (written communication to L. A. Stanley, 1961) noted that at least one intermittent stream disappears into the debris. Springs are common (Shannon and Wilson, 1963). Blocks of lithified Rhododendron material are scattered randomly over the slide surface (Figures 61, 62, 63). Mounds of large angular andesite boulders derived from the crest line are incorporated into the slide debris on the north side of the valley. Voids are common between the boulders (Shannon and Wilson, 1963). In places, the slide mass overlies terrace material (Qtg) (Figure 64).

Direct measurements of the depth of failure in the deeper parts of the slide are not available. Shannon and Wilson (1963) record depths of 90 feet to bedrock near the north abutment of Bull Run Dam No. 2. Upslope the slide debris may easily exceed 100 feet in thickness.

The slide is probably a few thousand to 15,000 years old. The reduced low-lying topography of the distal parts of the slide may have resulted from erosion or from mudflow processes during sliding. Possibly also some of the lower-lying material mapped as Quaternary landslide debris may be deeply weathered Rhododendron Formation in place. Wood debris in the slide material could possibly be used to obtain a radiocarbon age date for the sliding (Sceva, written communication to L. A. Stanley, 1961).

The Headworks slide is apparently inactive under present conditions. The major impacts of the slide include the unpredictability of cut slopes in excavations, the highly variable foundation characteristics, and the high permeability of various rock types within the slide mass. Two deaths during construction of the dam and related facilities are attributed to cave-ins. Piping of reservoir water was a prime concern during construction (Shannon and Wilson, 1963).

Detailed engineering investigations are recommended for all future construction in the slide area. The potential for unpredictable cave-ins should be fully appreciated and guarded against in all excavations. In addition, piezometer readings and dam-water surface elevations should be monitored, recorded, and correlated with precipitation data. Deviations from the norm may indicate impending trouble.

## Runoff

Average annual runoff for the Bull Run Watershed upstream from the Headworks is 105 inches. Runoff in the steeply sloping, eastern parts of the watershed approaches 145 inches per year; runoff near the Headworks is as low as 40 inches per year.

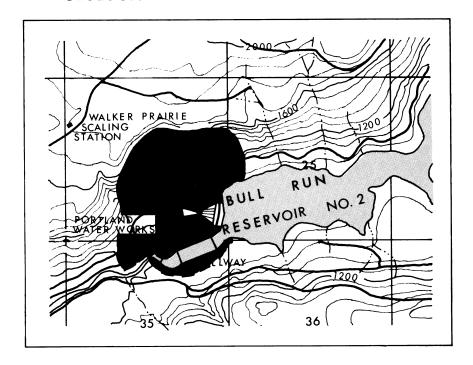


Figure 59a. Headworks landslide location map.

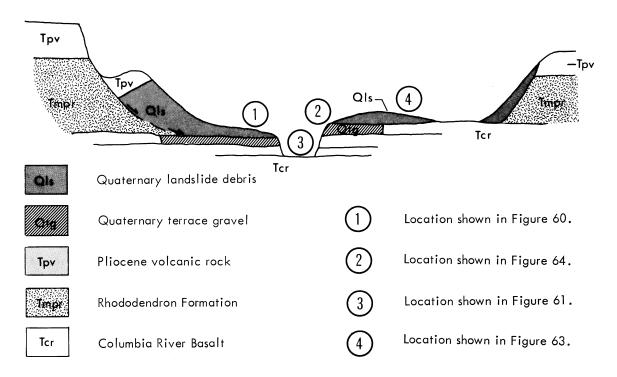


Figure 59b. Diagrammatic cross section of Headworks landslide area.



Figure 60. View from Bull Run Dam No. 2 looking north at irregular terrain of the Headworks landslide; note the poorly sorted, unbedded rubble in the cut to the left.



Figure 61. The plunge pool for the Headworks spillway is cut into flows of Columbia River Basalt. Large block of Rhododendron breccia probably slid to its present location.

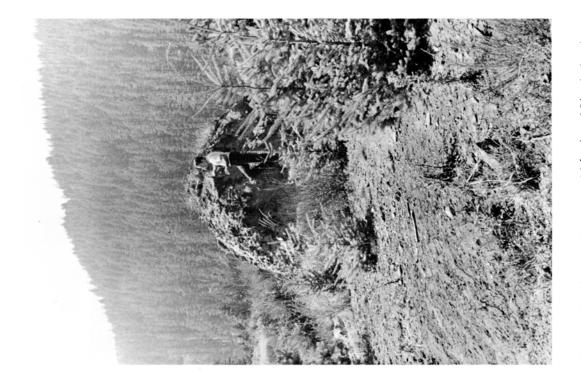


Figure 63. Large disoriented blocks of Rhododendron Formation breccia are present in the Headworks landslide.



Figure 62. Riprap and cribbing protect displaced block of Rhododendron breccia from high winter runoff.

Average daily flow of the Bull Run River is 516 million gallons (Table 1) or six times the average daily use (88 million gallons). Annual flow averages 180 billion gallons (Figure 65). Maximum daily use (228 million gallons) is almost six times the all-time-minimum daily flow (40 million gallons). Coincidence of maximum use and low stream flow necessitates reservoir drawdown in the late summer months (Figures 66 and 67). Reservoir capacity is 250 times average daily use. Transmission capacity of the conduits (225 million gallons per day) leading to Portland is approximately equal to maximum daily use (228 million gallons).

Runoff data for four of the major streams within the watershed is presented on Table 2. Average flow for the streams is approximately 8 to 9 cubic feet per second per square mile of drainage area. Maximum peak flow for the North Fork of the Bull Run River for the period 1965–1970 (1,160 cfs) does not differ from that of other streams when expressed in terms of cubic feet per second per square mile. The surge of 9,800 cubic feet per second calculated for January 20, 1972 is subject to various interpretations and probably resulted from unnatural influences (see Rapid Runoff).

Table 1. Surface water data, Bull Run drainage

Average daily flo Maximum daily f Minimum daily f Peak discharge (l	low (De ow (Au	ıg. 14	4, 1	926	 ) - 	- - - -	- - -	516 mgd (564 cfs) 16.2 bgd (25,000 cfs) 40 mgd (63 cfs) 265,000 gps (35,000 cf
Use Average daily us Maximum daily u		 	-	- ·		. <u>-</u>	- -	Million gallons per day 88 228
Storage  Bull Run Lake - Reservoir No. 1 Reservoir No. 2 Portland Total	  	  		- ·	  	· -	- - - -	Billion gallons 5 10 7 0.235 22
Transmission capacitie Conduit No. 2 Conduit No. 3 Conduit No. 4 Total	es   	  	- - -	- ·	  	· - · -	- - -	Million gallons per day 50 75 100 225

Rapid runoff: Occasionally during the wet season, the saturated soil conditions, steep slopes, and heavy rainfalls of the Bull Run Watershed produce hazardous runoff. Under exceptional circumstances the impact reaches disastrous proportions. Exceptionally heavy rains coupled with a rapidly melting snowpack produced a recorded flow of 35,000 cubic feet per second at the Headworks on December 22, 1964. Streambank erosion immediately downstream from the spillway plunge pool of Bull Run Dam No. 2 nearly severed conduits 2 and 4, a circumstance which would have severely restricted Portland's water supply (Figures 68, 69,70).

There is no way to restrict high runoff from the entire watershed during conditions as extreme as the flood of 1964. However, protective measures can be taken to prevent disastrous consequences in critical areas. For example, a qualified engineering geologist should examine the area of the stream bank attacked by the 1964 flood to determine what corrective measures, such as grouted riprap or piling, may be required to adequately protect it against similar erosion in the future.

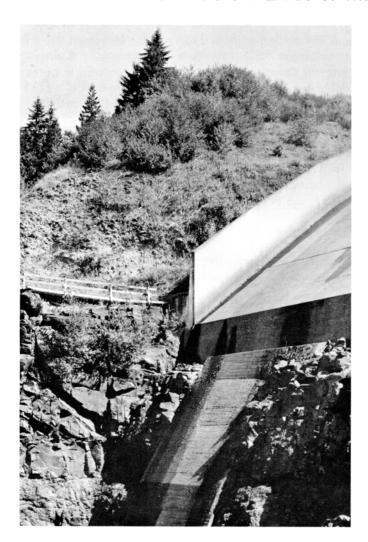


Figure 64. At the Headworks spillway, terrace gravel overlies the Columbia River Basalt and underlies slide debris.

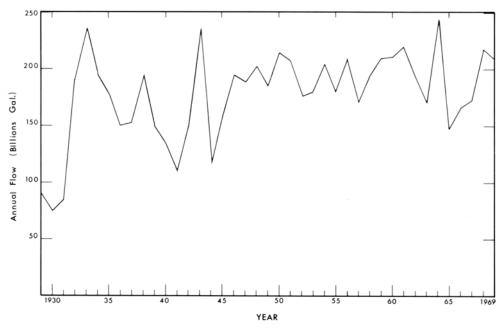


Figure 65. Bull Run River streamflow (1929-1969).



Figure 67. Dry weather and high consumption of water necessitate drawdown by late summer.

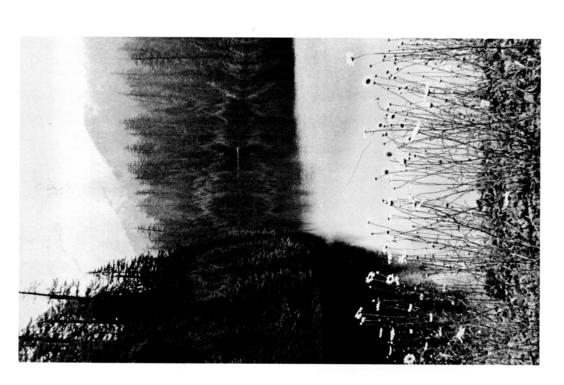


Figure 66. Reservoir levels in winter and spring are high.



Figure 68. Low streamflow of the Bull Run River in the summertime belies the threat of rapid runoff.



Figure 69. Streamflow at the Headworks on December 22, 1964 was 35,000 cfs (same location as Figures 68 and 70).

Drainage	Area (sq mi)	Avg flow (cfs)	Min flow (cfs)	Max flow (cfs)	Max flow per sq mi
Blazed Alder Creek (1963–1970) 600' downstream from confluence of Bedrock and Hickman Creeks	8.2	57.7	1.5	1220	149
Bull Run River (1966-1970)  1.2 miles upstream from mouth of the North Fork	50	400	33	6540	131
North Fork of the Bull Run River (1965–1970)  Near mouth	8.3	70.2	9.8	1160 9800*	140 1180
Cedar Creek (1965-1970)  Mile 2.5	7.9	61.5	7.1	884	112
*January 20, 1972 (see text)					

Table 2. Runoff of four drainages in the Bull Run Watershed

On January 20, 1972, a surge of water gushing down the channel of the North Fork of the Bull Run River triggered a landslide (see Landslides - North Fork Slide) which elevated stream turbidity to extremely high levels (see Turbidity). By examining available flood marks and employing standard slope-area measurement techniques, personnel of the U.S. Geological Survey determined a flood level of 9.89 feet and an equivalent streamflow of 9,800 cubic feet per second at the North Fork gaging station (Clyde Anderson, 1973, oral communication). Because substantial amounts of debris, mud, and logs were incorporated in the surge, actual streamflow may have been considerably less. However, the size of the measured flow is an order of magnitude larger than any other floods recorded on the North Fork (Table 2). More reliable streamflows determined later in the same flood (2,800 cfs at 9:30 p.m., January 20, and 1,700 cfs at 1:00 a.m. January 21) also are significantly greater than any other floods on the stream.

The surge flood was probably caused when warm rains and an abrupt rise in temperature broke an ice dam on the Boody Reservoir spillway upstream, sending the impounded water cascading down the valley of the North Fork. Photographs taken shortly thereafter document a rapid drawdown at the reservoir (Figure 71) and record the marked erosion of the spillway leading from the reservoir (Patterson, 1973). At the mouth of the North Fork, nearly 2 miles from the slide area and 6 miles from the spillway, a large-diameter culvert was washed out; boulders hurled by the floodwaters ripped bark off trees 10 feet above the ground (Figure 72), and the delta was greatly enlarged (Figure 73). Although log jams may have been of local significance, they clearly did not generate the flood. Their damming effect, however, did amplify the recorded flood peak.

Owing to the potential for high turbidity along the North Fork, corrective measures are needed to minimize the flood potential of the channel. Ice jamming of the Boody spillway should be prevented through constant surveillance, redesign, or removal of the spillway constriction. The extent of the upland meadows at the head of the North Fork and the road crossing at the Boody site, however, pose the threat of ice damming and surge flooding even if the dam is removed. Use of the dam to adjust runoff during times of high winter streamflow is worthy of investigation from a geologic standpoint.

Logging in the drainage basin of the North Fork should be restricted as a means of retarding the melting rate of the snowpack. Also, corrective measures employed to date at the slide area should be reevaluated in terms of new data regarding stream flow, channel roughness, and actual performance (Figure 74). Removal of red clay and other debris from the overflow channel (see North Fork slide) is recommended. Riprap may be needed to buttress the stream bank against further sliding.

Most roads in the Bull Run Watershed are well constructed to allow for rapid runoff. Culverts generally are well-spaced and are of adequate size to handle surface water (Figures 75 and 76). However, problem areas of small culverts which might plug quickly are a matter of concern. Because much of the

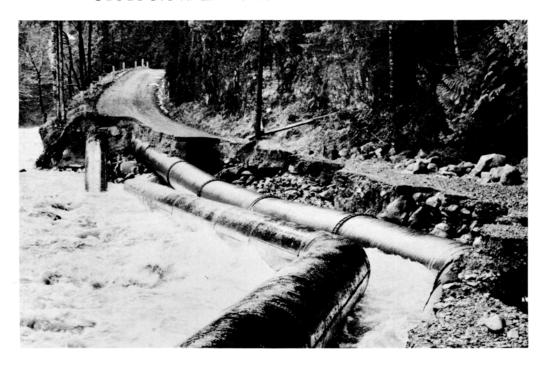


Figure 70. Stream-bank erosion on December 22, 1964 destroyed part of one conduit and threatened two others (same  $1\infty$  ation as Figures 68 and 69).

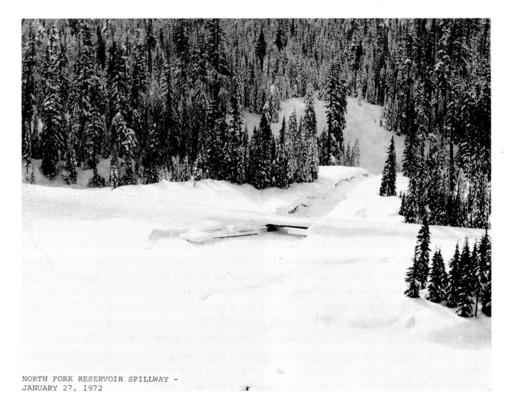


Figure 71. Sagging ice at the North Fork (Boody) Reservoir immediately after the North Fork flood suggests rapid drawdown.

runoff in the watershed occurs short distances beneath the ground surface in the upper soil zones, roads with significant cuts must be adequately engineered.



Figure 72. Geologist points to boulder scars on a tree at the mouth of the North Fork.

Logging can have adverse impact on land stability and water quality in certain areas. The removal of trees increases the water content of the soil as discussed below. This, in addition to the loss of root support, may promote sliding. Accelerated snowmelt in areas no longer protected by trees can lead to gullying, flash flooding, stream-bank erosion, and increased turbidity. During warm summer months exposed slopes may experience increased evaporation as shown by the disappearance of springs in such areas as the Tillamook Burn.

Rainfall-generated runoff in areas similar to that of the Bull Run Watershed shows little adverse impact from logging (Rothacher and others, 1967; Dyrness, 1969; Rothacher, 1970; Harris, 1973). Increases in peak flow are minimal, and in one study (Harris, 1973) no measurable increase of flooding accompanied logging. However, Harris (1973) found that logging in a drainage basin tributary to the Alsea River in the Oregon Coast Range increased slightly the total runoff and late-summer streamflow. This phenomenon contradicts the observations in the Tillamook Burn and underscores the need for rigorous investigation of each basin on an individual basis.

Clear-cutting eliminates the gradual water loss from the soil through evapotranspiration of the trees, resulting in increased annual runoff even though peak flood discharges show no significant change. It is estimated that in areas of thick soil, high precipitation, and high evapotranspiration (such as the Bull Run Watershed), the increased annual runoff following logging may be as much as 18 inches (Rothacher, 1970).

Sustained yield practices, selective logging, aerial logging, care in road construction, and local geologic, geographic, and climatic conditions may significantly alter the influence of logging on land



Figure 73. The delta at the mouth of the North Fork was greatly enlarged during the flood of January 20, 1972.



Figure 74. Large riprap is needed for channel modifications at the site of the North Fork slide.



Figure 75. Heavy rains result in rapid runoff at or slightly below the ground surface.



Figure 76. For most roads, culverts are needed to handle rapid runoff after storms.

stability, turbidity, and runoff. It is imperative that each basin be evaluated on an individual basis and with an appreciation of the potential offered by various logging techniques. The hydrology of the Bull Run Watershed is not now completely understood.

Turbidity: Water quality in the Bull Run Watershed is generally very good (Figure 77). Little basic data is available, however, regarding the precise turbidity of streams in the Bull Run Watershed under varying conditions over extended periods of time. During the North Fork flood of January 1972, runoff entering Bull Run Reservoir No. 1 from that stream was reddened with colloidal clay derived from the North Fork slide. Turbidity of water in the reservoir registered 170 JTU (Jackson turbidity units), exceeding current Federal standards by a factor of 85 times.

Starting on January 1, 1973, daily records of the turbidity have been kept for Bear Creek, Cougar Creek, Deer Creek, the North and South Forks of the Bull Run River, Cump Creek, the West Fork of Camp Creek, and Fir Creek. No regular records are being kept for West Branch, Falls Creek, Blazed Alder Creek, Log Creek, and the upper Bull Run River. Between January 1, 1973 and October 15, 1973, turbidity on the North Fork exceeded Federal standards for drinking water (2.0 JTU) four times and turbidity on the South Fork exceeded Federal standards one time (Tables 3 and 4).

The North and South Forks of the Bull Run River pass through Rhododendron Formation terrain. Exposures of the unit along the North Fork, which displays the most critical turbidity, contain pods of colloidal red clay and beds of fine-grained pyroclastic material. Both streams are relatively large compared to other streams passing through Rhododendron terrain which have little or no turbidity problem (e.g., Bear Creek, Deer Creek, Cougar Creek). The interaction of rock type and stream-bank erosion has produced massive landslides along the North and South Forks. In addition, the course of the North Fork meanders greatly in the area of the North Fork slide.

Table 3. Stream turbidity (January 1 - October 15, 1973)

	-	ant maxima .5 JTU)		
Creek	in JTU*		Minimum	Average
Bear Creek	.6	Jan. 17	.1	.15
Cougar Creek	.5 .7	Jan. 3 Jan. 12	.1	.15
Deer Creek	.9 1.1	Jan. 3 Sept. 24	.1	.15
North Fork	2.8 1.3 1.2 19.0 .9 2.5 5.5	Jan. 12 April 15 June 25 Aug. 23 Sept. 7 Sept. 20 Sept. 24	.2	.30
South Fork	1.6 .5 3.1	Jan. 12 April 17 Sept. 24	.1	.20
Camp Creek	.6 .7	Jan. 12 Jan. 17	.1	.15
West Fork of Camp Creek	.5 .5	Jan. 12 Jan. 17	.1	.20
Fir Creek	.6	Sept. 24	.1	. 25
*Jackson turbic	lity units			

Table 4. Stream turbidity and precipitation (January 1 - October 15, 1973)

Days of high turibidity* in at least one stream	Rainfall at the Headworks (inches)			
January 3				
January 12	1.6			
January 17	0.9			
April 15	1.5			
April 17	0.7			
June 25	1.5			
August 23	1.7			
September 7	1.7			
September 20 – –	0.3			
September 24 – –	1.6			
* > .5 Jackson turbidity un	its			

Although turbidity along Fir Creek is not presently a problem, the creek does possess critical features related to turbidity. The stream is relatively large, passes through the Rhododendron Formation, and is bordered in places by massive landslides. In addition, pods of red clay are present in the Rhododendron Formation nearby (Figure 13). Possibly the limited scope of turbidity data available at the present time does not reflect the true turbidity potential of that creek.

Under natural conditions, the discharge, velocity, bedload, and channel geometry of a stream are in an approximate state of equilibrium. Changes in any one of the factors has an impact on the others. For instance, an increase of discharge generates modifications of channel geometry, an increase of streambank erosion, and an increase in turbidity.

In the Bull Run Watershed the erodability of the Rhododendron Formation causes the high turbidity potential of the North Fork, the South Fork, and possibly Fir Creek. Modifications of the regimen of these streams could have adverse effects. Consequently, diversion of runoff from the Good Fellow Lakes area into the headwaters of Cedar Creek is not recommended. The possible hazards posed by ice jamming of new channels at high elevations (see Rapid Runoff) also argue against such a project. Aternatively, the potential for flood and turbidity control favors a dam on Cedar Creek.

Although available studies indicate that logging operations may greatly increase annual sediment yield and water temperature (Harris, 1973; Dyrness, 1969), it is clear that each watershed must be evaluated on an individual basis. In the H. J. Andrews Experimental Forest east of Eugene, Dyrness (1969) noted no change in sedimentation during clear-cut logging for a period of 2 years. After logging was completed and all slash had been burned, sediment yield increased greatly. During the first year (1966–1967) after slash was burned, sediment yield increased by a factor of 67. During the second year (1967–1968) sediment yield was still 28 times the norm. Apparently, removal of debris from the creeks and vegetation from the slopes by indiscriminant slash burning is a critical factor in turbidity. Such practices should be restricted in the Bull Run Watershed, where water quality is a prime concern.

Bedload and turbidity data for extended periods of time in the H. J. Andrews Experimental Forest is given on Table 5. It is emphasized that the Bull Run Watershed differs significantly from the H. J. Andrews Experimental Forest in many important respects: (1) Average slope of the Bull Run Watershed is approximately 30 percent rather than 50 percent; (2) Bedrock of the Bull Run Watershed consists largely of relatively slide-resistant volcanic rock rather than slide-prone mid-Tertiary pyroclastics, and (3) Road failures are almost nonexistent in the Bull Run Watershed, whereas they are common and contribute considerably to turbidity in the H. J. Andrews Experimental Forest (see Table 5).



Figure 77. In their natural state, the smaller streams of the Bull Run Watershed are characterized by very low turbidity.

Figure 78. Goodfellow Lakes drain into the Sandy River (left) under natural conditions. Earlier proposals to shift the drainage into the Bull Run Watershed (right) are of questionable merit from a geologic standpoint (see text).



Table 5.	Changes of suspended load and bedload in two logged drainages in the
	H. J. Andrews Experimental Forest*

Watershed	Sediment yield (tons/sq mi)	Sediment yield of control watershed (tons/sq mi)	Sediment yield relative to control
Clearcut without roads			
Suspended load	195	46	4.2
Bedload	112	47	2.4
Total load	307	93	3.3
Patch-cut with roads			
Suspended load	1,430	36	39.0
Bedload	6,550	37	1 <i>7</i> 8.0
Total load	7,980	73	109.0
*Adapted from Dyrness	(1969)		

Because water from the Bull Run Watershed is used for domestic purposes with only minimal treatment, turbidity is a critical parameter requiring close study. The turbidity of West Creek, Falls Creek, Log Creek, the upper Bull Run River, and Blazed Alder Creek should be measured on a regular basis. Ideally, a control watershed within the drainage should also be established in which no development is allowed. Changes of turbidity in other streams could be compared with those of the control watershed to determine whether they resulted from natural means or from logging, road construction, dam building, or other activities of man. Information provided by daily stream monitoring and comparison with the control watershed could provide the factual basis for future policy decisions in the Bull Run drainage. The control watershed need not encompass the entire drainage of a creek.

Logging may eliminate loss of water through plant transpiration and thus may lead to increases in the water content of the soil. The slides which result can increase turbidity considerably or can destroy man-made structures. Consequently, logging should be severely restricted in landslide areas. Selective logging may be possible in places. Maps provided in this bulletin should be regarded as approximate, and on-site evaluations must take precedence over them in making final decisions regarding individual areas. Logging in areas of active sliding (see Massive landslides) should be prohibited.

Log jams which redirect stream flow against the sides of the stream can easily initiate slides and increase turbidity (Figure 79). They should be removed (see Massive landslides - South Fork slides). Reservoir drawdown in the late summer months exposes silt and clay to wave action (Figure 80). No realistic means of control is known for turbidity generated in this way.



Figure 79. Log jams, windfalls, and other obstructions promote stream-bank erosion and turbidity; they should be removed wherever feasible.



Figure 80. Late summer drawdown exposes large areas to wind, water, and wave erosion and can be a significant factor in reservoir turbidity.

#### Tectonic Hazards

The West Coast of North America is situated in the Circum-Pacific ring of fire, a band which encircles the Pacific Basin and which is characterized by the greatest volcanic and seismic activity in the world. The crustal structure and tectonic behavior of the northwestern United States are very complex. With the limited knowledge available to us at the present time, it is not possible to predict future tectonic activity with any degree of precision.

### Volcanism

The bedrock of the Western Cascades in northern Oregon represents the cumulative result of volcanism over a period of at least 40 million years. Although little is known about the older unit, it is evident that in the past 7 million years more than 100 cubic miles of rock has been erupted in the Mount Hood area alone (Wise, 1969). Almost half that volume is represented by Mount Hood volcano and neighboring vents of Quaternary (0 to 2 million years) age. In the Bull Run drainage young vents include west Ashoff Butte, a cone at Wlker Plain, and an intracanyon accumulation of flow rock at the west end of Bull Run Lake.

A dacite plug was extruded from the vent of Mount Hood volcano as little as 2,000 years ago (Wise, 1968). Historic records of activity on Mount Hood are poorly documented and subject to debate. The August 17, 1859 edition of the weekly <u>Oregonian</u> comments on activity at that time, and in 1865 a night guard at Fort Vancouver reported seeing and hearing an eruption on the mountain (Folsom, 1970). Fumaroles and hot spots near the crest are active at the present time.

The extreme glacial dissection of Mount Hood indicates that the cone has not been significantly active for at least 10,000 years. Such a time span is little in the life of a large volcano, however. Although there is comfort in the great number of years involved, that time span does not eliminate the possibility of future volcanic activity in the area (Figure 81).

Mount St. Helens, located 60 miles to the north, was active nine times between 1831 and 1857. The eruption of 1831 spread a layer of ash as far north as Mount Rainier; eruptions of 1842 continued during most of the year and spread ash as far east as The Dalles (Folsom, 1970). Numerous flows and eruptions during the past few thousand years in the Cascades to the south are described by Taylor (1965).

To assess the probability of further activity on Mount Hood, personnel of the U.S. Geological Survey have begun geophysical monitoring on a limited basis. Personnel of the Oregon Department of Geology and Mineral Industries have made preliminary arrangements to receive infrared imagery of the vent area on a periodic basis. Follow-up seismic studies may be warranted in the future.

A determination of the consequences of an eruption of Mount Hood requires an estimation of the type of eruption that might occur. McBirney (1968) groups the Cascades volcanoes into two types. The divergent volcanoes, such as Mount Mazama (Crater Lake) are composed largely of two distinct rock types, rhyolite and basalt, and are characterized in their later stages by violent eruptions. The convergent volcanoes are composed primarily of one rock type of intermediate composition (e.g. andesite).

Eruptions in the Mount Hood area consisted of andesite between 4 and 7 million years ago and andesite with minor basalt between 2 and 4 million years ago. Mount Hood volcano, erupted during the last 2 million years, consists of olivine and pyroxene andesite and hornblende dacite. Possible divergence of rock types is indicated and Mount Hood is similar in some respects to Mount Mazama during its early stages of development. It would appear that lava flows, mudflows, and violent eruptions are possible. Pyroclastic rocks are common on the flanks of the mountain.

Lava flows, mudflows, and breccia eruptions would have no significant impact on the Bull Run drainage. The divide at Hiyu Mountain would direct the material to the northeast or southwest away from the watershed. Extremely large mudflows proceeding down the Sandy River could conceivably destroy the aqueducts near Dodge Park, however.

The eruption of ash from Mount Hood would have a profound effect on the quality of water in the Bull Run Watershed. As the material settled into the reservoirs or onto the land, later to be washed into the reservoirs, turbidity would increase considerably. If the ash fall were sufficient to kill vegetation, water quality would be affected for years to come.

Events of low probability but high impact, such as volcanic eruptions, are difficult to incorporate into the planning process. Moreover, there is no means of controlling volcanic activity. If in future years it should be determined that volcanic activity is imminent, the only realistic course of action would be to develop a supplementary source of water for the Portland area and to draft emergency procedures for distribution if that supply were limited.

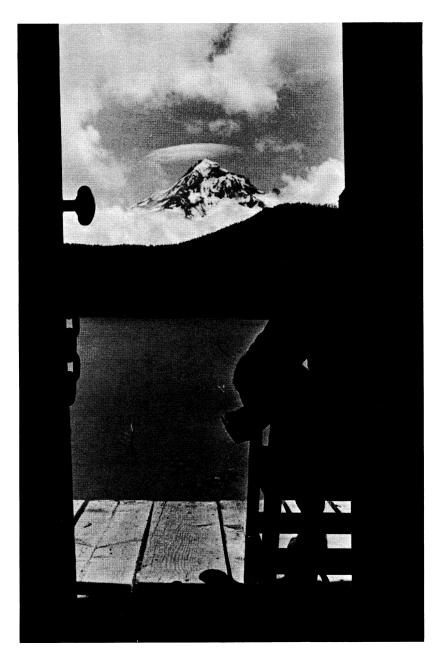


Figure 81. Placid though Mount Hood may appear from Bull Run Lake, the threat of possible future eruption is very real.

## Earthquakes

The shaking of the earth's surface which accompanies the release of energy at depth is called an earthquake. Associated with the release of energy are displacements of rock along planar surfaces. The specific location of the displacement within the earth is called the focus; the geographic location above the focus is called the epicenter. Where planes of displacement intersect the ground surface they are mapped as faults. Only rarely do we actually see ground displacement associated with a particular earthquake.

A seismic risk map for the State of Oregon (Figure 82) shows the Bull Run area to lie in zone 2, an area where quakes with intensities as high as VII on the Mercalli Scale are possible (Table 6). Historic earthquakes in the Portland area vary between intensities IV and VI (Berg and Baker, 1963; Dehlinger and others, 1963; Schlicker and others, 1964; and Couch and others, 1968) and may be related to the Portland Hills Fault. Earthquake activity in The Dalles area (Berg and Baker, 1963) may be related to the Hood River Fault Zone. An earthquake of Mercalli intensity IV+ was reported at Bull Run on December 26, 1919. The quake is statistically of little significance and possibly was mislocated. There are no mappable faults in the Bull Run Watershed.

An earthquake of Mercalli intensity VII is capable of cracking walls and causing general alarm. Under unfavorable circumstances, such a quake can initiate movement on landslides which, in turn, can damage aqueducts or generate turbidity. It is recommended that the safety factors for landslide-correction projects in critical areas be calculated on the basis of a Mercalli VII earthquake, if possible.

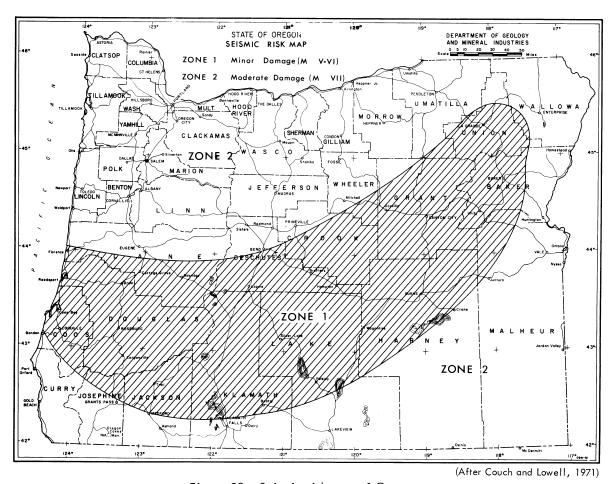


Figure 82. Seismic risk map of Oregon.

Table 6. Scale of earthquake intensities\*

Mercalli Intensity	Description of effects	Equivalent Richter magnitude
1	Instrumental: detected only by seismographs	
П	Feeble: noticed only by sensitive people	3.5 to
Ш	Slight: like the vibrations from a passing truck; felt by people at rest, especially on upper floors	4.2
IV	Moderate: felt by people walking; swaying of loose objects, including standing vehicles	
٧	Rather Strong: felt generally, most sleepers awakene and bells ring	to d 4.8
VI	Strong: trees sway and all suspended objects swing; damage by overturning and falling of loose object	4.9 to 5.4 s
VII	Very Strong: general alarm; walls crack; plaster fal	ls 5.5 to 6.1
VIII	Destructive: car drivers seriously disturbed, masonry fissured, chimneys fall; poorly constructed buildir damaged	y 6.2 ngs to
IX	Ruinous: some houses collapse where ground begins to crack, and pipes break open	6.9
X	Disastrous: ground cracks badly; many buildings destroyed; railroad lines bent; landslides on steep slopes	7.0 to 7.3
ΧI	Very Disastrous: few buildings remain standing; bridges destroyed; all services disrupted; large landslides and floods	7.4 to 8.1
XII	Catastrophic: total destruction; objects thrown into the air; ground rises and falls in waves	Max. recorded 8.9
*After H	Holmes (1965)	

#### MINERAL RESOURCES

The Bull Run Watershed is characterized by moderate to heavy rainfall, exceptional timber potential, and volcanic bedrock. Quarry stone capabilities and ground water are briefly reviewed here. Timber growth is beyond the scope of this paper. No metallic mineralization is present in the watershed.

# Quarry Stone

Local demand for quarry stone in the watershed includes the need for coarse to medium riprap for channel modifications and stream-bank protection and the need for road metal to surface the many access roads. The three major rock units (Columbia River Basalt, Rhododendron Formation, and Pliocene volcanic rock) provide reserves for each of these uses.

# Columbia River Basalt

The Columbia River Basalt consists of coarse- to medium-jointed, hard, dense, basaltic flow rock with subordinate amounts of punky flow rock or pillow lavas in places. Quarries with a potential for producing medium-sized riprap include those located a short distance upstream from the Headworks on the south bank of the Bull Run River and a short distance downstream from the Headworks on the north side of the Bull Run River. Bedrock along the entire south bank of Bull Run Reservoir No. 2 is mantled with only thin surficial debris, and large areas are favorable in terms of quarrying.

In the upper reaches of the Bull Run River, large cliffs and talus deposits in the Columbia River Basalt are composed of rock well-suited for riprap. Commonly, however, inaccessibility or excessive overburden prohibit development. In these areas, also, stream-bank erosion is minimal and the need for riprap is small.

In road construction through terrain underlain by Columbia River Basalt, material from local cuts is generally adequate for use as fill in nearby topographic lows. At the mouth of Bear Creek, basalt taken from adjacent spurs was used to construct a road fill over the creek.

### Rhododendron Formation

The Rhododendron Formation consists of a wide variety of rock types including indurated and unindurated breccia, agglomerate, fine-grained pyroclastics, and platy flow rock. The flow rock is particularly well-suited to use as road metal (Figure 83). Excellent quarries are located in the center of section 10 half a mile north of the center of Bull Run Reservoir No. 1 and in section 1,  $1\frac{1}{2}$  miles northeast of the mouth of the North Fork. Coarse road rock ready for use can be produced by ripping and a minimum of blasting.

### Pliocene volcanic rock

The Pliocene volcanic rock consists of fresh platy to massive flows of andesite and subordinate amounts of basaltic flow rock and agglomerate. Weathering is deep on the gentle upland slopes in the western parts of the watershed. Quarry potential is greatest on the sides of valleys and in the eastern part of the drainage (Figure 84). Excavations into platy talus on the south side of the Bull Run River  $1\frac{1}{2}$  miles downstream from Bull Run Lake provide much of the road metal used in the eastern half of the watershed. The potential for quarry rock is good throughout much of the eastern half of the watershed and local quarries are numerous.

Coarse riprap is available on the talus slopes between the North Fork of the Bull Run River and Falls Creek (Figure 85). Depth of the talus is uncertain and may be small. No survey of the volume or size range of the talus has been made. Gently sloping talus located half a mile west of the Boody Reservoir



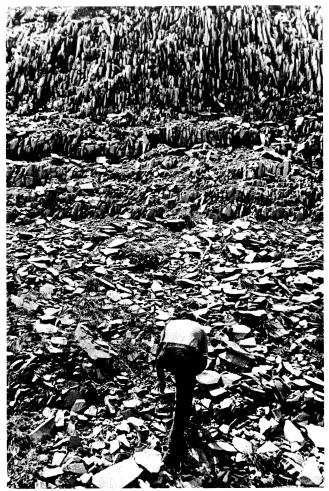


Figure 83. Platy andesite of the Rhododendron Formation is well suited for use in road construction.

Figure 84. Platy andesite of the Pliocene
volcanic rock unit (Tpv) provides
adequate road rock for the eastern
end of the watershed.



Figure 85. Large riprap needed for stream modification is a scarce commodity.

(head of the North Fork of the Bull Run River) was used as riprap for the channel restoration project of the North Fork slide.

## Ground Water

Most of the Bull Run Watershed has good to excellent hydrologic characteristics. Rainfall is moderate to high. Soil thicknesses are great on the gentle slopes in the southwestern part of the watershed and adequate talus mantles most of the steeper slopes elsewhere. Where soil is thin in the east, the Pliocene volcanic rock is well-jointed and accepts large quantities of water. In the valley of the Bull Run River, the Columbia River Basalt is relatively impermeable, but it is mantled in places by terrace material and thick soil. For the watershed as a whole, streams are widely spaced and most runoff occurs in the subsurface. Stevens (1964) provides a detailed presentation of the water yield characteristics of the various soils of the Bull Run Watershed.

### SUMMARY

Geologic hazards in various parts of the Bull Run Watershed include landslides, rapid runoff, turbidity potential, earthquake potential, and possible volcanism. Activities of man include conduit and aqueduct construction, dam construction, road building, logging, and slide correction. To improve or maintain the quality of water available in the watershed, it is necessary that man's activities be keyed to the geologic conditions. This involves adequate engineering investigations for specific projects and the formulation of a realistic management plan for long-term development.

### Conduits and Aqueducts

In the lower Bull Run drainage, aqueducts and footings at river crossings are stable with the possible exception of potential stream-bank erosion and undercutting at the north end of the Dodge Park crossing. Conduits on moderate slopes may be subject to displacement by landslides. In 1965 a conduit at the Ditch Camp slide was temporarily put out of service after sliding, and at the Larson's Bridge slide a buried conduit was slowly crushed after excavations for the conduit apparently had reactivated an old landslide. During the flood of January 1965 extremely heavy runoff at the Headworks spillway undercut conduits 2 and 4.

It is recommended that all conduit construction and modification be preceded by adequate engineering investigations. Special consideration should be given to areas of landslide topography. It is further recommended that all construction for slopes on which conduits are located be evaluated in terms of the potential for reactivating old slides. County road construction initiated movement on the Ditch Camp slide in 1965. In general, trees and other vegetation should not be removed from slopes on which conduits are located. Landslides known to be active, such as the Ditch Camp slide, should be monitored regularly to assure that the conduits are not threatened. Areas where stream-bank erosion threatens conduits, such as the Headworks spillway, should be investigated by qualified personnel and necessary corrective actions taken.

### Dams

Inadequate evaluation of sites for large dams can result in settling, piping, or dam failure. Areas of deep massive failure provide poor foundations and abutments and should be either avoided or investigated in detail prior to construction. Small dams at high elevations may threaten water quality by modifying stream regimen.

Piezometer readings at Bull Run Dam No. 2 should be taken on a regular basis and should be correlated with precipitation data to establish a norm. Variations from the norm may signal piping and an impending disaster. Engineering reports dealing with construction of Bull Run Dam No. 2 should be useful in determining which piezometers to monitor. In all excavations and construction of Bull Run Dam No. 2, the heterogeneity of the land should be fully appreciated. Appropriate safety measures should be taken to avoid damage or loss of life as a result of unpredictable cave-ins.

At high elevations, ice damming of artificial channels and spillways is a constant winter threat. Sudden thaws can send large volumes of water cascading downstream. For several weeks following the North Fork flood and slide of 1972, Portland's water supply was discolored with red colloidal clay. Redirecting runoff into new stream channels elsewhere in the watershed can have similar consequences.

It is recommended that proposed upland impoundment structures be evaluated in terms of potential hazards as well as potential storage capacity. Runoff should not be redirected to new channels unless the potential for stream-bank erosion and increased turbidity can be demonstrated to meet necessary standards. During the winter season the outlet at Boody Reservoir on the North Fork should be observed on a regular basis and should be kept free of ice.

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#### Timber Production

Much of the Bull Run Watershed is well-suited to the production of timber from the standpoints of hydrology, topography, climate, and bedrock geology. The drainage is better suited to timber production than in other areas where logging practices have been linked to increased sliding and increased turbidity. In view of the objective of maintaining strict water-quality standards, however, restrictions on specific logging practices may be needed in certain areas and restrictions on all logging may be required in others.

Clear-cutting should not be allowed in areas of active landsliding and should be restricted in areas of landslide topography. The geologic hazards map outlines these areas in general; however, on-site investigations should accompany final decisions for specific sites. Buffer zones should separate clear-cuts and streams in valley bottoms; clear-cutting may not be advisable in the drainage basin of the North Fork upstream from the North Fork slide, where exposure of slopes could result in rapid snowmelt, heavy overland flow, and flash flooding. Many areas closed to clear-cutting could possibly be harvested by selective logging.

In other areas, extremely large increases in turbidity have been linked to slash burning, and restrictions on slash burning may to be initiated in the Bull Run Watershed. An effort should be made to maintain vegetative cover in logged areas where possible. In areas where understory vegetation is sparse or lacking, selective logging may be required.

#### Roads

Roads provide ready access to most of the watershed for logging and fire prevention. If improperly designed, roads are subject to failure through sliding or washouts, and increased surface-water turbidity may result. Engineering studies should be required for all roads. Culverts and stream crossings should be designed to accommodate the maximum possible runoff. In areas of moderate to steep slopes and thick talus, streams are widely spaced and roadcuts may intersect the dominant subsurface runoff. Fills should be avoided on steep bedrock slopes and care should be taken to avoid oversteepening slopes. Blasting can initiate slides on steep slopes and should be kept to a minimum. Present roads in the Bull Run Watershed are well designed.

#### Slide Correction

Slide correction has been undertaken at the North Fork slide, the Soapstone Hill slide, and the Ditch Camp slide. Because the slides are critically located, it is prudent to reevaluate the corrective measures whenever significant new information pertaining to the slide areas is obtained.

Moderately high streamflow on the North Fork rearranged some of the recently placed riprap at the North Fork slide. Capacity of present structures to accommodate larger floods should be reevaluated in light of this phenomenon. In addition, red colloidal clay that has slid into the overflow channel should be removed because the mere contact of this material with water will result in significant increases in turbidity.

Conduits traversing the Ditch Camp slide are warped downslope, indicating continued movement on the slide. A qualified engineering geologist should examine the slide to determine if further corrective measures are required. As a minimum precaution, movement should be monitored on a regular basis. Increases in the rate of movement may signal a very real threat to the conduits. Vegetation should not be removed from the slide area.

#### Long-Term Programs

A comprehensive regular program of turbidity sampling should be developed for all major streams. In addition, where signficant road building, dam construction, or logging are anticipated, sampling should be conducted before, during, and after construction on a more local basis. Data obtained in this way will provide the factual basis for future modifications of construction or logging techniques or for policy changes. Ideally, control drainages should also be established to permit accurate allowances for natural variations in runoff and turbidity.

Just as natural constraints must be considered in all construction projects, they must also be considered in timber harvesting. In determining annual yield for a sustained yield program, for example, areas where logging is not allowed, such as landslides, should not be included in the calculations. Likewise, windfalls should be considered part of the annual yield. Without accurate data obtained in this way, long-range projections will be in error.

A secondary source of water for the Portland area should be developed for use in the event that Bull Run water should become temporarily unavailable through landslides, ash falls, or mudflows. In addition,

future conduits should be routed to avoid landslide areas, if at all feasible.

By following the guidelines set forth in this study, long term management can deal with present and future geologic hazards in a realistic manner. By avoiding and minimizing future disasters in this way, the well-being of the public will be served.

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