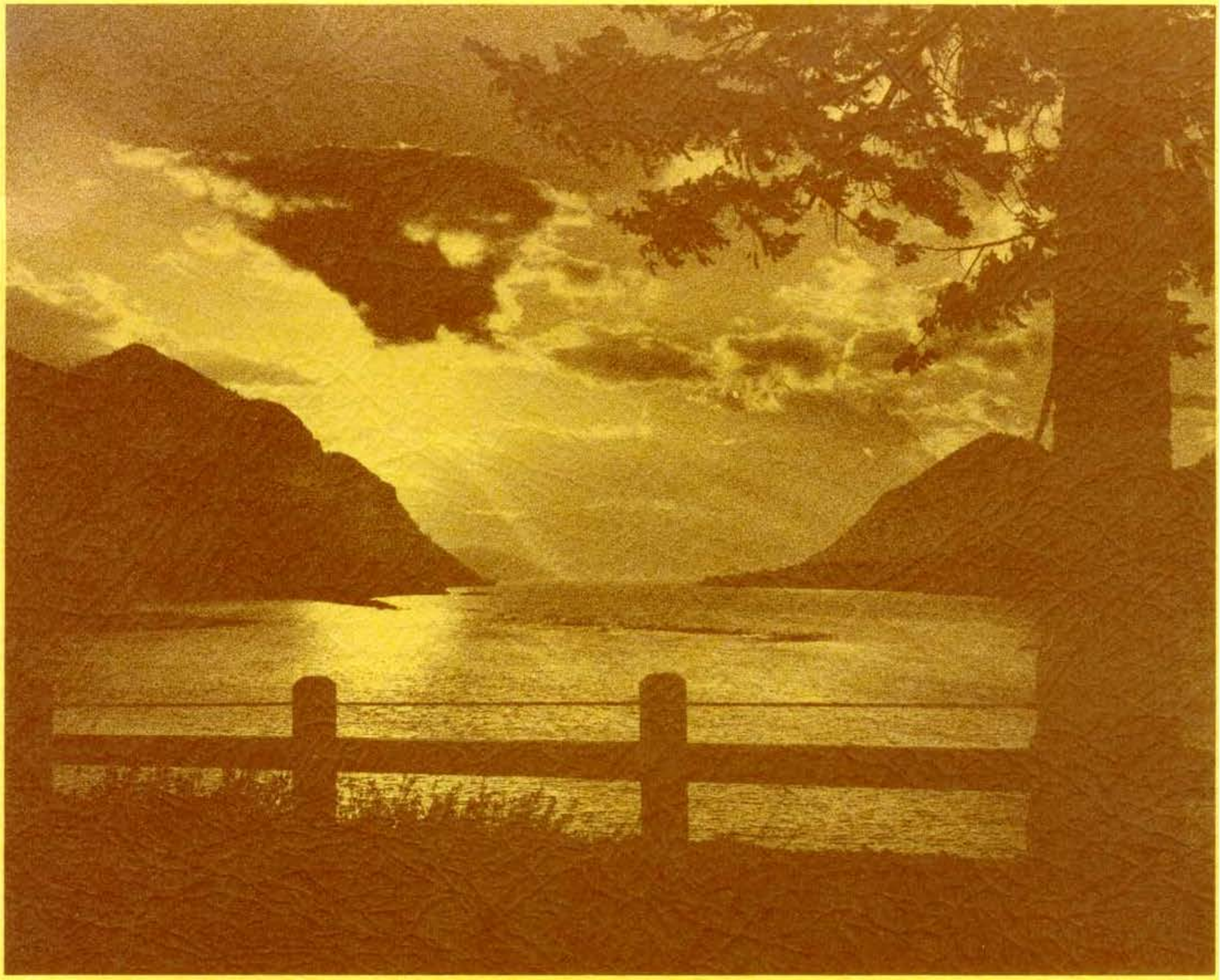

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

GEOLOGIC HAZARDS OF PARTS of NORTHERN HOOD RIVER, WASCO, and SHERMAN COUNTIES, OREGON

1977

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DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1069 STATE OFFICE BUILDING,
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BULLETIN 91

GEOLOGIC HAZARDS OF PARTS of NORTHERN HOOD RIVER, WASCO, and SHERMAN COUNTIES, OREGON

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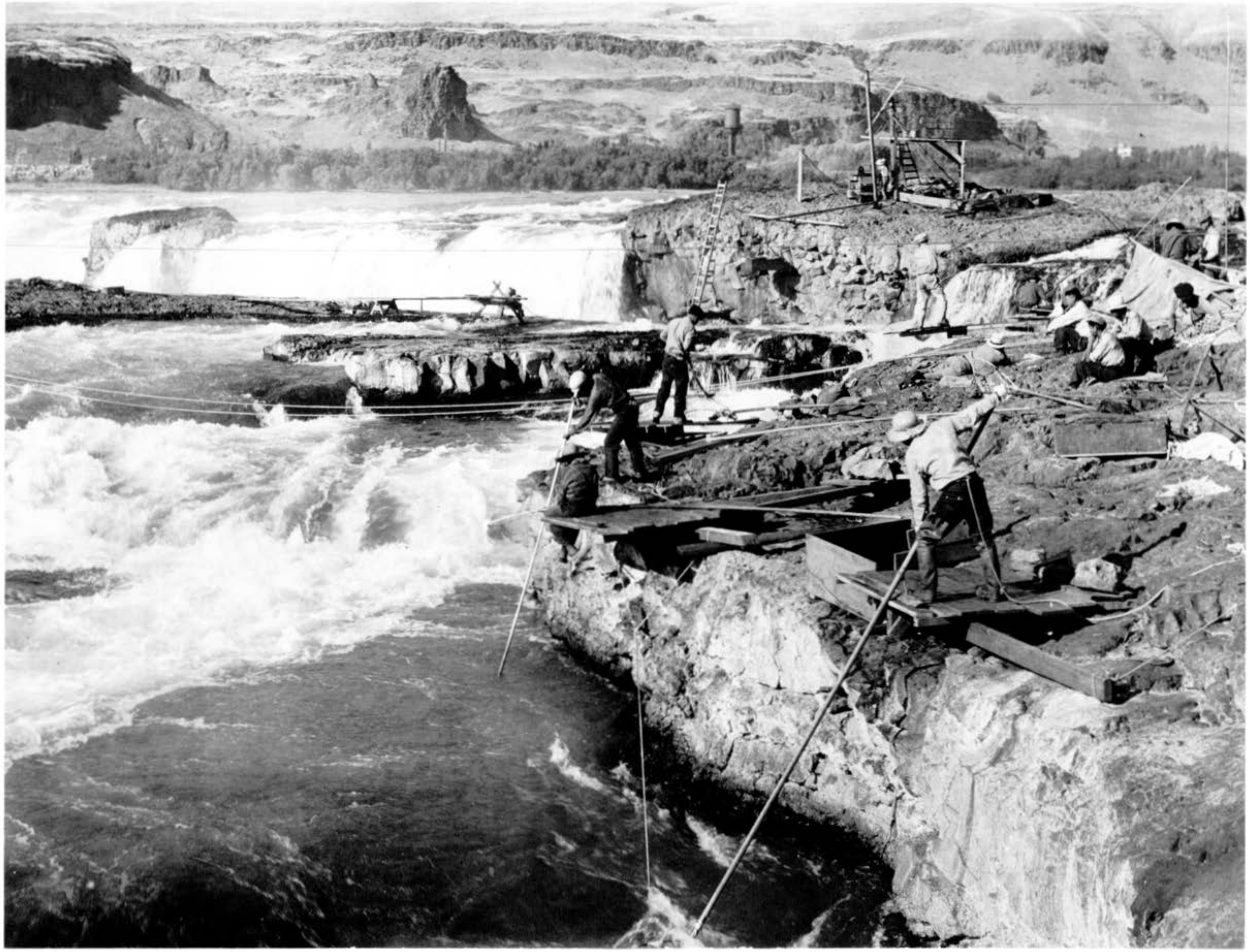

Before completion of the Dalles Dam, the Columbia River flowed over Columbia River Basalt at Celilo Falls near The Dalles, Oregon. Indians, shown here spearing and netting fish from the rocks, were granted sole fishing rights at the falls by government treaty dating from 1855. (Photo courtesy Oregon State Highway Commission)

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Wishram

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Bonneville Dam and Wasco
Hood River
The Dalles
White Salmon
Wishram

Geologic hazards map of The Dalles and vicinity

GEOLOGIC HAZARDS of PARTS of NORTHERN HOOD RIVER, WASCO, and SHERMAN COUNTIES, OREGON

INTRODUCTION

Purpose

Effective land use planning and land management require an adequate data base with regard to the potential uses and limitations of the land. The purpose of this study is to provide practical information on the geologic hazards and engineering geology conditions of northern Hood River, Wasco, and Sherman Counties.

The need for systematic and reliable information of this sort is gaining wider recognition by State officials, county officials, planners, developers, engineers, and private citizens. The need is articulated in Goal 7 of the Land Conservation and Development Commission, which provides for the incorporation of geologic hazards information in planning.

Legal trends in recent years have been toward placing increasing emphasis on comprehensive plans in land use decisions in Oregon (Fasano and Baker v. Milwaukee; Green v. Hayward). Nationwide the trend has also been toward the placing of greater responsibilities on agencies granting permits. In California, for example, when a county road project initiated a landslide, and when runoff from a county-approved subdivision adversely affected neighboring property, liability was placed upon the county (Schlicker and others, 1973).

How To Use

General

Land use planners are persons who use or manage the land with foresight regarding the characteristics of the land. In addition to county and city planners, land use planners to some degree include developers, policy formulators on the national, state, and local level, as well as landholders, architects, engineers, and natural resource specialists.

This bulletin provides planners in northern Hood River, Wasco, and Sherman Counties a synthesis of current thought regarding geologic conditions and hazards in the study area. The material is reconnaissance in nature, however, and is subject to refinement based on additional investigations. The maps represent average conditions as they actually occur on the ground, and on-site examination is required for site-specific evaluation.

The subject matter is organized and cross-referenced to facilitate easy reference. The maps and tables interrelate the various hazards and present information about them systematically. The text is divided into sections dealing with specific hazards or topics structured around the formats of the map legends. The net result is a hazards analysis with a potential for a wide variety of uses (see Figure 1).

Site evaluations

The maps, tables, and text can be employed in assessing the use potentials and use limitations of the land. When these are matched with the specific site requirements of the proposed development and the surrounding area, it will be possible to determine whether the development and site characteristics are compatible. An appreciation of the limitations of map scale is a key prerequisite to final site-specific decisions. On-site investigations are generally required, and consultation of other sources of information is recommended.

Land use capability analyses

Data provided in this bulletin and on the accompanying maps can be used directly in the preparation of land use capability maps or instead in the development of sequences of overlays which will in turn be used to develop land use capability maps. Map-overlay techniques are appropriate preliminary exercises in the preparation of comprehensive plans or in their revision or refinement. To be valid, however, such maps should meet three specifications:

1) The maps should be prepared for individual types of development or for closely related types of development, since the physical requirements of different types of development show considerable variation.
2) Capability categories described in the map legends should be keyed to field observations and site-specific data to assure that they are realistic. Engineering solutions to problems should also be considered.
3) Scale must be properly appreciated, and provisions should be made for exceptions based upon more detailed information. Maps in this study should be regarded as generalized first approximations of actual conditions as they exist on specific parcels of land.

Projection of data

On the county and city levels, specialists commonly possess a wealth of detailed information on specific sites in their respective fields of expertise; but they do not readily have at their disposal a mechanism for projecting their observations into other areas. Thus, an individual may have detailed site-specific information on septic tank failures, aggregate sources, or landslides, but may not have adequate means of anticipating similar problems elsewhere. In this bulletin, geologic units, slopes, and hazards are interrelated in both text and maps to provide the specialist with the tools he needs to extrapolate his observations into new areas, allowing him to make preliminary assessments on sites for which he has no detailed information.

Policy formulation

Used in conjunction with a realistic set of goals, this publication can be invaluable in formulating land use policies on the local and regional level. Such policies should represent a coordinated effort on the part of government agencies of various levels, should consider all significant geologic hazards, and should make provisions for local conditions as revealed by more detailed study or on-site investigation. Although policies should be designed to protect the safety and well-being of the public and the best interests of society, they should not be based on over-reactions arising from inadequate or inappropriately applied information regarding geologic hazards.

Map Scale and Detail

Obtaining appropriately detailed data for a particular planning task is often the most significant informational concern of the planner. Inventories are generally conducted for a variety of purposes and are available on a variety of levels of detail. Confusion may result if the degree of generalization needed to generate a planning tool on a statewide, countywide, or citywide basis is not distinguished from the degree of specificity needed for local implementation such as site-specific decision making or the construction of zoning maps. Maps made for one purpose are generally not adequate for other purposes involving different levels of inquiry.

Where gaps of information of this sort exist, arbitrarily adjusting the scale of the map to fit the new need does not generate the additional map detail required by the new use. Increased detail requires

1. DEFINE TASKS

Examples include evaluating proposed developments, developing or revising comprehensive plans or zoning ordinances, evaluating requests for variances, advising residents or developers, and developing goals or guidelines.

2. LOCATE SITE OR AREA

Locate the site visually on the appropriate geologic map and geologic hazards map.

3. IDENTIFY GEOLOGIC HAZARDS OR HAZARDOUS ENGINEERING CONDITIONS

Use the geologic map and text to determine the engineering properties of the underlying geologic unit or units. Use the geologic hazards map and text to determine geologic hazards.

ACQUIRE ADDITIONAL INFORMATION

For site-specific work or for construction of additional maps on a significantly larger scale, consultation or additional field work by qualified staff may be needed to establish accurate boundaries.

4. ASSESS THE SITE

Define the physical capabilities and liabilities of the land. The text is organized and cross-referenced to facilitate this type of use. Consult cited references or appropriate agencies where necessary.

5. EVALUATE THE PROJECT

Compare the physical capabilities and liabilities of the land with the physical requirements of the proposed use. Consider possible engineering and land management solutions and their impact on surrounding areas.

6. PLAN

In arriving at a final decision consider local and regional goals, political and economic factors, citizens' input, and other appropriate data.

Figure 1. Suggested use of this bulletin in site evaluations.

additional investigations (as discussed above under Site evaluations and Land use capability analyses). The needed information can be obtained by consultation, additional studies, on-site investigation, or in-house revision based on additional information. The text of this report is intended to supplement the maps and to serve local jurisdictions in generating maps of required level of detail for local implementation.

In summary, completion of regional inventories, such as this report represents, is a necessary prerequisite for local decision making; but it is not a substitute for site-specific information. Unfortunately, recent court decisions do not clearly make this distinction. In Green v. Hayward (1976), for example, it was ruled that zoning variances must conform to the comprehensive plan regardless of its level of specificity. Clearly, court actions are elevating the comprehensive plan into a distinguished and fundamental role in local planning. Accordingly, more care must be given to the formulation of comprehensive plans than in the past.

To preserve the option of making justified zoning variances based upon additional future information, the planner must begin now to phrase land use restrictions more carefully as they are presented in the comprehensive plan. One reason the text and maps of this report make repeated reference to the place of site-specific information in the planning process is to alert the planner to this developing phase of comprehensive plan formulation as it relates to geologic hazards information.

Acknowledgments

The author greatly appreciates the cooperation and help given by many individuals and organizations in the preparation of this report. The investigation was funded in part by grants from the Land Conservation and Development Commission to the Mid-Columbia Economic District and to Wasco County and also by a grant from the U. S. Department of Housing and Urban Development to Sherman County. The grants were implemented on a matching basis by the Oregon Department of Geology and Mineral Industries. Special thanks are extended to Mr. Ronald T. Bailey, Wasco County Planning Director; Mr. David W. Porter, Hood River County Planning Director; and Gary L. Shaff, Sherman County Planning Director, for their efforts in securing these funds.

The Planning Departments of the three counties, the Mid-Columbia Economic Development District, the U. S. Geological Survey (Portland Office), the U. S. Soil Conservation Service, and the U. S. Army Corps of Engineers supplied major assistance.

Staff members of the State of Oregon Department of Geology and Mineral Industries assisting in the project included Steven R. Renoud and Chuck A. Schumacher, cartographers; Beverly F. Vogt, geologist-editor; Ainslie Bricker, editor; and Ruth E. Pavlat, typist.

In particular the Oregon Department of Geology and Mineral Industries would like to acknowledge the efforts of the local jurisdictions to coordinate their individual needs into a single regional request for assistance. The numerous economics made possible by their efforts were significant in keeping the cost of the project to a minimum.

GEOGRAPHY

Location and Extent

The study area (Figure 2) encompasses the northern parts of Hood River, Wasco, and western Sherman Counties as well as small areas around major communities to the south, including Dufur, Tygh Valley, and Maupin along Highway 197 and Moro and Grass Valley along Highway 97. Total areal extent is approximately 550 square miles. Parts of six topographic quadrangle maps lie within the boundaries of the regional map area.

Climate and Vegetation

Climate is variable in response to moist Pacific storms in the winter, dry high-pressure cells from the east in the summer, and location within the study area. The mountainous terrain of the western half of the study area is considerably moister than the arid terrain east of The Dalles, which lies in the rain shadow of the Cascades Range (Table 1). Rainfall varies from 80 inches annually south of Cascade Locks to less than 10 inches annually east of the Deschutes River. Annual precipitation ranges from 60 inches in west Hood River Valley to 30 inches in east Hood River Valley (Oregon Water Resources Board, 1965).

Table 1. Climatic data for selected communities to 1974

Community	Number of Years of Record	Average Ppt. per Year (in.)	Max. Temp. (°F.)	Min. Temp. (°F.)
Cascade Locks	52	77		
	54		107	-9
Hood River	91	31		
	83		106	-27
Kent	51	11		
	49		108	-19
Moro	66	11		
	44		111	-23
Parkdale	65	42		
	73		105	-27
The Dalles	112	15		
	98		115	-30
Wasco	67	12		
	18 *		110	
	39 *			-28

* Records not available after 1952.

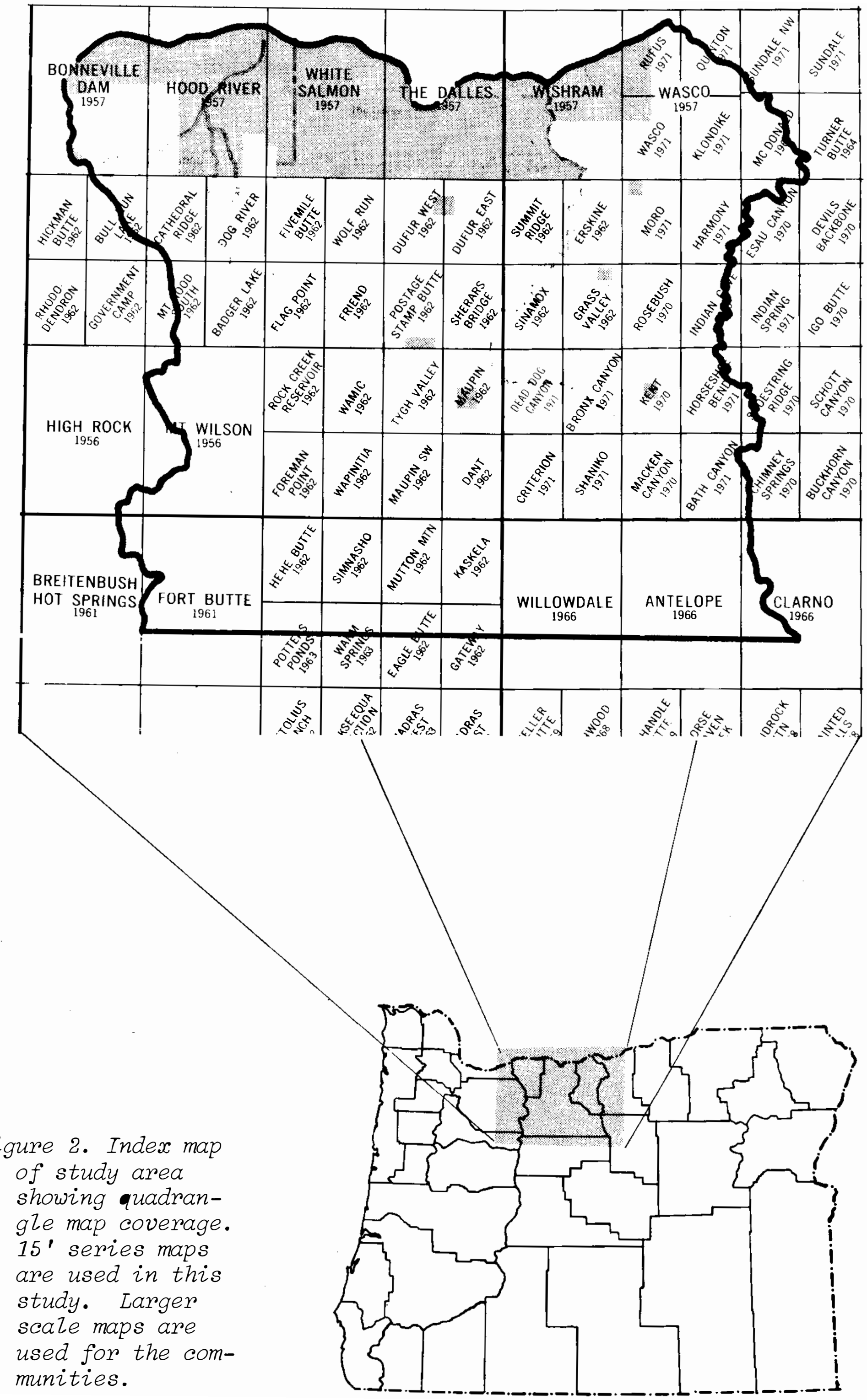


Figure 2. Index map of study area showing quadrangle map coverage. 15' series maps are used in this study. Larger scale maps are used for the communities.

The Douglas fir and western hemlock, which are the dominant tree types in the Hood River area, pass eastward into stands of ponderosa pine and into range-land grasses in response to decreasing rainfall. Agriculture is devoted to orchards in the west and to wheat and barley in the east. Dryland farming techniques are utilized locally. In the transition zone between forest land and grass land near The Dalles, shaded north slopes are forested, whereas exposed south slopes are devoid of trees.

Topography

Major physiographic regions of the study area include the Columbia River Gorge, the Cascade Range, the Hood River Valley, and the dissected plateaus and ridges east of The Dalles. The antecedent Columbia River cut the Columbia River Gorge in Pliocene and Pleistocene times as the Cascade Range was being formed by uplift, folding, and outpourings of lava from nearby volcanic vents. Major folds which displace bed rock several hundreds of feet vertically are visible along the sides of the Gorge. Exposure of incompetent bed rock in the core of the Cascade Range between Cascade Locks and Shellrock Mountain has resulted in numerous massive landslides.

The Hood River Valley occupies part of the faulted east limb of the Cascade Range upward and is faulted along its eastern border. Late Pleistocene volcanic rocks and possible minor faults separate the Upper and lower Hood River Valleys. Lower lying areas are underlain primarily by glacial outwash and lacustrine deposits.

Between Hood River and The Dalles, anticlines form major ridges and locally control the course of the Columbia River. Regionally, the Columbia River follows the axis of the Dalles-Umatilla syncline from The Dalles eastward. Between the Hood River Valley and The Dalles, stream valleys leading eastward off the Cascades exhibit intracanyon flows, massive bedrock failures, steep slopes, and torrential flood channels. Farther east, valleys of wind-deposited loess lead northward to steep ravines which spill abruptly through cliffs of Columbia River Basalt to the Columbia River.

A series of Pleistocene floods of glacial meltwater flowing down the Columbia River which culminated in the Missoula Flood greatly modified lower lying topography and produced extensive scablands, overflow channels, oversteepened slopes, and local perched deposits of sand and gravel. Distribution of these features has influenced patterns of cultural development and will continue to do so in the future. As development places increasing demands on the land, the continuing processes of flooding, sliding, erosion, and deposition will take on added significance to the planner.

Population and Land Use

Population of the incorporated communities of the study area has remained basically unchanged in recent years. Exceptions are Hood River, The Dalles, and Maupin, which show steady growth (Table 2). Projections for the counties as a whole indicate continued growth for Hood River and Wasco Counties (Table 2a) and redistribution of population from southern Sherman County to northern Sherman County (Mid-Columbia Economic District, 1975).

The economy of northern Hood River County is centered around forestry and orcharding of pears, apples, and cherries in rural areas, and retail trade, food processing, and transportation in urban areas. The economy of northern Wasco County is oriented around forestry, cherry production, and wheat in rural areas. The Dalles is a core city with a diverse economy centered around retail trade, communication, transportation, power, manufacturing, and administration. The service and manufacturing segments of the economy are expected to expand in the future. The economy of northwestern Sherman County is oriented around grain harvesting and transportation services. Future growth and development of the study area will be concentrated along major transportation routes, in the valleys surrounding major communities, and in the western Hood River Valley.

Table 2. Population of communities and counties

Table 2a. Populations of communities

Communities	1950 *	1956	1960 *	1965	1970 *	1975
Cascade Locks	733	795	660	700	574	690
Dufur	422	504	477	530	493	560
Grass Valley	195	196	234	210	153	160
Hood River	3,701	4,050	3,657	3,750	3,991	4,540
Maupin	312	410	381	410	428	605
Moro	359	364	327	330	290	310
Mosier	259	259	252	270	217	275
Rufus	---	---	---	---	---	405
The Dalles	7,676	10,600	10,493	11,600	10,423	10,800
Wasco	305	325	348	560	412	395

Table 2b. Populations of counties

Counties	1930	1940	1950	1960	1970	1974 **	1995 ***
Hood River	8,938	11,580	12,740	13,395	14,130	13,800	16,866
Sherman	2,978	2,321	2,271	2,446	2,370	2,130	2,139
Wasco	12,646	13,069	15,552	20,205	21,570	20,050	31,540

* Federal census figures; other figures estimated.

** Estimated figures; all other figures according to Federal census.

*** Mid-Columbia Development District (1975) estimates.

(Information provided by the Center for Population Research and Census, Portland State University.)

GEOLOGIC UNITS

General

Geologic units are distinguished primarily on the basis of rock type and, to a lesser extent, on the basis of physical properties, distribution, and age. A total of 21 geologic units are recognized within the study area; eight are surficial deposits of relatively young age, and 13 are stratigraphic units of primarily volcanic origin. In the discussion that follows, the surficial geologic units are grouped into four associations on the basis of mode of origin: stream deposits, wind deposits, slide deposits, and Pleistocene flood deposits. To facilitate discussion, many of the younger volcanic units of local distribution are grouped with the High Cascades Formation (QTv). The geologic units of the study area range in age from approximately 40 million years to the present (Figure 3). Owing to limitations of funding, engineering properties are not a prime consideration in this investigation.

Bedrock deformation in northern Hood River, Wasco, and Sherman Counties is briefly reviewed to provide the geologist with information necessary to assist the planner in 1) delineating the distribution of rock units as they relate to the engineering characteristics of the ground, 2) interpreting mineral potential, 3) identifying possible active faults as they relate to earthquake potential, and 4) interpreting areas of future landslide potential. Major structures are shown on the geologic maps.

Bedrock Geologic Units

Eocene volcanic rock - Ohanapecosh Formation (Teo)

The Ohanapecosh Formation consists of andesitic flows, tuffs, mudflows, debris flows, and related volcaniclastic rocks exposed north of the study area in south-central Washington. Use of the term Ohanapecosh by Waters (1973) is justified on the basis of age and lithologic similarities with exposures of true Ohanapecosh rocks in the Mount Rainier area. No definite exposures of Ohanapecosh rocks are mapped in Oregon, although possible distribution in the shallow subsurface is inferred on the basis of both regional structure and also the presence of red clay in talus and mud boils east of Wyeth and near the mouth of Dig Creek near Cascade Locks (Waters, 1973).

Unlike younger rocks in the area, the Ohanopecosh rocks are tightly cemented by zeolites and other low-temperature alteration minerals. The uniform and widespread alteration has sealed most joints, pores, and cracks in the rocks to produce a highly impermeable unit. In addition, deep chemical weathering prior to the deposition of younger units produced a thick clay-rich saprolitic zone which is now exposed in Washington beneath the contact with the Eagle Creek Formation.

The massive landslides lining the Washington shore from Table Mountain on the west to Dog Mountain on the east owe their origin in large part to the combined influences of the impermeability of the Ohanapecosh Formation, the low bearing strength of the saprolitic horizons, the regional tilt of the bed rock to the south, and the undercutting by the Columbia River. Possible recognition of this unit in massive slide areas south of the Columbia by Waters (1973) may be a significant contribution to future engineering investigations (see Mass Movement - Deep bedrock slides).

Early Miocene volcaniclastic rock - Eagle Creek Formation (Tme)

The Eagle Creek Formation in the Cascades Locks area consists of interbedded sedimentary rocks and mudflows derived from early Miocene volcanic vents to the north in Washington (Allen, 1932). Thicknesses vary from a few hundred feet in Oregon to 2,100 feet in Washington (Barnes and Butler, 1930) and are restricted to exposures in the uplifted core of the Cascades Range in the Cascade Locks—Stevenson area.

Major rock types in the Cascade Locks area include boulder conglomerate, sandstone, shale, tuff breccia, and debris flows or slurry deposits. Rock fragments are primarily andesitic. Clay and carbonate cementation is generally more complete in the sandstones and conglomerates than in the debris flows. Much of the Eagle Creek Formation south of Cascade Locks is displaced and broken by massive landslides (see Mass Movement - Deep bedrock slides).

The Eagle Creek Formation is unconformable over the saprolites of the Ohanapecosh Formation. Oligo-Miocene age determinations on the basis of leaves are summarized by Piper (1932), and the unit is similar in age to the upper part of the John Day Formation of central Oregon.

Major hazards associated with the Eagle Creek Formation include active sliding in the Ruckel Creek area, highly variable foundation and cutbank stability properties in areas of ancient landsliding, and variable cutbank stability properties between interbeds in terrain where no landsliding has occurred. Permeability is variable. Streams disappear into the ground at the heads of slides and resurface farther downslope near the base of the slides. A U. S. Forest Service well in unslid terrain yields 4 gallons of water per minute, with 170 feet of drawdown (Sceva, 1966), indicating low ground-water potential. Resource potential is limited. Potential for use as landfill sites is highly variable and requires thorough investigation.

Miocene flood basalts - Columbia River Basalt (Tcr)

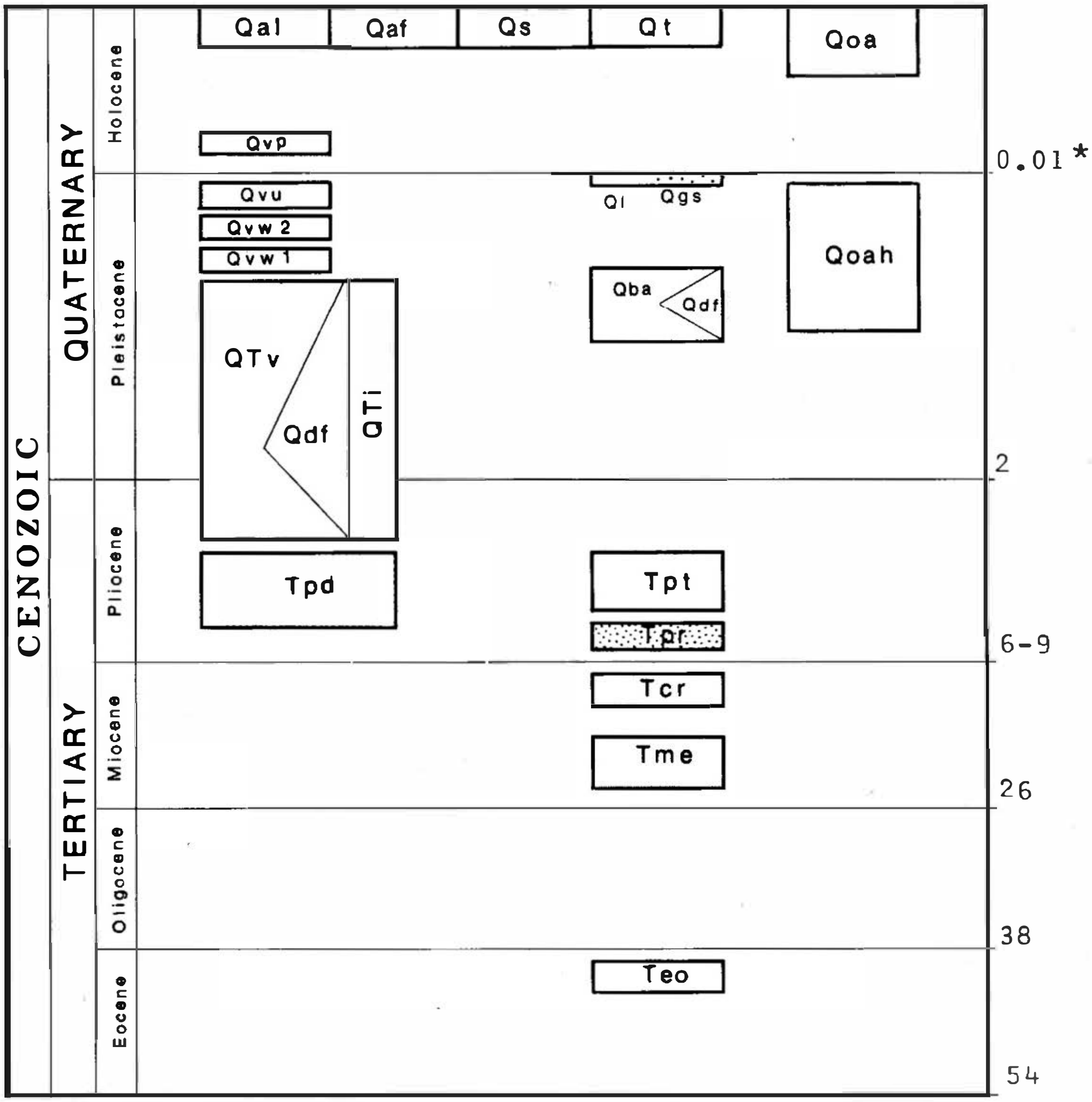
The Columbia River Basalt consists of 2,000 feet of basalt flows exposed primarily as steep slopes and cliffs along the Columbia River and its tributary streams. The flows, equivalent to the Yakima Basalt of Waters (1961), include the Priest Rapids, the Roza, and the Frenchman Springs flows according to Schmincke (1967) and Kienle (1971). The Columbia River Basalt of the study area was formed when tensional tectonics in northeastern Oregon tapped the mantle (McDougall, 1976), causing basalt to flow to the surface through a series of dikes (Gibson, 1966) and spread westward into lower lying areas. Flow velocities probably were between approximately 5 and 35 miles per hour. Kienle (1971) notes westerly flow directions in the Columbia River Gorge. No Columbia River Basalt dikes have been found in the study area, but dike swarms occur to the east.

On the basis of numerous radiometric age dates and scattered fossils, Columbia River Basalt is believed to be late Miocene in age. In the Yakima area, Holmgren (1969) reports an age range of 10 to 16 million years for flows equivalent to those of the study area. Evernden and James (1964) report an age of 13.4 million years for the Vantage flora, which is situated stratigraphically below the exposed flows of the study area. Sedimentary interbeds of the Ellensberg Formation, located stratigraphically above the flows of the study area, contain early Pliocene camel bones northeast of Roosevelt, Washington (Newcomb, 1971) and have been radiometrically dated at 10.1 million years (Evernden and James, 1964).

The Columbia River Basalt of the study area consists of hard, dark, jointed basalt in flows averaging 80 feet in thickness. The higher parts of the unit in The Dalles area and to the south also contain layers of pillow basalt set in a matrix of hydrated basaltic glass where the basalt flowed into water and was rapidly cooled. Interbeds of sedimentary rock are thin and local. At Mitchell Point they include cemented basaltic conglomerate with a quartz sandstone matrix (Sceva, 1966) and a coal seam (Williams, 1916). A few thin interbeds are revealed at depth in water-well records (Newcomb, 1971). Some of the interbeds and pillow basalt horizons are associated with mass movement (see Mass Movement - Deep bedrock slides).

Jointing of the basalt strongly influences mass movement and ground-water potential. Joints include 6-inch to 12-inch vertical cooling fractures, flat sheeting joints on the tops of individual flows, and large regional joints up to 10 feet wide and several miles long. A prominent escarpment directly west of Mosier (sec. 2, T. 2 N., R. 11 E.) is controlled by a regional joint (Newcomb, 1969); and the slide area at Mayer State Park 5 miles east of Mosier appears to be largely controlled by a prominent north-south joint on its western boundary.

Geologic hazards of the Columbia River Basalt include rockfall and rockslide potential along steep slopes, especially in the Columbia River Gorge; deep bedrock slump potential along faults, joints, and incompetent interbeds; and torrential flooding in areas of high relief and steep stream gradient. Permeability varies from very high to very low as a function of jointing (Newcomb, 1969). Foundation strength is generally very good, and potential for waste disposal in landfills is variable as a function of jointing. Resource potentials include aggregate, fill material, wildlife potential, and, especially in the Columbia River Gorge, scenic values.



*Age in millions of years.

Surficial Geologic Units

Stream deposits

Qal	Quaternary alluvium
Qoa	Quaternary older alluvium
Qaf	Quaternary alluvial fan deposits
Qoah	Quaternary older alluvium of Hood River Valley

Wind deposits

Qs	Quaternary eolian sand

Slide deposits

Qt	Quaternary thick talus

Pleistocene flood deposits

Qgs	Quaternary glacial flood gravel and sand
Ql	Quaternary glacial flood silt

Bedrock Geologic Units

QTv	Cascades Formation
Qvp	Parkdale flow
Qvu	Underwood lava flows
Qvw1, Qvw2	Wind River flows
Qba	Young basalt and andesite
Qdf	Debris flows
Tpd	The Dalles Formation
Tpt	Troutdale Formation
Tpr	Rhododendron Formation
Tcr	Columbia River Basalt
Tme	Eagle Creek Formation
Teo	Ohanapecosh Formation
QTi	Quaternary and Pliocene intrusive rock

Figure 3. Time distribution of stratigraphic and surficial geologic units.

Soils developed on the Columbia River Basalt are variable and include thick silts and silt loams over weathered bed rock in the highlands south of Mosier; thick wind-blown silts and lacustrine silts in highlands east of The Dalles, especially on north and east facing slopes; and thin rubbly silts and silt loams up to 2 feet thick in gulleys and along streams. Quarry cuts in China Hollow (sec. 29, T. 1 N., R. 16 E.) 3 miles north-northwest of Wasco expose 2 feet of silt overlying fresh basalt along a sharp contact that is sheet-joint controlled (Figure 4). Pieces of deeply weathered basalt in the lower soil indicate that the soil at this locality was derived by weathering in place.

At lower elevations along the Columbia River, one or more catastrophic floods at the close of the Ice Age (see Pleistocene lake deposits) have removed the soil, leaving rugged bedrock exposures (scablands) over large areas including much of the Columbia River Gorge and parts of Hood River, Mosier, and The Dalles. Well-developed scablands east of The Dalles on Kaiser and Fulton Ridges are 800 feet above the present level of the river (Figure 5). Difficulty of excavation in scablands greatly increases the costs of underground utility installations and other construction projects. Agricultural potential is negligible except in protected areas where layers of silt were deposited over bed rock by the floodwaters. Budgetary constraints did not allow the separate mapping of scablands in this investigation.

Pliocene Columbia River deposits - Troutdale Formation (Tpt)

The Troutdale Formation consists of semiconsolidated water-rounded conglomerate, sandstone, and pebble beds which form benches between the Columbia River Basalt and the Cascades Formation along the cliffs of the Columbia River Gorge between Cascade Locks and Hood River. Bedrock deformation has raised the unit to elevations of 1,250 feet at Multnomah Creek, 1,800 feet between Mosier and Hood River, 2,500 feet at Nesmith Point, and 2,700 feet south of Wyeth (Barnes and Butler, 1930; Allen, 1932). Exposures near the mouth of Hood River are less than 200 feet in elevation. Sceva (1966) reports more than 100 feet of Troutdale at a depth of 135 feet in a well log at Odell in the Hood River Valley. Farther east, exposures of Pliocene river gravels are of very limited extent south of the Columbia River and are included in the Dalles Formation. Exposures in The Dalles and along Fulton Ridge overlooking the Columbia River one mile west of Celilo are situated near the base of the Dalles Formation. Quartzite pebbles in exposures of Pliocene river gravel cannot be traced to any local source and therefore indicate an upper Columbia River provenance.

Although Lowry and Baldwin (1952) cite a lower Pliocene age for part of the Troutdale Formation in the Portland area, the age of the unit may vary considerably as a function of preservation and the continual migration of the channel of the Columbia River as the unit was being deposited. Immediately to the north of the study area Pliocene river gravels are found scattered over the crest of the Columbia Hills anticline (see Structure) from Klickitat to Goldendale. After these gravels were deposited, the growth of the Columbia Hills anticline forced the Columbia River progressively to the east to its present location at Umatilla Gap. Dislocations of this magnitude suggest that the age of the Troutdale Formation in Oregon may extend throughout much of the Pliocene.

Gravels of the Troutdale Formation are characterized by moderate cutbank stability, variable permeability and foundation strength, and moderate excavation difficulty. Parts of the Troutdale Formation are described as deeply weathered (Allen, 1932). These exposures may represent silt and clay-rich interbeds. Analogous parts of the Troutdale Formation assigned to the Sandy River Mudstone (Trimble, 1963) in the Sandy River drainage (Beaulieu, 1974) are prone to mass movement, suggesting the possibility of similar hazards for parts of the Troutdale Formation in the present study area.

Pliocene volcanic rocks

Pliocene volcanic rocks include the Dalles Formation, which forms large exposures east of the Hood River Valley, and the Rhododendron Formation, which forms isolated exposures between the Columbia River Basalt and the Cascades Formation in the Columbia River Gorge west of Shellrock Mountain. Rocks equivalent to the Troutdale Formation occur near the base of the Dalles Formation and overlie the Rhododendron Formation outside the study area (Beaulieu, 1974).

Figure 4. Columbia River Basalt exposed in quarry in middle reaches of China Hollow north of Wasco. Note thin soil cover.

Figure 5. Bench 700 feet above present level of the Columbia River was eroded into Columbia River Basalt by the Missoula Flood. Dalles Formation forms steep slopes on far left.

Rhododendron Formation (Tpr): The Rhododendron Formation consists of poorly cemented agglomerate, tuff breccia, tuff, and ash with a maximum thickness of approximately 800 feet north of Indian Mountain (Allen, 1932). The patchy distribution of the unit suggests that it was deposited in structurally controlled topographic lows that were developing in Pliocene times. A radiometric age of 7 $\pm$ 2 million years is reported by Wise (1969) on Lost Creek in the Government Camp quadrangle south of the study area. This age probably corresponds with the upper part of the Dalles Formation. The stratigraphic position of the Rhododendron Formation below the Troutdale Formation, in contrast to the position of the Dalles Formation above rocks similar to the Troutdale Formation, underscores the possible wide age range of that unit.

Exposures of Rhododendron Formation were not directly observed in this study. Engineering properties probably include variable permeability, variable ground-water potential, and variable foundation strength. Exposures of the Rhododendron Formation elsewhere are locally prone to sliding.

The Dalles Formation (Tpd): The Dalles Formation is a broad andesitic debris fan centered beneath Mount Hood lavas 25 miles south of Mosier and exposed in thicknesses of 1,800 feet east of the Hood River Valley in the study area. The unit thins quickly to extinction westward in the valley of the West Branch of Hood River. To the east it thins to 500 feet at The Dalles and lower Fifteenmile Creek, 250 feet on the east side of the Deschutes River Canyon, and 160 feet near Rufus (Newcomb, 1969).

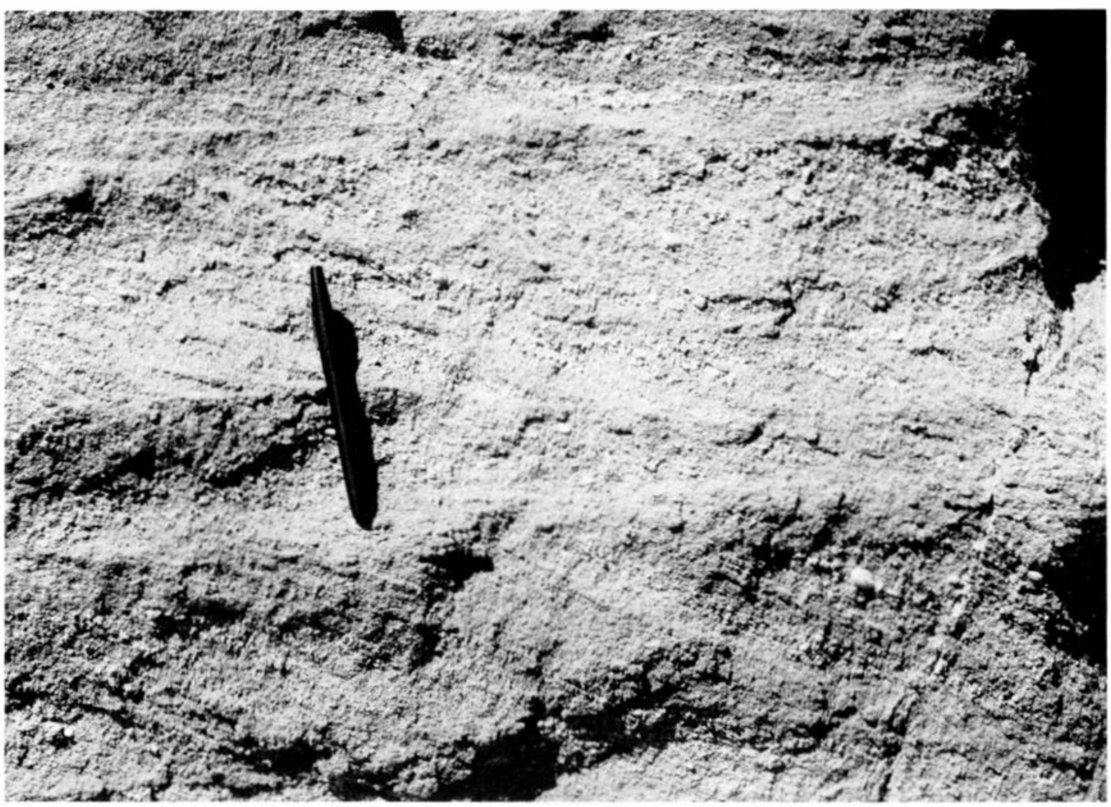


Figure 6. River-deposited andesitic debris of Dalles Formation exposed near mouth of Chenoweth Creek.

Rock types include hard gray agglomerate with clasts of hornblende and pyroxene andesite set in a hard shard-rich matrix, coarse boulder conglomerate, tuff breccia, and ash flows in the southern Mosier and Dalles quadrangles. Northward and eastward away from the source areas these rocks pass into a variety of water-laid fan deposits (Figure 6) including tuff, sandstone, and siltstone. A prominent basalt flow is interbedded in the Dalles Formation along Kaiser and Fulton Ridges east of The Dalles. Farther to the east outside the study area, the Dalles Formation may be equivalent to other Pliocene units (Newcomb, 1966) mapped above the Columbia River Basalt and possibly to the upper part of the Ellensberg Formation (Newcomb, 1971). Isolated exposures of water-worn gravels equivalent to the Troutdale Formation are included in the Dalles Formation in The Dalles and along Kaiser Ridge (see Pliocene Columbia River deposits-Troutdale Formation).

Leaves and vertebrate fossils recovered from the Dalles Formation in the study area indicate an early Pliocene age for part of the unit (Newcomb, 1971). The lava flow between Fifteenmile Creek and the Deschutes River has been radiometrically dated at 10.6 and 15.2 million years (Newcomb, 1966). The younger age is more consistent with regional stratigraphy. East of the study area, middle Pliocene ages are assigned to rocks regarded as equivalent to the Dalles Formation near Arlington (Newcomb, 1966) and at McKay Reservoir (Hogenson, 1964). Vertebrate fossils recovered from the volcanic debris facies of the unit west of Lyle and southeast of The Dalles are late Miocene to early Pliocene (Newcomb, 1966). The Dalles Formation underlies flows with an age of 7 million years in the Cascades Range (Wise, 1969).

The Dalles Formation is unconformable over the Columbia River Basalt, according to Newcomb (1966), and is unconformable under younger units. Deposition of the Dalles Formation in Pliocene times forced the Columbia River northward from its ancient channel through the Mount Hood area to its present location.

Mass movement is the major hazard associated with the Dalles Formation. Deep bedrock slumps and translation slides (see Mass Movement) occur near the base of the Dalles Formation in the community of The Dalles and along Mosier Creek and Brown Creek. Numerous other failures occur higher in the unit. Landslides within the community of The Dalles are associated with the contact of the Dalles Formation and the underlying Columbia River Basalt and, like many of the larger slides, can be largely attributed to the combined influences of parallel topographic slope and bedrock dip, ground water, and rock type (see Mass Movement - Deep bedrock slides). Many gentle to moderately steep slopes of the Dalles Formation are prone to future landsliding in areas of changing land use where drain fields, septic tanks, modified runoff, or irrigation may increase the local supply of ground water.

Difficulty of excavation ranges from high in areas of hard fresh bed rock in the south and western parts of the Mosier and The Dalles quadrangles to low in the more deeply weathered, less well-cemented rocks exposed farther to the east.

Ground-water potential of the Dalles Formation is limited to domestic production from scattered perched water bodies in the more permeable sandy lenses throughout the unit or from horizons immediately overlying impermeable parts of the Columbia River Basalt. Generally, catchment basins for the individual water bodies are very small, and commonly several must be tapped to provide adequate production for domestic use (Piper, 1932). No other significant resource potential is recognized, although pozzolan has been mined from the unit east of the study area (Newcomb, 1971).

Soils over the Dalles Formation south and west of The Dalles include thin bouldery silt and silt loam and thick silt and silt loam derived from wind-blown material. They also include silt and silt loam over lacustrine deposits and bed rock east of The Dalles. East of Fifteenmile Creek, soils greater than 10 feet in thickness occur on the north sides of some ridges. Soils derived from deep weathering of poorly cemented fine-grained rocks of the Dalles Formation are sometimes distinguishable from eolian silts on the basis of randomly distributed andesitic boulders or faint relict textures visible only in fresh excavations or wind-blown roadcuts.

In the community of The Dalles, differential cementation and differential protection from rain and other weathering processes have produced spires of andesite breccia beneath large protective cap rocks. These features, called hoodoos, include Pulpit Rock and Pigeon Rock and are of high scenic value. The many shallow caves which are developed in the hard massive interbeds of the Dalles Formation appear to be similar to tafoni (shallow weathering depressions in massive bed rock) observed recently in calcite-cemented sandstones in California (Grantz, 1976). They owe their origin to deep winter infiltration of slightly acid rain waters and to summer surfaceward percolation of the same waters containing dissolved calcite. Cement depletion of the interior coupled with random penetration of the case-hardened exterior by rain, wind, or animals produces the depressions.

High Cascades volcanic rock - Cascades Formation (QTv), (Qba, Qdf, Qvw1, Qvw2, Qvu, Qvp)

The Cascades Formation consists of porous porphyritic flows of gray pyroxene andesite, basaltic andesite, and olivine basalt along with andesitic agglomerate, andesitic tuff breccia, and debris flow deposits. Structurally the unit is primarily an aggregate of coalescing shields and volcanic cones, but it also includes numerous intracanyon flows of various ages preserved at various topographic levels in present-day canyons. Through continued erosion, some of the older intracanyon flows now form ridge crests. Age of the unit varies from several million years to the present, geologically speaking.

All rocks of the Cascades Formation west of Mount Defiance and originating from undefined vents outside the study area are mapped as QTv in this study. The rocks include flows of porphyritic andesite and agglomerates. The rocks lie stratigraphically above the Troutdale and Rhododendron Formations and underlie Benson Plateau and Nick Eaton Ridge in the Bonneville Dam quadrangle.

Middle to late Pleistocene flows of basaltic andesite, andesite, and basalt originating from Mount Defiance and also occurring at Middle Mountain and the Odell area in the Hood River Valley area are mapped as Quaternary basalt and andesite (Qba). Several episodes of volcanism in the Hood River Valley are indicated by the complex topography associated with the Quaternary flows (Qba) in the Hood River Valley. Interbedded debris flows are mapped around the edges of the Hood River Valley (Qdf) and are undoubtedly also present in the basalts and andesites of Mount Defiance (Qba).

In the Herman Creek area, two thick flows or series of flows of light gray andesite overlie the Eagle Creek Formation and presumably flowed across the Columbia River from their source up the Wind River valley at Trout Creek Hill north of Stevenson (Waters, 1973). These flows (Qvw1, Qvw2) have diverted the drainage of Herman Creek to the west and presumably also dammed the Columbia River to an elevation of 400 feet or more (Allen, 1932).

The maximum elevation of flows originating from across the Columbia River is a subject of debate in the literature (Allen, 1932; Wilkinson and Allen, 1959; Waters, 1973) and the 400-foot figure is a conservative figure. Age of the flows is greater than 35,000 years (Waters, 1973); but they are late Pleistocene, because the present level of the river appears to have been reached when the river was dammed by the flow (Williams, 1916). The base of the flows is approximately at river level.

In the west Hood River area, flows from Underwood Mountain (Qvu) and contemporaneous flows from the later stages of Mount Defiance volcanism (Qba) dammed the Columbia River in middle to late Pleistocene times to a depth of several hundred feet. Exposures of pillow lavas and associated hydrated basaltic glass of possible Underwood Mountain parentage are mapped as unit Qvu west of Hood River. The bases of many of these flows lie above the present level of the Columbia River, and they are interpreted to be considerably older than the flows at Wind River.

The Parkdale lava flow in the Upper Hood River Valley is a thick, rubbly, very sparsely vegetated andesite that was extruded from low on the north side of the Mount Hood volcano approximately 6,890 years ago (Harris, 1973). The flow is approximately 250 to 300 feet thick.

Numerous distinct kinds of rocks are found in the Cascades Formation, and associated engineering properties and geologic hazards vary considerably. Excavation difficulty, cutbank stability, permeability, and foundation strengths are generally low to moderate in the breccias. Flow rock units are characterized by greater excavation difficulty and greater cutbank stability. Ground water generally occurs as local perched bodies at various levels throughout the unit. Production is generally low, and care must be taken to avoid draining perched bodies when drilling through underlying impermeable layers of rock. Where younger flows overlie relatively impermeable bed rock, a potential for ground-water production may exist. The highly fractured Parkdale flow, for example, discharges ground water from a series of springs situated along its northern edge.

Soils overlying the Cascades Formation are primarily loam and stony loam, especially over weathered flow rock. Soil thickness is greatest on gentle slopes and at the bases of steeper slopes where colluvial material accumulates. Soils developed over breccias are generally thicker than soils developed over flow rock. Subsoils developed on gentle slopes especially over debris flow deposits (Qdf) commonly are clay-rich. Soils in the Odell area are loam and silt loam which locally contain compact subsoil horizons of hardpan which retard drainage and tree root development. No soils are developed on the relatively young Parkdale lava flow.

Quaternary and Pliocene intrusive rock (QTi)

The many volcanic centers which comprise the Cascades Formation were fed by numerous dikes, sills, and plugs in the Earth's crust. Where erosion has exposed these feeders, they are mapped as Quaternary and Pliocene intrusive rock. Shellrock Mountain is the largest intrusion in the study area and is composed primarily of diorite porphyry. Around its edges, the Eagle Creek Formation is baked; and the Columbia River Basalt is upbowed (Williams, 1916). Emplacement occurred prior to the final uplift of the Cascades, and a Plio-Pleistocene age is inferred. Wind Mountain, directly across the river, is also a diorite exhibiting similar structural relationships with the surrounding Eagle Creek Formation and Columbia River Basalt.

Numerous plugs of andesite and diorite are exposed in the Cascade Locks area. Those exposed in Government Cove northeast of Cascade Locks are hard, fresh, and coarsely jointed and are utilized for quarry rock. It is uncertain whether some of the intrusions were feeders for the Eagle Creek Formation rather than the Cascades Formation. Allen (1932) infers several vent areas for the Eagle Creek Formation north of the Columbia River.

Major geologic hazards associated with the Quaternary and Pliocene intrusive rock occur at Shellrock Mountain, where extensive talus deposits are developed. Debris flows spill onto the talus from canyons upslope, and the talus is prone to sliding either in areas of cuts or at times of particularly wet weather. Many large slides are visible in the talus surrounding Wind Mountain directly to the north. Shallow subsurface flow of ground water requires adequate drainage facilities on retaining buttresses.

Surficial Geologic Units

Pleistocene lake deposits - gravel and sand (Qgs) and silt (Ql)

At the close of the Ice Age, a large ice dam blocking the Clark Fork of the Columbia River gave way, releasing an estimated 500 cubic miles of water (Baker, 1973) in a catastrophic flood which can be traced along the Columbia River from northeastern Washington to Portland.The flood theory was first proposed by Bretz (1923), largely on the basis of channeled scablands developed throughout southeastern Washington. Later studies include an inventory of flood deposits by Allison (1933), a general flood survey by Flint (1938), and a study of flood hydraulics by Baker (1973). It is now recognized that, although the catastrophic Missoula Flood actually did occur, some of the numerous and widespread lacustrine deposits formerly attributed to the flood probably were laid down either by other floods or were deposited in quiet lacustrine environments behind one or more of the lava dams which from time to time blocked the Columbia River (Newcomb, 1969; Waters, 1973) (see Cascades Formation). The name Lake Lewis which appears in the literature refers to the lake or lakes in which the lacustrine deposits were laid down. It has different meanings for different authors and is probably best viewed as a general name applicable to all Pleistocene lakes involving the Columbia River in the Columbia Basin area.

Carbon-14 dating indicates that the Missoula Flood occurred less than 32,000 years ago, and studies of volcanic ash deposits indicate that it occurred more than 12,000 years ago (Baker, 1973). An age of approximately 20,000 years is most consistent with all of the available evidence. The maximum extent of Lake Lewis in Missoula Flood times (Flint, 1938) requires a volume of water far greater than that of Lake Missoula, which was impounded behind the ice dam at the present site of Lake Pend Oreille (Baker, 1973). It is therefore inferred that water was contributed from other sources as well and that the Columbia River was partially or totally impounded for a short while during the flood by early movement of the Bonneville slide (see Mass movement). Maximum elevation of the Missoula Flood waters in the study area was 1,150 feet.

Pleistocene flood waters have significantly affected the natural resource base of the study area in several ways: 1) Severe erosion during the flood removed valuable topsoil and scoured out scabland topography (Figure 7) to elevations of up to 1,000 feet (Figure 8), producing large, poorly drained areas with little or no agricultural potential. 2) Side channel erosion during the flood greatly oversteepened slopes in the Dalles Formation, producing very steep slide-prone hillsides along Kaiser Ridge and in The Dalles from which several deep bedrock slides may have occurred during or shortly after the flood. 3) Scouring of overflow channels between streams formed small areas of scabland topography within the Dalles Formation which are easily mistaken for hummocky landslide topography. 4) Deposition of sand, gravel, and silt in protected areas produced thick, isolated bodies of sand and gravel east of The Dalles; deposits of gravel, sand, and silt in low-lying areas near Mosier; and silt in the lower Hood River Valley. Recognition of these deposits is essential to an accurate soils inventory.

Minimum flood levels east of The Dalles are indicated by the presence of ice-rafted erratics at elevations of 750 feet in the drainage of Fivemile Creek near the Old Dufur Road and 900 feet in the Fifteenmile Creek area (Allison, 1933). Flood waters which spilled through gaps on either side of Kaiser Ridge left thick gravel and sand deposits in the Petersburg and Fairbanks areas. Farther east, Allison (1933) noted gritty silt and sand of flood origin 4 miles south of Rufus. West of The Dalles, flood water silt (Ql) occurs in the valleys of Chenoweth, Brown, and Mill Creeks, and scablands (scoured bed rock) are developed to an elevation of 1,100 feet on Sevenmile Hill. (Scablands are present in The Dalles below an elevation of about 200 feet.) Fluvial silt is undoubtedly a significant component of most soils in the east half of the study area. Redistribution by the wind has produced thick accumulations of silt on the north and east side of ridges.

West of The Dalles, talus has generally been stripped from the Columbia River Gorge; and erratics have been discovered to elevations of up to 850 feet (SW$\frac{1}{4}$ sec. 12, T. 2 N., R. 11 E., Allison, 1933). In the Hood River Valley, scattered erratics have been found at elevations of up to 700 feet. One erratic was discovered on Van Horn Butte at an elevation of about 800 to 900 feet (Allison, 1933). As early as 1914, an eroded soil phase was recognized at lower elevations by Strahorn and Watson (1914). Lacustrine silt is an important component of the silt loam soil which occupies the 12 square miles of the lower Hood River Valley. Without the benefit of knowledge of the Missoula Flood, Strahorn and Watson (1914), noting the uniform texture of the soils of this area in conjunction with the diversity of underlying deposits, postulated bay or estuarine deposition of the silt.

The silt deposits and some of the sand and gravel deposits are used for agriculture. The thick gravel and sand deposits east of The Dalles are utilized for sand and gravel. Old gravel pits generally should not be used for solid waste disposal because of their very high permeability and their locations on the sides of valleys overlooking flowing streams. East of the study area, dikes of sandstone injected through Pleistocene flood deposits by rapidly migrating ground water have been occasionally misinterpreted as fault or landslide features. Correct interpretations are available in Newcomb (1962) and Shannon and Wilson (1974).

Stream deposits (Qoah, Qoa, Qaf, Qal)

Stream deposits, listed in general order of decreasing age, include Quaternary older alluvium of the Hood River Valley (Qoah); Quaternary older alluvium (Qoa); Quaternary alluvial fan deposits (Qaf), situated in areas subject to torrential flooding at the base of steep canyons; and Quaternary alluvium (Qal), which is generally subject to flooding. Ages of the various units overlap to a degree. As noted in the text and on the map legends, map scale precludes separation of the units in some areas.

Quaternary older alluvium of the Hood River Valley (Qoah): In the lower Hood River Valley, this unit consists of thick deposits of poorly sorted glacial outwash and possibly interbedded lacustrine deposits. Low in the section near Hood River the unit contains fluvial sand and coarse basaltic-boulder conglomerate immediately above the Columbia River Basalt. Soils above the unit contain significant amounts of Missoula Flood lacustrine silt, and erratics are widespread (see Pleistocene lake deposits). Prior descriptions of the unit in this area as glacial till are inconsistent with known extents of Pleistocene glaciation (Crandell, 1965) and with the lack of morainal landforms.

In the Upper Hood River Valley, this unit is probably derived from a variety of sources including abundant glacial outwash, mudflows, debris flows, and ash falls. Exposures are scarce because younger units form terraces along the sides of valleys. Debris flows are mapped locally. Glacial outwash is probably the major rock type.

Scattered well logs in parts of the Hood River Valley indicate thicknesses greater than 100 feet for the Quaternary older alluvium of the Hood River Valley, and maximum thicknesses of several hundred feet are estimated by Sceva (1966). The deposits are generally very poorly sorted and have low permeability. Ground-water potential is severely limited, and producing water wells in the area penetrate the underlying formations.

Figure 7. Scablands developed on Columbia River Basalt immediately northwest of The Dalles.

Figure 8. Scablands developed on Columbia River Basalt along the north side of Fulton Ridge are characterized by shallow soils and low vertical escarpments.

Minor flooding of small stream channels, especially in Upper Hood River Valley, is the major geologic hazard of the unit. Where hardpan is developed at shallow depths, ponding or high ground water also constitute a problem. Difficulty of excavation is low to moderate, depending on the distribution of boulders. Potential for solid waste disposal is generally good. The unit has little resource potential. Soils generally consist of silt and silt loam. Small, poorly drained areas in the Upper Hood River Valley and areas of hardpan in the lower Hood River Valley are generally characterized by dark gray to black organic soils but require on-site investigation for proper recognition.

Quaternary older alluvium (Qoa): This unit consists of unconsolidated gravel, sand, and minor silt located above the flood plains of major streams of the study area and also of indistinctly bedded to massive silt found along the smaller streams in the east half of the study area. It is equivalent to the Quaternary older alluvium and part of the Quaternary younger alluvium of Newcomb (1969).

In the Hood River Valley the unit consists of a series of coarse to very coarse boulder conglomerate and sand terraces overlooking the Hood River between Dee Flat and the Columbia River. The conglomerates are particularly coarse downstream from Winans Narrows. Quaternary older alluvium mapped along the Columbia River is subject to minor flooding because of fluctuations of reservoir level behind Bonneville and The Dalles Dams.

Quaternary older alluvium along the many smaller streams south and east of The Dalles consists of wind-blown and fluvial silt that has been recently incised by renewed downcutting of the streams. Mastodon bones recovered from some of the silts indicate late Pleistocene age and suggest that silts associated with the Missoula Flood may also be incorporated into the unit. Stream-bank erosion constitutes a considerable hazard locally. Owing to the limitations of scale, flood-prone Quaternary alluvium is included in the unit locally. Distribution of these areas can be inferred by inspection of the flood hazards of the Geologic Hazards Maps.

Quaternary alluvium (Qal): This unit is made up of gravel and sand along major streams and streams with steep gradients in the study area. It also includes deposits of sand and silt along some of the smaller streams in the eastern half of the study area. The unit is equivalent to part of the Quaternary young alluvium of Newcomb (1969) and is generally subject to stream flooding (Figure 9). Small areas of Quaternary alluvium are mapped with Quaternary older alluvium because of scale limitations (see Stream deposits - Quaternary older alluvium).

No Quaternary alluvium is mapped along the banks of the Columbia River because the reservoirs behind Bonneville and The Dalles Dams have permanently flooded all exposures. Channel deposits of the major streams, torrential flood channels, and the Columbia River also belong to the Quaternary alluvium. Recent studies of the bottom deposits of the Bonneville Reservoir (Whetten and Fullam, 1967) show that the fine to coarse sands are still in motion and form giant sand waves up to 100 feet long and up to 7 feet high, which move at a rate of 2 feet per day when the river is in flood stage.

Quaternary alluvium is subject to stream flooding and to accelerated erosion or deposition, depending upon the impacts of changing land use in surrounding and upstream areas. These topics are discussed further under Geologic Hazards - Stream Erosion and Deposition.

Quaternary alluvial fan deposits (Qaf): This unit consists of moderately sloping subaerial deposits of poorly sorted angular rubble, gravel, and sand located at the base of steep canyons cut in Columbia River Basalt and extending northward from highlands to the Columbia River (Figure 10). The most notable fan underlies Rufus; many other fans are located westward to Biggs. Farther west in the Columbia River Gorge, small fans that are obscured by vegetation are not indicated on the Geologic Maps. Their presence can be inferred, however, at the mouths of all torrential flood channels indicated on the Geologic Hazards Maps. Maximum thickness of the fans is generally less than 50 feet.

Fan deposits are subject to torrential flooding and extremely rapid stream erosion and stream deposition. They are generally free of soil, highly permeable, and are sometime mined for sand and gravel.

Figure 9. Flood-prone bottomland underlain by Quaternary alluvium in Grass Valley canyon north of the community of Grass Valley.

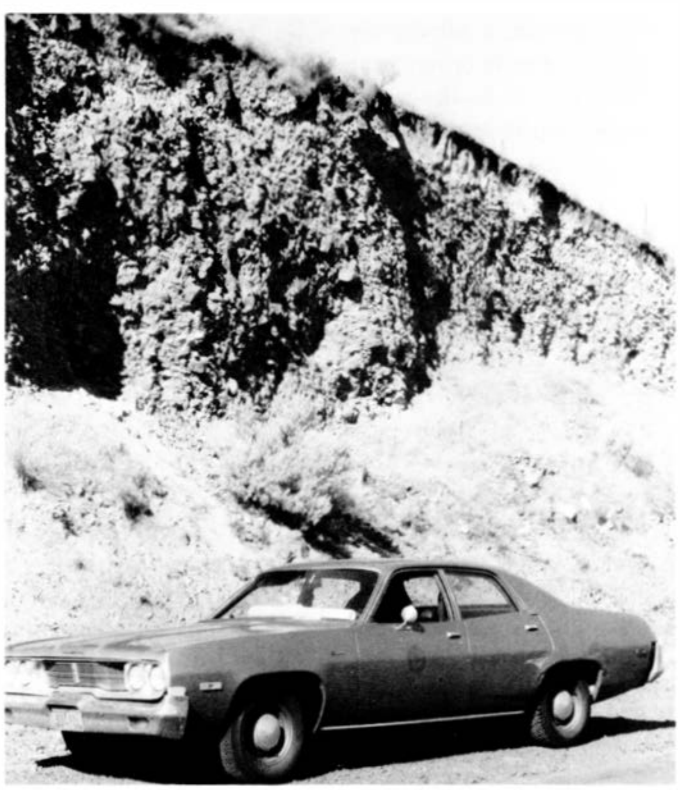


Figure 10. Massive, poorly sorted deposits of angular rock debris perched along the sides of lower Gherkin (Girkling) Canyon mark former levels of the creek.

Slide deposits - Quaternary thick talus (Qt)

This unit consists of uniformly sloping, unconsolidated rock and soil debris accumulating at the bases of cliffs, primarily as a result of rockfall and rockslide. The estimated thickness of mapped occurrences generally exceeds 50 feet in many areas. Thinner deposits are widespread but are not mapped because of scale limitations. The many other types of slide deposits including creep colluvium and bedrock slide blocks present in the study area are discussed in detail under Mass Movement rather than in this section.

Thick talus overlying Columbia River Basalt occurs at the bases of cliffs along the Columbia River east of The Dalles, along the Deschutes River, and near Cascade Locks. Thick talus also surrounds intrusive rock at Shellrock Mountain (Figure 11). Talus over these units generally consists of coarse, angular rubble near or at the surface with increasing proportions of silt and clay components at depth. Talus is patchy or absent along much of the Columbia River Gorge between Hood River and The Dalles, presumably because it was removed during the Missoula Flood.

Talus developed over the Dalles Formation is present along north-facing escarpments overlooking the Columbia River between the mouth of Chenoweth Creek and the Deschutes River. Many of the steeper slopes overlooking and underlying the talus probably were formed by the scouring action of the Missoula Flood (see Pleistocene lake deposits). To the south the headwalls of deep bedrock slumps in the Dalles Formation are covered with thick deposits of talus. Because of the many different rock types found between the various interbeds of the Dalles Formation (see Dalles Formation), talus developed over the unit is typically composed of angular blocks having a wide variety of size, shape, and rock type.

From an engineering standpoint, talus can be viewed as poorly placed fill that has neither been size sorted nor properly compacted. Hazards include differential settling, especially in the case of the extremely heterogeneous talus developed in the Dalles Formation, and the potential for mass movement under varying conditions of climate, infiltration, and land use. Massive earthflows and debris flows which have developed in some of the larger talus deposits are visible on the flanks of Wind Mountain from the Oregon shore of the Columbia River. At least one earth slide of large proportions has been recorded on the Oregon side of the river (see Mass Movement - Shallow earthflow and slump topography). Oversteepening of the talus by deep road cuts is not recommended. Shallow subsurface flow of rainwater over impermeable horizons at shallow depths in the talus must be properly accommodated by any engineering projects in the talus. Buttresses require adequate drainage facilities; secondary roads, pipelines, and aqueducts constructed on talus slopes must permit unrestricted flow of subsurface water.

Wind deposits - Quaternary eolian sand (Qs)

This unit consists of an isolated body of unconsolidated fine- to medium-grained sand found at elevations between 200 and 1,000 feet west and northwest of Kaiser Ridge as well as a small body of sand located on the east bank of the mouth of the Deschutes River. The unit does not include wind-blown silt that is mixed with the soils of the Columbia River Basalt and the Dalles Formation in the east half of the study area, nor does it include the wind-blown silt that makes up much of the Quaternary older alluvium along many of the smaller streams in the east half of the study area. The wind-blown silts are thickest on the northern and eastern slopes of hills and ridges.

The deposits near Kaiser Ridge, which form easterly-migrating, elongate barchan dunes far above the present level of the Columbia River, are probably derived from Missoula Flood deposits in the Signal Hill area. The deposits at the mouth of the Deschutes River are apparently derived from Quaternary alluvium. Hazards associated with the Kaiser Ridge deposits include blowing sand which obscures vision along the highway and covers the highway at times. Control by planting is not feasible because of the arid climate; and structural controls or actual removal of the deposits is required.

Figure 11. Quaternary thick talus deposits on north slope of Shellrock Mountain.

Figure 12. Small Pliocene fault in the Dalles Formation is exposed near the mouth of Chenoweth Creek.

Structure

General

The term structure refers to the folds, faults, and joints that affect the disposition and arrangement of the geologic units in the study area. Structure is of significance in interpreting rock distribution, earthquake potential, and mass movement. In addition to field observations, information on structures was obtained primarily from Newcomb (1967, 1969) and Portland General Electric (1974a, b). Thick vegetation, the wide distribution of young units, and the lack of adequate previous geologic mapping contribute to the relative lack of structural information presented here for the western half of the study area.

All exposed folds and faults in the study area are probably mid-Pleistocene in age or older. Faults trending northwestward underlie undeformed mid-Pleistocene or older Simcoe lavas in Washington (Portland General Electric, 1974a). The Columbia Hills anticline, which straddles the north side of the Columbia River east of The Dalles, is mid-Pleistocene in age. East of the study area, faults intersecting the anticline merge with the anticline (Goldendale fault) or change orientation and style of deformation (Warwick fault) as they cross the axis of the anticline, indicating formation concurrent with that of the anticline. Hence, they are no longer active. More detailed analyses in support of a mid-Pleistocene age of deformation are available in Portland General Electric (1974a, b), Shannon and Wilson (1973a), and Newcomb (1969).

Present-day earthquakes (see Earthquakes) in the study area can be related to major structures such as the Columbia Hills anticline (Shannon and Wilson, 1973b) but are generated along undefined faults at considerable depth that are not exposed at the surface. Detailed stratigraphic analyses (Farooqui and Kienle, 1976), made possible by flow-by-flow mapping of the Columbia River Basalt, reveal several pulses of tectonism in the late Miocene and Pliocene and may lead to the recognition of additional inactive faults in the future.

Folds

Major folds of the region surrounding The Dalles include the Dalles-Umatilla syncline, which extends down the Mill Creek valley through The Dalles and Fulton Ridge toward northeastern Oregon, and the Columbia Hills anticline, which forms the prominent ridges lining the Columbia River along the Washington shore. Southwestward into Oregon, the Columbia Hills anticline splays into several compressional structures in the White Salmon quadrangle. These include the Mill Creek Ridge anticline, Chenoweth fault, the Ortley anticline, and other lesser folds.

The Dalles-Umatilla syncline (Newcomb, 1967, 1969) forms a broad trough with a vertical displacement of 2,000 to 4,000 feet and a width which varies from 5 miles on its western end to 50 miles in its center, east of the study area. Deposits of the Dalles Formation on the upturned limbs of the syncline were eroded prior to extrusion of the Cascades Formation (QTv) (Newcomb, 1969). Deformation was probably middle Pliocene to mid-Pleistocene.

In the western part of the study area, the core of the Cascade Range is upbowed several thousand feet, so that the top of the Columbia River Basalt is at river level at Corbett and Hood River but is at elevations greater than 3,000 feet in the Herman Creek drainage midway between. South-dipping exposures of underlying Ohanapecosh Formation in the core of the anticline contribute greatly to the generation of massive landslides in the Cascade Locks area. Along the east side of the Hood River Valley, the Columbia River Basalt is displaced upward along a series of faults (Hood River fault zone) which merge to the north with the Bingen anticline. Immediately north and northwest of Hood River, the Underwood lavas are elevated several hundred feet above the river, indicating middle Pleistocene or possibly late Pleistocene uplift.

Faults

Major mapped faults of the study area include the Hood River fault zone along the east side of the Hood River Valley; the Chenoweth fault, which trends westward from the mouth of Chenoweth Creek through the center of the White Salmon quadrangle; and the Laurel fault, which passes southeasterly between Kaiser and Fulton Ridges. None of the faults are believed to be active. Minor faults are exposed locally in road cuts (Figure 12).

The Hood River fault zone passes along the base of a 1,000-foot uplifted escarpment of Columbia River Basalt which trends north-south along the east edge of the Hood River Valley and passes northward into the Bingen anticline in Washington. It displaces rocks of early Pliocene age and is believed to be mid-Pleistocene in age (Shannon and Wilson, 1973b).

The Chenoweth fault, which is 8 miles long, displaces Columbia River Basalt upward on the north side for as much as 200 to 600 feet. It postdates early Pliocene units, which it displaces; and it predates overlying early Pleistocene intracanyon flows of the Cascades Formation. Although epicenters in The Dalles area were tentatively attributed to the fault (Portland General Electric, 1974b), regional relationships with surrounding rock units show that it is not presently active. Several bedrock failures are located along the fault in the upper Chenoweth Creek area.

The Laurel fault extends into the study area from Washington and displaces rocks of the Dalles Formation a distance of 80 feet in the Kaiser Ridge-Fulton Ridge area (Portland General Electric, 1974a). A mid-Pleistocene or older time of deformation is inferred for this fault, as for all faults that are structurally closely related to the Columbia Hills anticline. Farther to the north, the Horse Heaven Hills anticline and associated faults are interpreted to be the youngest exposed structural features in the region (Newcomb and others, 1972). A mid-Pleistocene age of deformation is broadly accepted, although ongoing deformation is also suggested by some workers (Brown and McConiga, 1960).

GEOLOGIC HAZARDS

General

Accommodation of orderly development while insuring public health, safety, and welfare is difficult and complex. The complexity, however, is greatly reduced where an understanding of the natural characteristics of the land, the processes that shape it, and the geologic hazards that threaten it is rationally applied in guiding growth. Geologic hazards of concern to the planner include mass movement, slope erosion, stream flooding, stream erosion and deposition, earthquake potential, and volcanic potential. Each hazard is characterized by unique distribution, causes, and ranges of impacts. In this report, recommendations for treatment or mitigation of geologic hazards are flexible to allow for variations in physical, social, political, and economic settings. The distribution of geologic hazards based on reconnaissance investigations is indicated on the accompanying Geologic Hazards Maps.

Mass Movement

General

Mass movement is the movement of rock or soil material downslope in response to gravity. Table 3 summarizes several kinds of mass movement recognized in the study area, including deep bedrock slumps and slides, bedrock translational slides, earthflow and slump, steep-slope mass movement, creep, and potential mass movement. The parts of this study dealing with mass movement are reconnaissance and provide a valuable tool for regional planning. Although they are also guides to on-site evaluations, they are not substitutes for on-site investigations; and they should not be used as such for site-specific decision making.

Causes

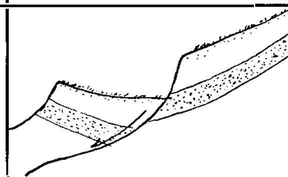
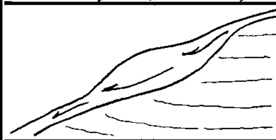
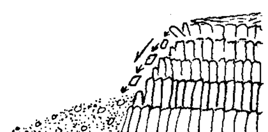
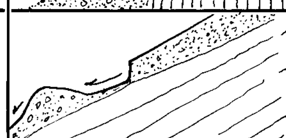
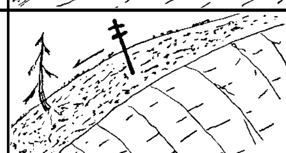
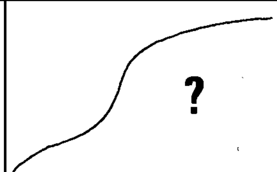
Mass movement occurs on slopes where the downslope component of gravity exceeds shear resistance. In areas of potential sliding, the activities of man should be controlled to assure that the downslope component of gravity is minimized and that shear resistance is maximized.

Downslope gravity component: Weight of the soil column is increased by placement of fill for road construction or other purposes. Increased water content of the soil during winter rains adds to the downslope gravity component. Obstructions to runoff or springs, such as improperly designed roads or poorly located dwellings, may direct surface water into the subsurface or retain subsurface water, adding to the weight of the soil column. Debris flows and earthflows may result on moderately steep slopes; and bedrock translational slides may be generated, even on very gentle slopes. In wooded areas it is doubtful, however, whether increased soil moisture associated with logging has a measurable impact on slope stability. Slides there generally occur in the winter when soils, even under forest cover, are saturated.

Models of slope failure presuppose that the weight of the soil column is perpendicular to the earth's surface. Where nearby blasting or seismicity is a factor, a horizontal component of acceleration is introduced along with the vertical gravity component. The resulting inclined direction of acceleration has the same effect as does steepening of the slope.

Shear resistance: Under saturated conditions, water in the soil buoys the soil particles, reducing internal friction, and thereby also reducing shear resistance. Thus, where soil water is increased to the point of saturation by rainfall, drainage interference, or blocking of springs, the net result is a decrease of shear resistance and increased potential for sliding. Under conditions of heavy rain, infiltration may

Table 3. Classification of mass movement in northern Hood River, Wasco, and Sherman Counties, Oregon

Type		Description		Distribution
Deep bedrock slumps			Slip of rock along a curved basal shear plane along with backward rotation of the slide block as a unit; characterized by irregular topography on a grand scale, sag ponds, and a pronounced headscarp.	High slopes in the Columbia River Gorge in Tcr, Teme, and Teo; steep valleys of major tributaries in Tpd; stratigraphically and fault controlled. Slopes oversteepened by the Missoula Flood.
Bedrock translational slides			Sliding of large bedrock slabs downslope and downdip along incompetent interbeds with no backwards rotation and little or no disaggregation.	Moderate to very gentle slopes in Tpd immediately overlying Tcr; include Government Flat landslide and slides in middle reaches of Mosier Creek (deep bedrock slumps in part).
Shallow earthflow and slump topography			Irregularities of slope, soil distribution, drainage and other features which suggest downslope movement along innumerable shear planes.	Randomly distributed in moderately sloping terrain of Tpd, but especially common in the upper reaches of creeks.
Steep-slope mass movement	Rockfall and rockslide		Falling and rolling rock at the base of cliffs; hazardous areas include talus downslope; deposits often obscured by vegetation.	Cliffs of Tcr along the Columbia River especially in the Gorge; also cliffs along tributaries. Most prominent talus mapped as Qt.
	Debris flow and debris avalanche		Flow or sliding of rock and soil material along a surface parallel to the slope; generally rapid; slurry-like flows generated by high water content.	Steeply sloping terrain along middle and upper reaches of major tributaries especially in the White Salmon quadrangle.
Soil creep			Random, particle-by-particle movement of soil and rock material in response to gravity and random processes such as root action, expansion and contraction, and animal activity; no slip plane.	Steeply sloping terrain; cowtrails in the eastern half of the study area are formed partly by animals but also by creep.
Potential future mass movement			Unmapped. Those areas for which relatively high potential for future sliding can be inferred on the basis of other slides in the study area. Accurate delineation requires more detailed mapping than provided here.	Potential mass movement is most likely on sloping terrain near mapped faults in Tcr; on steep slopes with increased water content in Tpd; near contacts of Tcr and Tpd, or Teme and Teo; and in logged steep terrain.

exceed the rate of subsurface drainage so that the liquid limit of the soil is actually exceeded (Campbell, 1975). Debris flows involving thin soils or pockets of colluvium over impermeable bed rock can be attributed in large part to these factors.

Cohesion, the bonding attraction of soil particles, varies with soil type and water content. Silts, which dominate the soils of the study area, have low cohesion when dry, moderate cohesion when damp, no cohesion when very wet;liquefaction occurs in saturated silts when they are disturbed. On the other hand, clays, which may form interbeds in certain bedrock units of the study area, may accommodate large quantities of water before gradually reaching their liquid limit. Slow-moving landslides that are active over prolonged periods of time may result.

Other factors which contribute to shear resistance include independent means of support and the distribution of soil on the slope. Root support by trees is now recognized as a primary agent of stability in steeply sloping forested lands. Root support declines rapidly after logging, and many slides in logged areas are attributed to loss of support through root decay. Removal of the toes of slides through stream bank erosion or improper grading may initiate slides on any slopes, especially in talus. Deep cuts may intersect critical joints or faults in bed rock to initiate mass movement.

Deep bedrock slides

Deep bedrock slides are situated in areas of high relief and are recognized primarily on the basis of the displacement of large bodies of rock downslope. Two major types of deep bedrock slides are recognized. Slumps are those slides which involve downdropping and backward rotation along a curved basal slip plane, and translational slides are those which involve sliding of large masses of bed rock along gently dipping interbeds. Translational slides generally involve less vertical displacement and result in very gently dipping slide deposits. Many bedrock slides are combinations of slumps and translational slides.

Not included in deep bedrock slides are two kinds of features which superficially resemble them but which do not involve the actual dislocation of bed rock: old meander scars situated above stream level in canyons, and localized scabland developments along ridge crests in the Dalles Formation. Some meander scars, such as those surrounding the Big Eddy substation on lower Fifteenmile Creek, resemble headscarps, and some scabland features resemble hummocky topography associated with deep landslides. Distinction from true landslides is sometimes difficult.

Slides in the Eagle Creek Formation: The Eagle Creek Formation, which rests upon saprolitic clays of the southerly dipping and impermeable Ohanapecosh Formation, is exposed in the core of the Cascade Range along the Columbia River. Downcutting of the Columbia River has prompted the development of several massive landslides including the Bonneville slide (Figure 13) and the Ruckel slide.

The Bonneville slide, on the north side of the river, covers approximately 10 square miles and is the site of the legendary Bridge of the Gods. The last major episode of sliding occurred approximately 700 years ago (Brogan, 1958) and dammed the Columbia River to an estimated depth of 200 to 300 feet (Lawrence, 1937; Lawrence and Lawrence, 1960). Water was still impounded at the time of Lewis and Clark (Strong, 1967). Drowned forests and cataracts over the landslide dam are mentioned in at least 50 independent articles in pioneer times (Lawrence, 1937).

Sliding was probably first initiated in the Pleistocene when downcutting exposed the base of the Eagle Creek Formation over the Ohanapecosh Formation. In late Pleistocene times, erosion by the Missoula Flood may have initiated an episode of major sliding which, in turn, may have partially blocked the river. This would explain the large volume of Lake Lewis in comparison to that of Lake Missoula (see Pleistocene lake deposits).

Episodes of southward movement of the Bonneville slide through geologic time directed the Columbia River against the south shore to initiate first the Cascade Locks landslide in mid-Pleistocene times and then the more recent Ruckel slide. The Cascade Locks landslide is situated between Cascade Locks and Herman Creek and rests on a basal shear zone approximately 200 feet above the river. Dry Creek and Rudolph Creek flow into the slide mass from above, disappear into the ground, and then reappear as a series of springs such as Oxbow Springs along the base of the slide (Sceva, 1966). The slide is no longer active, but it poses several problems to development including poor drainage, springs, highly variable soils, heterogeneous bedrock conditions, and local sliding in present-day drainages. Cutbank stability is highly variable.

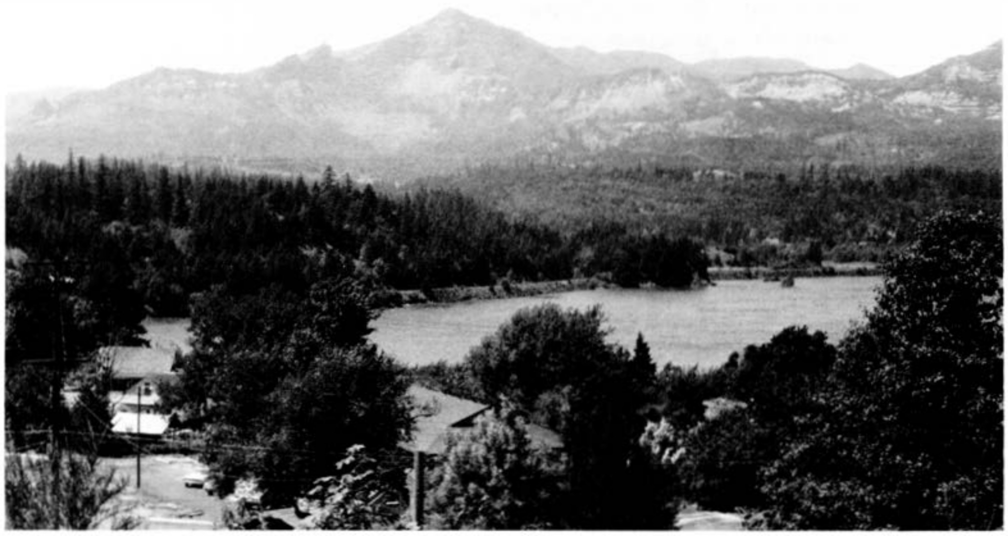


Figure 13. The Bonneville landslide, site of the legendary Bridge of the Gods, extends to the steep slopes in the background and has been active for thousands of years.

Figure 14. Active bedrock failure (bounded by points A, B, and C) in Columbia River Basalt is located in middle reaches of Chenoweth Creek. Slide occurs at the intersection of two faults.

The Ruckel slide, situated between Cascade Locks and Ruckel Creek to the west, is located along the greatest restriction of the Columbia River and is still active. Movement was largely arrested by the installation of a number of drainage tunnels in the 1930's (Sceva, 1966), but minor displacements of the railroad tracks still are occurring. Drainage through the tunnels is highly seasonal. Development in this area should proceed on the basis of detailed site investigations.

Slides in the Columbia River Basalt: Deep bedrock slides in the Columbia River Basalt include slides near Rowena Dell east of Mosier; slides in the middle reaches of Chenoweth Creek and on the north face of Signal Hill; and a slide along Stecker Creek, 8 miles south of the mouth of the Deschutes River. With the exception of the Signal Hill slides, which are governed by an incompetent palagonite interbed, the slides owe their origin to steep-slope development along structural discontinuities including faults and regional joints. The Chenoweth Creek slides (Figure 14) and the Stecker Creek slide are active; slides along the Columbia River near Mosier may be active. The Signal Hill slides are located far above the Columbia River and probably are no longer active, although slide-related foundation problems may still be of significance. These include poor drainage, high ground water, and highly variable foundation strengths and cutbank stabilities.

Slides in the Dalles Formation: Deep bedrock slides in the Dalles Formation include translational slides and combination slump-translational slides near the contact with the Columbia River Basalt as well as deep slumps higher in the section. The major translational slides near the base of the Dalles Formation are developed where topographic slope and regional bedrock dip are generally in the same direction and where undercutting has exposed the contact. Among these are slides in the middle reaches of Mosier Creek, the Government Flat landslide (Figure 15) along Brown Creek, and a landslide mass in the community of The Dalles. The Government Flat landslide has downdropped parts of the Dalles Formation several hundred feet and is bordered on its upper edge by a prominent headscarp. Variable dips, large hummocks, and gentle slopes characterize the slide mass. The base of the slide is fronted by stream terraces and is situated above present stream level. Stream drainage is moderately well integrated on the slide mass, and the slide is probably mid-Pleistocene in age. Although it is no longer active, secondary slides that developed along major streams in the slide mass east of Brown Creek are active and should be carefully studied prior to any development. Origin of the Government Flat slide is obscure but may be partly attributed to the wetter mid-Pleistocene climate and to active undercutting by Brown Creek before it was captured in its upper reaches by Mill Creek.

The slides in the middle reaches of Mosier Creek are situated along the contact with the Columbia River Basalt and are deeply dissected by streams. They are no longer active and do not pose a threat to most development. The translational slide along the contact with the Columbia River Basalt in the community of The Dalles is discussed in detail under Geologic Hazards of Communities - The Dalles.

Deep bedrock slumps are mapped above the base of the Dalles Formation at scattered localities between Hood River and Fifteenmile Creek and are recognized on the basis of their pronounced headscarps and gentle slopes. Recognizable perched meander scars are not included. Commonly the headscarps are mantled with a talus cover of broken and disoriented blocks of the Dalles Formation. The series of large slump blocks between The Dalles and the mouth of Threemile Creek show apparent offsets of several hundred feet. Slumps high in the Dalles Formation are not presently active but could be reactivated if the subsurface water budget were greatly modified by drainfields, drainage modifications, or irrigation. Detailed on-site geologic investigations are needed to guide development.

Slides in the Cascades Formation: The most significant deep slump in rocks of the Cascades Formation is located along the Columbia River three miles west of Wyeth in the younger Wind River flow unit (Figure 16). The toe of the slide displaces the freeway upwards several tens of feet and is still active. Periodic roadwork is required to maintain a safe grade. Attempts to halt the slide by removing material from the head of the slide have been unsuccessful. Possibly the slide is not a simple slump. It may be caused in part by boiling up of saprolitic muds of the Ohanapecosh Formation in response to regional hydrostatic pressures as first proposed by Waters (1973) or by failures within the Eagle Creek Formation at the base of deep fills as proposed by Meyers (1953). Numerous other large active slumps are developed in the Cascades Formation along the tributaries of the West Fork of the Hood River.

Figure 15. Mid-Pleistocene Government Flat landslide is largest example of bedrock failure in study area. Note gentle slopes in slide terrain and areas where sliding has not occurred.

Figure 16. Highway I-80N passes over toe of large slump 3 miles west of Wyeth. Continuing displacement requires periodic maintenance.

Shallow earthflow and slump topography

Shallow earthflow and slump topography refers to those areas for which earthflow and slump of soil and the upper regolith are inferred on the basis of small-scale irregularities of topography and drainage as revealed by field investigations or aerial photographic interpretations. Other features visible on the ground may include small sag ponds, bowed trees, broken regolith in road cuts, irregular soil distributions, and springs. Care has been taken not to include Missoula Flood features, irregular weathering, heterogeneous bed rock, or other features which superficially resemble slide topography but which are stable.

In this reconnaissance, investigation areas mapped as shallow earthflow and slump topography are largely restricted to sparsely vegetated areas in the vicinity of The Dalles, especially on moderately steep slopes of the Dalles Formation in the upper parts of drainages or short streams. Slopes of talus (Qt) also are sites of periodic earthflow and slump. Shallow earthflow and slumps are not developed in the gentler slopes of the eastern part of the study area and are generally not discernable under the dense forest cover in the west. Although recognition of shallow earthflow and slump topography in forested areas is difficult, regions of highly probable earthflow and slump can be inferred on the basis of slope, topographic setting, and general geology (Figure 17).

Depending on the depth and rate of movement of shallow earthflows and slumps, potential damage may include warping of highways, destruction of buildings, and other losses, either in a relatively short period of time or over a period of years. Slow-moving earthflows are particularly bothersome because of difficulty of recognition and the prolonged episodes of damage associated with them.

The general aspects of earthflows and slumps as they develop in talus (Figure 18) are discussed under Surficial Geologic Units - Slide deposits. A specific earthflow which occurred in early February 1946, west of the study area and less than one mile east of Multnomah Falls, is particularly informative. Small cutbank failures and slides formed in State Highway Department roadcuts during a period of heavy rains and soon developed into massive failures which buried the railroad tracks under 350,000 tons of debris. Repairs required the services of 150 crewman using 10 bulldozers and a fleet of trucks.

Deep excavations in talus or other unconsolidated material are not advised, especially during the rainy season. Moreover, repair activities should be postponed until after stormy weather. In the above slide, renewed activity almost injured a telephone repairman on February 7 (*Oregonian*, Feb.8, 1946), and true disaster would have occurred had the slide become active during the daylight hours instead of at night when the workers were not on the job. A similar incident claimed the lives of nine workers in Douglas County in January 1974.

Steep-slope mass movement

Steep-slope mass movement includes both rockfall and rockslide (Table 3) along cliffs of jointed or fractured bed rock and also debris flow and debris avalanche on steep slopes with relatively thin soil cover. Rockfall and rockslide are most common in terrain of Columbia River Basalt (Figure 19) or intrusive rock along the Columbia River Gorge. They are caused by the wedging loose of rock fragments by root action, percolation of ground water, or animal activity and result in the accumulation of talus at the base of the slope. Many geologic hazards in addition to rolling and falling rock are associated with talus, as discussed under Surficial Geologic Units - Slide deposits.

The danger of rockfall or rockslide can be minimized by 1) controlling blasting where vibrations may jar rock fragments loose, 2) screening or scraping cliffs located near incompatible uses, 3) erecting retaining walls or constructing embankments to contain rolling rocks, 4) placing warning signs at critical localities along roads and trails, and 5) grouting cliffs where necessary. Immediately east of Mosier, electric fences have been installed along upslope sides of the railroad tracks. They are designed to automatically set block signals if large boulders should happen to break the wires and roll onto the tracks.

A continuous mass of rock and soil begining to slide down a steep slope is called a debris slide. As the slide mass disaggregates into smaller and smaller pieces, it is called a debris avalanche or a debris flow, depending upon moisture content and the precise nature of the displacement. Such failures occur on steep slopes and involve surfaces of failure that are parallel to the hillside. Because these failures generally occur at shallow depths, recognition of them in reconnaissance investigations in thickly vegetated terrain is difficult. On the Geologic Hazards Maps, areas of steep-slope failure can be inferred in

Figure 17. Shallow slumps such as these in gully near Wasco are generally not mappable in reconnaissance work but can be inferred on the basis of slope, rock type, and position near the head of gully.

Figure 18. Massive earthflows extend upslope in talus to exposedbed rock of Wind River Mountain.

a general way on the basis of slope. Debris-avalanche and debris-flow deposits observed in the field were most common in areas mapped as having greater than 100 percent (vertical distance/horizontal distance > 1) regional slopes, especially very steep-gradient side gulleys characterized by subsurface rather than stream flow.

Debris flow and debris avalanche are caused by the accumulation or development of colluvial material on steeply sloping terrain, followed by a loss of support or shear resistance through loss of root support, improperly designed road construction, or heavy rains. Campbell (1975) determined that most debris flows and avalanches in a study area in California could be correlated with periods of intense rain. For some slides he determined that the contribution of water to the subsurface exceeded subsurface flow and that the liquid limit of the soil was exceeded at the time of sliding. Slurry-like debris flows in the upper reaches of Mosier Creek may have a similar origin. In areas of debris-avalanche and debris-flow potential, the removal of vegetation must be controlled; and all road fills and embankments must be properly designed with adequate consideration given to subsurface runoff.

West of the study area at the foot of Ladd Glacier in Multnomah County, warm heavy rains initiated a large debris flow on August 31, 1961 which transported boulders weighing up to 130 tons for distances of up to 5 miles down Ladd Creek. The Ladd Creek bridge was destroyed, and the waters of Ladd Creek were diverted into another drainage (Freer, 1963). Future slides of this type are possible in the upper reaches of the West Fork of the Hood River (Ladd Creek) and the Middle Fork of the Hood River. Impacts in the study area would probably be restricted to temporarily increased stream turbidity.

Soil creep

Soil creep is the random, particle-by-particle movement of soil or rock material downslope in response to gravity and to other external factors including animal activity, freeze-thaw or wet-dry expansion and contraction, root action, and plowing. The randomness of movement with no shear planes and the contribution of external forces besides gravity distinguish soil creep from other types of mass movement. Creep is a shallow phenomenon occurring on steep and convex slopes. The cow trails common to many of the steep slopes of the study area are a special form of soil creep in which the influence of animal activity is dominant.

Soil creep typically is associated with tilted trees, tilted fenceposts, and leaning retaining walls or tombstones. Over a long period of time, the forces associated with soil creep may crack retaining walls or foundations. Soil creep is relatively insignificant in the study area, but it should be noted that slopes with recognizeable soil creep and thick soil cover are very sensitive to artificial cuts. Cutbank failures, once initiated, may extend for great distances upslope to affect structures far from the original cut.

Potential future mass movement

The foregoing discussion treats present-day landslides in terms of their distribution, causes, impacts, and mitigations. To plan for the future in a meaningful way, the planner must also ask where tomorrow's landslides will be. To do this, one must identify the specific causes of the various types of landslides, isolate these factors on a map, and evaluate their relative significance in terms of future land use. Areas of potential future mass movement are briefly reviewed below. Time and budget limitations and inappropriate map scales made the actual mapping of slide-prone areas impossible for this study.

Future deep bedrock failures will include continued activity both on slides described as active in the Eagle Creek Formation in the above discussion and also on deep cuts or areas of streambank erosion in ancient slide masses such as the Cascade Locks slide. Bedrock failures in the Columbia River Basalt will be largely restricted to deep cuts or steep terrain along faults or in areas of steep downslope dips or incompetent palagonitic interbeds. The slides in the middle Chenoweth Creek area involve palagonites and intersecting faults.

Future deep bedrock failures in the Dalles Formation can be expected on active slumps and also on inactive slumps where drastic changes in the subsurface water budget are caused by excessive irrigation or by blocking of springs by construction or other means. Bedrock translational slides are possible where bedrock attitudes are approximately parallel to slope, and critical interbeds or horizons are influenced by drastic changes in the subsurface water budget. The most critical horizon involved in present translational slides is the contact with the Columbia River Basalt. Changes in water budget may be caused by climate, drain fields, urbanization and consequent changes in runoff and infiltration patterns, or the blocking of springs by development.

Shallow earthflow and slumps will be most common in the upper reaches of streams and drainages where colluvial material is thickest and subsurface flow is most pronounced. It is emphasized that this type of sliding is not mapped in forested terrain and should, therefore, be considered in the evaluation of all developments on steep terrain in the west half of the study area. Fills should not be placed over springs and should not block shallow subsurface flow. Moderately steep to steep slopes in the Dalles Formation are susceptible in places to shallow earthflow, particularly in areas of increased subsurface water content resulting from septic tanks, drainfields, watering, or irrigation. Earthflows in talus may be expected to result from natural causes and also from excessive cuts or blocked shallow subsurface flow. Cuts that are made during the dry season may appear stable but probably will fail during wet seasons, sometimes years after they are made.

Rockfall and rockslide can be anticipated along all cliffs, and hazards of rolling rock should be anticipated for areas of sloping talus below. Debris avalanches and debris flows will be most common in steep gullys or draws with thick colluvial cover and characteristic subsurface flow. Removal of vegetation or improper construction of road fill in these areas will greatly increase the probability of failure.

Chapter 70 of the Uniform Building Code specifies practices to be followed in grading as it relates to building construction and contains provisions which deal with drainage and other special conditions. In problem areas, the local building official should require soils engineering or engineering geology reports prior to development. Implementation of the appropriate provisions of the Uniform Building Code in conjunction with the use of appropriate hazards inventories such as this one in urban areas can minimize future hazards associated with sliding.

In areas such as rural or forest land that are generally not covered by the Uniform Building Code, similar mechanisms of project review are recommended to mitigate landsliding. Mechanisms may include initiation or refinement of project evaluations by a variety of agencies such as the county, various communities that have not adopted the Uniform Building Code, or various State and Federal agencies which may exercise control over the land.

For longer range planning, the county or city planning staff can use the information in this study to place general constraints on future land use in critical areas.

Slope Erosion

Definition and causes

Slope erosion is the removal of soil or weathered bed rock by sheet wash (no conspicuous channels), rill erosion (numerous small rivulets), and gully erosion (larger, more permanent channels). It does not include erosion by larger channels between slopes, stream bank erosion, or mass movement, although these are sometimes lumped together in regional analyses of soil loss. Dominant factors controlling slope erosion are land use and land cover, slope, soil type, and rainfall intensity.

Soil erosion is extremely sensitive to slope gradient and moderately sensitive to slope length. The slope intensity factor in the study area is the greatest in mountainous areas in the west and along steep valley sides in the east. It is the least in flat bottomlands and on the low rolling hills east of The Dalles.

Soil erodibility varies greatly with land use and soil cover. Where sediment-yield rates have been measured, they provide a good general guide to slope erosion but should not be confused with actual soil loss (Wischmeier, 1976). Sediment-yield studies do not measure foot-slope deposition and other local forms of deposition which capture much of the eroded material before it ever reaches the basin undergoing investigation. Actual soil loss is always greater than measured sediment yield.

Knott (1973) demonstrated that the conversion of woodland to intensive agriculture and construction in California increased sediment yields 65 to 85 times. Yorke and Davis (1971) record a 90-fold increase in sedimentation during conversion of pastureland to townhouses in a small watershed in Maryland. In the H. J. Andrews Experimental Forest, uncontrolled clear-cut logging increased rates of sedimentation 67 times. Anderson (1971) reports similar results in a similar study in California. Langbein and Schumm (1958) determined that for areas with more than 40 inches annual effective precipitation, the sediment-yield rate under natural vegetation was approximately 200 cubic meters per kilometer per year (about 1,500 tons per square mile). This figure applies in a general way to the west half of the study area. For areas analogous to the east half of the study area (Figure 20) having annual rainfall of 8 inches, the sediment yield is double this amount because of decreased protective cover. These figures apply only to land in the natural state; erosion in agricultural areas is much higher.

Soil erosion is also a function of the permeability, structure, grain size, and organic content of the soil. In the study area, most of the soils (see Geologic Units, Bedrock Geologic Units, Surficial Geologic Units) are composed primarily of silt and fine-grained sand, both of which are easily eroded. On some of the steeper slopes, very shallow depths to bed rock increase soil-erosion potential due to increased runoff and decreased infiltration.

Methods of study

Many of the diverse factors controlling soil erosion are brought together in the universal soil loss equation developed by the U.S. Department of Agriculture (1972):

$$A = RKLSCP$$

A refers to the annual soil loss in tons per acre; R is the rainfall intensity factor; K is a measure of soil erodibility; LS is a slope intensity factor which considers slope gradient and slope length; C is the land cover and land use factor; and P is a factor of conservation practices. Until very recently, empirical data used in deriving the equation was based entirely on studies of flat to gently sloping agricultural land. Land use figures are now extended to consider nonagricultural uses. Figures for steeper slopes are extrapolated beyond the range of empirical data and are used only for speculative estimates. The universal soil loss equation is appropriate for estimating potential soil losses for particular parcels of land and gives good results within broad limits for gently sloping terrain (Williams and Berndt, 1972).

An additional technique for estimating erosion potential on a more regional basis is also available (Brown and others, 1974; Williams and Morgan, 1976). In it, a series of overlays depicting slope, bed rock, land use, and other pertinent factors are developed for a region; and a series of erosion provinces are defined. These are then correlated to existing erosion data and field evidence to produce semi-quantitative estimates of erosion potential. The definition of erosion provinces also allows the projection of erosion data from one locality to other areas of the same category. The erosion province method of analysis is appropriate for regional assessments of erosion and sedimentation potential.

Distribution

The potential for soil erosion is highest in the steeply sloping and unvegetated areas and lowest in the bottoms of the valleys. Rainfall and slope factors are most severe in the western part of the study area, and soil texture factors are fairly uniform within broad limits. The land use or land cover factor is most severe in the east where dry climate and agricultural practices leave the soil exposed for large parts of the year. Locally, erosion-control practices include contour plowing, the construction of dikes in gullys, and the preservation of more steeply sloping terrain in its natural state.

Sediments deposited in the Wicks Reservoir on the South Fork of Mill Creek southwest of The Dalles have been monitored for several years. The sediment consists of loamy clay sand and totals between 350 and 800 cubic yards per year. Most of it is derived from approximately 2,500 acres of moderately steep-sloping terrain that was burned over by a forest fire in 1967. The area, which was reseeded by natural grasses, produces about 2,800 pounds of sediment per acre. The indicated volume of sediment is only a partial measure of slope erosion because it does not include local deposition elsewhere within the drainage. Sediment contributed from forested areas of the watershed is considered minimal. Likewise, sediment loadings at the Crow Creek dam outside the study area and in an area of undisturbed natural forest are undetectable (William Keyser, 1976, written communication).

Under conditions of extreme rainfall and poor ground cover, sediment yields can be immense. In Spanish Hollow at Biggs, 64,000 tons per day of suspended sediment was measured after the peak flow of the 1964 flood (Waanenan and others, 1970). The sediment was derived from a 52-square-mile drainage area. This yield of 1,200 tons per square mile per day under flood conditions dwarfs the average yield

Figure 19. Large rockfall immediately east of Mosier.

Figure 20. Slide-free slopes in gently sloping terrain east of The Dalles. Accelerated erosion through agricultural use is thoroughly investigated by Soil Conservation Service.

of 90 to 200 cubic yards per square mile per year for the Wicks Reservoir area under normal climatic and ground-cover conditions. The figures for suspended sediment load in Spanish Hollow do not include a consideration of bed load or local deposition in the drainage basin.

Impacts and recommendations

Where land is denuded of vegetation through deforestation, fires, road or building construction, grass fires, or plowing, increased rates of sedimentation can adversely effect streams by increasing flood potential (see Stream Flooding) or by silting gravels at spawning sites. Loss of topsoil can hinder reforestation after logging or reduce productivity of agricultural areas. Slope erosion in areas laid bare by construction can mar the landscape and generate deposition downslope on roads, in lawns, and in storm sewers.

Various governmental agencies are involved in the control of erosion and sedimentation. The U. S. Forest Service conducts hydrologic studies and investigates sedimentation and erosion resulting from forest practices on Federal lands. The Oregon State University Department of Forestry has an ongoing program of investigation of erosion, sedimentation, and streamflow related to forest practices. The State Department of Forestry administers the Forest Practices Act of 1971.

The U. S. Soil Conservation Service maps soils and advises local officials on soil management. Most practical assistance in the agricultural parts of the study area will continue to come through the programs and publications of the Soil Conservation Service.

Preferred locations of roads in the mountainous areas are benches, ridge tops, and gentle slopes, not steep slopes and narrow canyon bottoms. Vegetation removal and soil disturbances should be kept to a minimum during construction or logging. Site-specific techniques to minimize slope erosion include both the use of buffer strips and settling ponds and also the application of protective ground cover such as mulch, asphalt spray, plastic sheets, sod, or jute matting in particularly critical areas. Logged areas should be replanted where reseeding is unsuccessful.

Engineering investigations prior to construction in critical areas should include an investigation of sediment yields and increased runoff downslope to assure that these impacts are kept within acceptable limits in terms of surrounding land use and storm sewer or drainage capacities. Basic techniques of estimating erosion potential are summarized above (see Methods of study).

Stream Flooding

General

As discharge of a stream increases, corresponding increases occur in the width (stream-bank erosion), depth (channel scour and rise of water level), and velocity of the stream. Thus, at a given point on a stream, the velocity increases with increasing discharge. In addition, for most streams, mean velocity increases in the downstream direction. This surprising pattern (Leopold, 1953) occurs because increasing depth and decreasing channel roughness and turbulence downstream more than compensate for decreasing slope downstream.

Flooding occurs when rising water in streams spills over established channels into the surrounding lowlands. Various categories of flood areas include the flood plain (inundated by larger floods), the floodway (channels that convey fast-moving waters), and floodway fringe (flood plain not in the floodway, but subject to periodic flooding).

The U. S. Army Corps of Engineers, U. S. Soil Conservation Service, and U. S. Geological Survey delineate areas subject to flooding with a variety of computor models. The programs are used to produce flood maps for a variety of selected frequencies. An Intermediate Regional Flood (also referred to as the 100-year flood) is the flood having a 1 percent probability of occurring in any given year.

In the absence of statistical models, maps showing past flooding can be assembled, using flood records, high-water marks, aerial and surface photographs, interviews, and newspaper accounts. Such data are, in part, the bases for determining flood-prone areas indicated for the study area (see Geologic Hazard Maps). The indicated flood is a composite of many historical floods of undetermined frequency, rather than a statistical model based on flood distributions of known frequencies, so it differs significantly in kind from the Intermediate Regional Flood. In view of the relatively small scale of mapping used in the study, however, the distribution of lowland flooding indicated probably does not differ significantly from that of the Intermediate Regional Flood.

For areas in which there were little or no recorded data, flood-prone areas were deduced from topography, landforms, soils, vegetation patterns, and other natural features (Figures 21 and 22). Techniques available for reconnaissance or preliminary on-site evaluations are described by Reckendorf (1973).

Segments of streams having little or no flood plain are the sites of torrential floods, which are characterized by catastrophic streamflow, erosion, and deposition. Floods like these are most common in the headwaters of Mosier Creek and in steep gradient canyons cut in Columbia River Basalt which pass through cliffs to the Columbia River. These floods impose constraints on road, fill, and bridge construction and are discussed under Stream Erosion and Deposition.

Causes

Flooding is caused by large increases in discharge or by natural or man-caused modifications of the channel. Review of the Manning equation of stream discharge provides a systematic basis for reviewing the causes of stream flooding and for qualitatively predicting the impacts of various possible channel modifications:

$$Q = (1.486/n)AR^{2/3}S^{1/2}$$

where Q is the discharge (cfs per square mile), n is the channel roughness, A is the cross-sectional area of the channel, R is the hydraulic radius (A divided by wetted perimeter), and S is the slope (gradient) of the stream. Flooding can be caused by increasing Q or by holding Q constant and modifying factors on the right side of the equation so that depth (a factor of A and R) is increased.

Natural flooding in the study area is the result of heavy orographic rainfall and possible rapid snowmelt or thunderstorms (see Geography - Climate and Vegetation), low infiltration rates into bed rock, steep slopes, and steep gradients. Most floods reach their crest shortly after peak precipitation. An additional potential cause of flooding is the impoundment or sudden release of waters behind landslide dams.

Local land use can influence flooding by altering surface water residence times and infiltration rates. In a recent study in Long Island, New York, urbanization of open land increased peak flow by a factor of 3 and total runoff by a factor of up to 4.6 (Seaborn, 1969). A similar study of the Colma Creek drainage in California revealed a doubling of storm runoff with no change in peak flow (Knott, 1973). A variety of modeling procedures is available for predicting runoff in areas of changing land use (Rantz, 1971) and should be incorporated into storm sewer design.

The impact of logging on stream flooding varies with tree type, soil characteristics, and climate; but it appears to be minimal. In the Alsea drainage (Harris, 1973) and the H. J. Andrews Experimental Forest (Rothacker, 1970a, b), no increase of peak flows with logging is noted. These conclusions are based on a 95 percent level of confidence in the graphical comparisons, however, and selection of less stringent statistical requirements might yield different conclusions. Also, changes in channel geometry and the manner of flood-water conveyance through lowland areas outside the watersheds have been little investigated. No pertinent studies of the influence of logging on flooding are available for the study area.

A beneficial effect of logging in many areas is increased streamflow during dry summer months when water consumption peaks. Removal of conifers under ideal conditions of soil thickness and climate reduces summer evapotranspiration by approximately 18 inches in the H. J. Andrews Experimental Forest (Rothacker, 1970a). As a result, after logging summer streamflow increased by about 30 percent (Moore, 1966). In regions of drier climate, thinner soils, and less uniform original conifer cover, the beneficial impact is less dramatic. In the Ochoco Mountains evapotranspiration was reduced by 2 inches and resulted in slightly increased streamflow (Berndt and Swank, 1970).

If discharge Q is held constant, flooding may be caused by modification of the cross-sectional area A or slope S . Thus, artificial fill, other obstructions (road fill, bridges, structures) in stream channels or floodways, gravel deposition generated by increased slope erosion, and channel obstructions by such natural causes as landslides can contribute to flood potential. The Flood Insurance Act of 1968, administered by the U. S. Department of Housing and Urban Development, and the Natural Hazard Goal, adopted by the Land Conservation and Development Commission, regulate obstructions in the floodway.

Figure 21. Flat bottomland gullies and channels which indicate frequent flooding are found in middle reaches of China Creek and are detectable by on-site inspection.

Figure 22. Barn located immediately downstream from area of Figure 21 is protected from small floods by small levee.

Placing of fill in channels is regulated by the U. S. Army Corps of Engineers and the State Land Board.

Slope *S* is influenced by aggradation (see Stream Erosion and Deposition) and channel modifications. If slope is decreased, cross-sectional area (and therefore depth) must be increased accordingly to accommodate a given discharge. Other factors which influence flooding include water impoundment by log jams, snags, and ice jams.

The impact on any particular river site of channel modifications, either for flood control, aggregate removal, erosion control, or other purposes, depends on the specific conditions at that site. Thus, channel restrictions in one part of a stream may aggravate flooding, whereas constrictions elsewhere may have no significant impact on flooding. Likewise, channel modifications may be justified in some areas to minimize flooding and may be inadviseable elsewhere because of undesireable effects on stream erosion.

Distribution and magnitude

Major floods occurred on the Columbia River in 1894 and 1948, with discharges at The Dalles of 1,240,000 cfs and 1,010,000 cfs respectively. The flood of 1894 inundated much of the downtown area of The Dalles (Figure 23). In recent years, dam construction along the Columbia River has greatly minimized the probability of floods of these magnitudes. Distribution of possible floods is given in Geologic Hazards of Communities, but is not indicated on the Geologic Hazards Maps, because of the limitations of scale. The 1964 flood had little effect on the Columbia River because of the large size of the drainage basin, seasonal low flows, and upstream dam regulation; in contrast, flow on the Deschutes River was almost double the previous 61-year maximum (Table 4). Gage data for smaller drainages in the study area are extremely limited (Table 4) and flood-prone areas were determined on the basis of field investigations of topography and landforms, vegetative patterns, driftwood, and soils, coupled with information from newspaper accounts of larger floods. Distribution of these floods is indicated on the Geologic Hazards Maps.

Precise figures for the recurrence frequencies of floods of varying magnitudes in the various drainages of the study area are not available. The Office of the State Engineer (Wheeler, 1971), however, provides a technique for constructing approximate recurrence frequency curves for the various streams on the basis of drainage basin area. Factors not considered are slope, land use, and microclimate. The technique was used to derive the very general comments of flood-recurrence frequency presented on Table 4. For some drainages the calculated frequencies were in error. For example, the 1964 flood at Wasco is assigned a 2- to 5-year recurrence time. This is clearly incorrect and is not shown on the table. The discharge data may be too low.

In addition to stream flooding, high ground water and ponding constitute geologic hazards in parts of the study area, particularly in the Hood River Valley. High ground water is a water table situated high enough to have an adverse effect on selected human activities. Ponding is the local accumulation of runoff or rain water because of low slopes, topographic restrictions, or low permeability of the underlying soil. Ponding constitutes a special case of high ground water because it represents perched water conditions in which the higher parts of the ground water body actually lie above the ground.

High ground water can flood basements and other subsurface facilities; buoy-up pipelines, unfilled underground storage tanks, swimming pools, basements, or septic tanks; cause differential settling; or complicate the installation of underground facilities. It is recognized on the basis of well-log data, marshy ground, presence of reeds and marsh grass, extremely flat topography or depressions, high organic content of soil, and black to blue-gray soil mottling. A general reconnaissance delineation of high ground water was not possible in this study. No patterns of soil distribution or landforms could be correlated with high ground water conditions. Strahorn and Watson (1914) first noted randomly scattered patches of hardpan in the subsoils of the Hood River Valley. A detailed soils investigation is needed.

Impacts

Flooding destroys structures through current action, siltation, and water damage. It inflicts losses on agricultural land by scouring topsoil, eroding streambanks, silting cropland, and killing livestock. It threatens citizens by isolating dwellings, damaging property, disrupting transportation, and polluting or disrupting water supplies. Projected flood losses along the Hood River alone, based on the 1965 dollar values, are $75,000, $95,000, $142,000 and $217,000 for the years 1965, 1980, 2000, and 2020 respectively (Oregon Water Resources Board, 1972).

Figure 23. Downtown area of The Dalles during 1894 flood. Such flooding will probably never occur here again because of upstream dam construction. (Photo courtesy The Elite Studio, The Dalles)

Table 4. Maximum floods for streams of northern Hood River, Wasco, and Sherman Counties, Oregon

Stream	Years of record	Drainage area(mi2)	Maximum discharge	and Date	Gage ht.(ft)	Comments
Columbia River at The Dalles	1858-present	237,000	1,240,000 1,010,000	6/ 6/94 5/31/48	160 154.6	Recurrence is unlikely in view of recent flood control projects upstream.
Deschutes River at the mouth	1897-99 1906-70	10,500	43,600 75,500	1/ 7/23 12/22/64	10.2 11.8	Floods were partly controlled by dams upstream.
Hood River 0.8 mi south of mouth;	1913-64	329	34,000	1/ 6/23	11.1	Flood of 1964 demolished gaging station, necessitating adoption of other.
Tucker Bridge 4 mi south of mouth	1964-70	279	33,200	12/22/64		
West Fork Hood River 0.3 mi upstream from Dead Point Creek	1913-16 1932-70	96	12,900 15,000* *daily mean calculated	12/22/34 12/22/64	12.4 27.0	1964 high water mark was partly the result of local ice dam.
Mosier Creek 2.8 mi from mouth	1960-70	41.5	4,790	12/22/64	8.9	20- to 100-year event.
Fifteenmile Creek near Wrentham	1946-53	171	3,540	1/ 9/53	8.8	No record for 1964 when it reached highest level in 50 years.
Eightmile Creek 0.3 mi below Jap Hollow	1946-53	56	385	2/10/49	7.1	Annual event or every few years; no 1964 record.
Fivemile Creek 5 mi from mouth	1925-53 intermittent	32	315	2/10/49	3.7	Bankfull = 3.5 ft, annual event; no 1964 record.
South Fork Mill Creek 0.2 mi upstream from Wicks Reservoir	1959-60 1964	28	104 1,220	3/30/60 12/22/64	 5.2	Recorded 1964 discharge not consistent with news accounts.
Spanish Hollow at Wasco	1964 1961	8	585 279	12/22/64 1/ 5/61	10.5 6.7	Overflowed banks in 1964.
Fulton Canyon	1964 1959-64	6.7	1,370 335	12/21/64 1/ 5/61	21.2 13.1	20- to 100-year event.

In the study area, the largest flood of this century occurred in late December of 1964, when 2 inches of warm rain in a 24-hour period and over 7 inches of rain in a one-week period melted exceptionally heavy snows throughout the region. Flood waters near The Dalles washed out the Chenoweth Road at the Grange Hall, flooded the Chenoweth Trailer Court, cut off access to the Petersburg Trailer Court, flooded the Mill Creek Trailer Park, and destroyed the Caldwell chicken ranch on Fifteenmile Creek, which was at at its highest level in 50 years (*The Dalles Chronicle* Dec.23, 24, 1964). Lower parts of Ericksens addition along lower Mill Creek were also flooded. Discharge at Wicks Reservoir was an estimated 300 million gallons per day(500 cfs) (*The Dalles Chronicle*, Dec. 28, 1964).

Towards central Wasco County the flood of 1964 washed out the Bakeoven Creek bridge at Maupin and flooded much of Tygh Valley (Figure 24) including the White Valley bridge near the Tygh Valley Lumber Company, the Tygh Creek bridge in the community of Tygh Valley, and the Sherors Bridge secondary road between Highway 97 and Tygh Valley. In the Maupin area, flood water from Bakeoven Creek smashed a barn against the Standard Oil building. Barns were carried away from the Hinzman home, one-half mile up from the mouth of Bakeoven Creek, and the Joe Dodd ranch at Tygh Valley.

In Sherman County more than one million dollars of damage was inflicted on the crop industry, and almost every bridge and culvert was damaged (*Sherman County Journal*, Dec. 24, 1964). The highway bridge over the mouth of the John Day River collapsed and there were five drownings. The flood waters washed out the Fulton Canyon bridge on Highway 30; parts of Highway 97, nine miles south of Grass Valley; and parts of the railroad bed between Biggs Junction and Kent. Highway 97 at DeMoss Springs was closed by high water. The new Lone Rock Road southeast of Moro was completely washed out. Water up to 2 feet deep flowed across Highway 97 for a distance of two blocks through the center of Wasco and flowed over the road a short distance north of the town. The Grass Valley business district was flooded with up to 10 inches of water for several hours. Flood waters were 3 feet deep near the Moro Lumber and Fuel Company on Highway 97 in Moro. Flood waters emerging from the Girkling Creek canyon eroded the trailer park at Rufus and spread sediment and debris through much of the town. The town's water supply was destroyed, and debris and mud were washed over Highway I-80N for a distance of a quarter of a mile. At Biggs Junction, railroad embankments and approaches to bridges on Highway 97 and I-80N were washed out.

In the Hood River Valley, the 1964 flood washed out numerous bridges and destroyed the gaging station near the mouth of the river. Data from the gaging station at Tucker bridge, several miles upstream, indicate that the flood was the largest on record (Table 4). Old flood channels were inundated near the community of Mount Hood(Figure 25), and Highway 35 near the Neal Creek bridge was flooded. One home was endangered in that area. Part of the East Side Grade Road near Panorama Point was washed out at Whiskey Creek (*Hood River News*, Dec. 31, 1964).

Flood waters at Dee rose an estimated 15 to 20 feet behind an ice jam and flowed over the banks, deposited silt in the Hines Lumber Yard power house (Figure 26), and established a temporary new channel immediately east of the mill. Heavy rains in Hood River initiated a landslide along Serpentine Drive, closing the street for several days. As it left the community of Hood River, a westbound train was struck by a landslide and derailed.

In the Fifteenmile Creek area, the flood of 1974 exceeded the flood of 1964 (Figures 27, 28, 29, and 30). The 1974 flood was the product of heavy precipitation at low elevations, whereas the 1964 flood was largely the result of rapid snow melt at all elevations.

Local flash floods generated by random thunderstorms constitute a significant hazard in much of the eastern half of the study area. The precise distribution of individual storms is not subject to prediction, but the distribution of possible flash floods is indicated in a general way by the mapped torrential flood channels on the Geologic Hazards Maps. All slopes are subject to potentially very high runoff during thunderstorms; and this factor must be adequately considered in the design of all runoff facilities in plans for urbanizing areas.

A flash flood on June 5, 1947 was centered on the Skyline Road area southwest of The Dalles and delivered high runoff to Threemile Creek and Dry Hollow. Rainfall totaled 0.6 inches in less than 10 minutes. Damages included a garage knocked from its foundation and a flooded home along the Skyline channel, heavy erosion along Threemile Creek, road damage and other losses in the Ericksen ranch area along Mill Creek, and partial flooding of the business district and a residential district of The Dalles near the mouth of Dry Creek. Other losses included washouts of the old The Dalles-California Highway, loss of summer follow, flooding of the Mauser storage yard, and flooding of the Union Pacific rail yards (*The Dalles Chronicle*, June 5, 12, 1947). A cloudburst of similar intensity in 1937 killed one person.

Figure 24. The 1964 flood eroded much valley bottomland in the Tygh Valley area. (Photo courtesy Wasco County Planning Office)

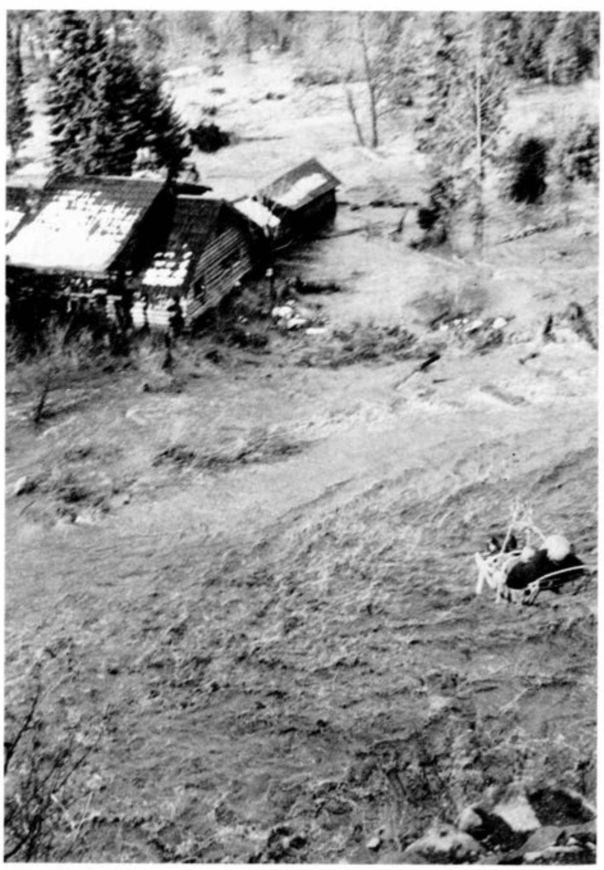


Figure 25. East Fork of Hood River 3 miles south of community of Mount Hood during 1964 flood. (Photo courtesy Hood River News)

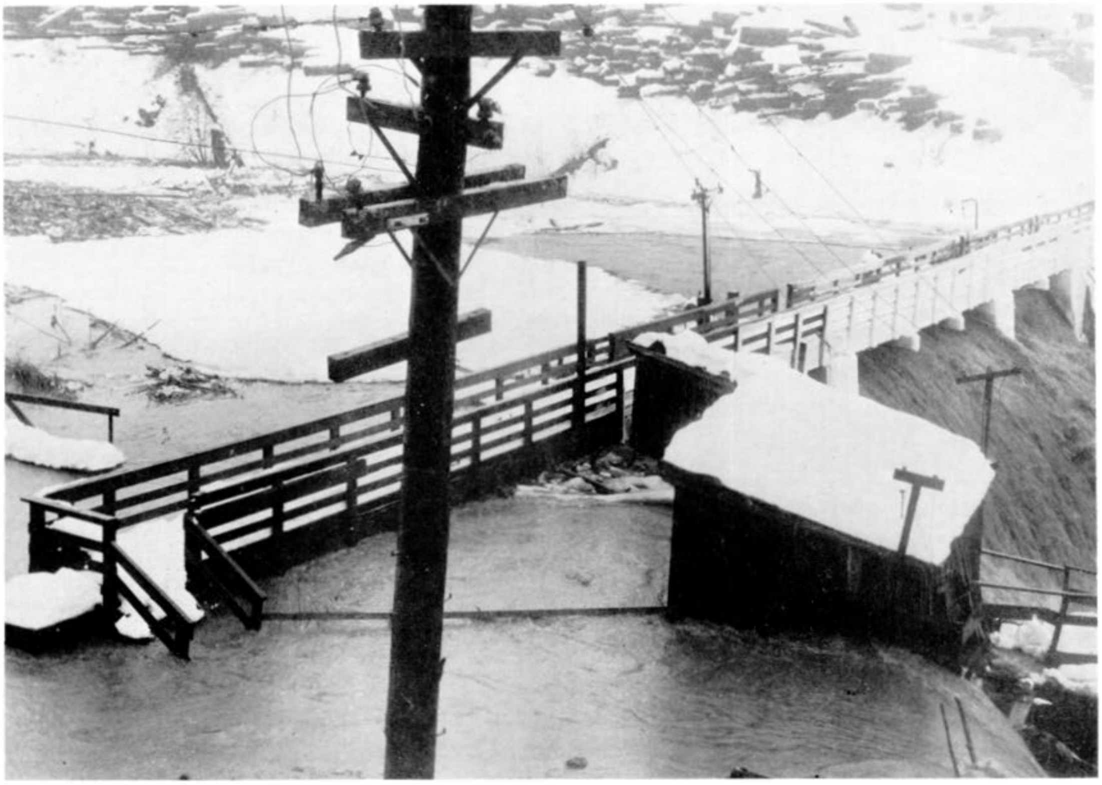


Figure 26. Debris jam at Dee during 1964 flood diverted water through generator station. (Photo courtesy Hood River News)

Recommendations

On the state level, assistance in developing flood-plain management plans is provided by the State Department of Water Resources; and broad policies are formulated by the Land Conservation and Development Commission. Numerous Federal agencies also assist in dealing with flood hazards as discussed below.

The U. S. Soil Conservation Service administers the Watershed Protection and Flood Protection Act of 1954 and provides technical assistance for channel protection and flood-related projects. Declaration of a flooded area as a disaster area by the Governor causes release of funds for public-facility restoration, for river-bank repair, and for low-interest loans to individuals and small businesses. The Office of Emergency Preparedness, the State Emergency Services Center, and local officials coordinate assistance of this type.

Emergency preparedness includes flood forecasting and flood warning by the National Weather Service River Forecast Center in Portland. Flood fighting by local personnel is commonly supplemented by the U. S. Army Corps of Engineers and is coordinated by the State Emergency Operations Center. The Flood Insurance Act of 1968, administered by the U. S. Department of Housing and Urban Development with the assistance of the State Department of Water Resources, provides flood insurance to individuals and businesses in regulated developments.

Zoning codes regulate regional land use and should be written to restrict certain kinds of land use in various parts of the flood plain. Subdivision codes should require disclosure statements and construction practices compatible with recognized flood potential. Building codes can be used to regulate floor elevations and to insure waterproofing, anchoring, and other appropriate construction practices in areas of potential flooding.

Structural control of flooding by dams or large levees is generally not feasible in the study area

Figure 27. Lower Fifteenmile Creek during 1974 flood. (Photo courtesy Wasco County Planning Office)

Figure 28. Fifteenmile Creek immediately downstream from Dufur during 1974 flood. (Photo courtesy Wasco County Planning Office)

Figure 29. Flooding and erosion of upper reaches of Fifteenmile Creek upstream from Dufur was extensive. (Photo courtesy Wasco County Planning Office)

Figure 30. Lower Eightmile Creek during 1974 flood. (Photo courtesy Wasco County Planning Office)

because of the number of streams and probable cost-to-benefit ratios. Available flood data is insufficient for statistical treatment of flood potentials in various streams, and the installation of gaging stations in the larger streams is recommended. In lieu of more adequate data, site-specific decisions and planning will be forced to rely heavily on on-site investigations, with this report as a general guide.

Road layouts and gutter and storm sewer designs in subdivisions must be planned with an adequate consideration of the high runoffs that may result from thunderstorms. Meteorologic records and standard civil engineering handbooks provide the basic data and techniques for such investigations. A detailed soil survey of the Hood River Valley is needed to delineate areas of high ground water or ponding potential.

Stream Erosion and Deposition

General

Much of the planning and designing of channel modifications emphasizes the water component of the total stream system. Equally important, but often neglected, are sediment load and other factors of stream channel geometry including width, depth, channel roughness, and channel layout. Changes in any one of these parameters inevitably leads to changes in one or more of the others as well as in stream velocity.

Larger particles in stream beds, including boulders, pebbles, and coarse sand grains, are moved by rolling, sliding, or bouncing and constitute the bed load. The capacity of a stream to transport bed load is determined by the geometry of the channel, the volume of the discharge, and velocity. Smaller particles, including fine sand, silt, and clay, generally are transported in suspension. The volume of suspended load is controlled primarily by runoff and slope erosion (see Slope Erosion). This aspect of sediment transport is particularly significant in terms of water-quality management in such storage reservoirs as the Wicks Reservoir. Medium-grained sand can be carried in suspension under extreme conditions of velocity and turbulence.

Specific elements of a stream that may attract the attention of a planner at particular sites must be viewed as integral parts of a complex system, if planning recommendations are to be realistic. Thus, meanders which cause stream-bank erosion are generated by the friction of a fluid flowing over a surface as well as by random obstructions. Transport of boulders and pebbles forming a gravel bar is controlled by many aspects of channel geometry and discharge in addition to slope. Flooding is extremely complex, and its local control must be planned with broad perspective.

Distribution and impacts

Torrential flood channels are located in the mountainous areas west of The Dalles and in the cliffs and canyons lining the Columbia River from Eagle Creek to Rufus. Recent torrential flooding is easily recognized on the basis of unvegetated coarse stream-bed deposits and scattered debris (Figure 31). In wooded areas where vegetation has reclaimed the channel, recognition of torrential flood potential is based upon indirect features including steep side slopes, steep gradients, impermeable bed rock, narrow stream channels, and the absence of a flood plain. Channels characterized by torrential flooding and channel scour commonly pass downstream into topographically more mature landforms such as flood plains.

Because torrential flood channels are generally cut in bed rock, they cannot adjust to rapid changes in discharge by channel modification. Instead, depth and velocity increase sharply during times of high flow. Consequently, torrential floods are highly erosive and commonly destroy artifical obstructions such as bridge abutments and road fill in the channel (see Stream Flooding - Impacts). Where torrential flood channels spill into flat terrain, rubble and debris fans (see Surficial Geologic Units - Stream deposits - Fan deposits) may quickly bury roads or clog culverts.

Concentrations of suspended sediment during torrential floods are commonly high. Waanenan and others (1970) record concentrations of 64,800 ppm for Fulton Canyon immediately following peak flow during the flood of 1964 (Figures 32, 33, and 34). This is equivalent to 64,000 tons per day or 2 tons per acre per day under the prevailing discharge. Sediments included 20 percent clay, 62 percent silt, and 18 percent sand. Under extreme conditions of slope erosion and rainfall, torrential stream channels may transport flowing mud and debris rather than water. No mudflow deposits were observed in Quaternary alluvial fan deposits, however, in this reconnaissance investigation.

Figure 31. Torrential flood deposits at Viento Park after 1964 flood. (Photo courtesy Hood River News)

The formation of alluvial fans at the foot of torrential flood channels constitutes a special form of gravel deposition of particular concern to the planner (Figure 35). Because the fans are rapidly deposited by broad migrating channels, they are composed primarily of very poorly sorted sands and gravels. Finer materials are winnowed from the surface, both by decreasing discharges in the waning stages of flooding and also by the wind between floods. The result is a protective surface armor that must be maintained or restored in any projects involving channel modification, levee construction, or placement of fill.

Gentler gradients, broader valleys, and the capacity to modify channel geometry in response to rapidly fluctuating discharge are characteristics which distinguish flood-plain stream channels from torrential flood channels. Short-term variations in depth and velocity are less extreme in these channels; but long-term changes in channel width, depth, and position also occur. Streams with flood plains include those in the Hood River Valley and major streams south and east of The Dalles.

Erosion in the flood plains is restricted primarily to the channels and to the outer bends of meanders. Stream-bank erosion is greatest in larger streams with gravel beds, such as the Hood River, where numerous sharp turns in the river direct water against the walls of its deeply incised canyon. Stream-bank erosion generates numerous slides in the mountainous areas west of Hood River to Eagle Creek but is generally of only local significance in the major streams east of The Dalles. The middle reaches of Fulton Canyon are deeply incised in silt and fine sand (Quaternary older alluvium), as are parts of several other of the major streams east of the Deschutes River. Parts of the upper reaches of Chino Hollow are characterized by braided flow during high discharge.

Stream deposition of flood-plain streams includes the formation of bars on the inner bends of meanders and behind channel obstructions and the general siltation of the flood plain as silt and clay settle from the relatively slow moving overbank flood waters. Gravel bar deposition is of greatest concern in the Hood River, where streamflow is commonly directed against opposite stream banks, resulting in increased

Figure 32. Critical stream-bank erosion in middle reaches of Fulton Canyon after 1964 flood.

Figure 33. Stream-bank erosion in steep lower reaches of Fulton Canyon a short distance from the Columbia River.

Figure 34. Large culvert used in repair of Fulton Canyon Road after 1964 flood.

Figure 35. Rufus, built on alluvial fan deposits, suffered extensive torrential flood damage and deposition in 1964 flood.

rates of stream-bank erosion. Extraction of channel gravels may constitute a viable control measure in certain critical localities, provided stream velocity is not greatly increased farther downstream and protective berms around the gravel operation are constructed of adequately sized material.

Channel deposits of the Columbia River behind Bonneville Dam consist of fine- to medium-grained sand, and those behind The Dalles Dam consist of a wide range of sediment types in response to highly variable channel conditions. Bed-load-sediment transport rates behind Bonneville Dam during peak flows in June 1968 measured 9 to 12 cubic feet per foot of channel width per day (Fullam, 1970). This is considerably less than would be expected in a nonrestricted channel.

Recommendations

Major changes in stream channels for flood control, gravel removal, or erosion control should be preceded by investigations of probable secondary impacts on the stream. For flood control, many potential problems can be minimized by innovative designs of composite channels which accommodate a range of discharges rather than just the peak discharge. For example, levees constructed away from a stream which is left in its natural state may accommodate large flows while the natural channel accommodates lower flows and eliminates the hazard of greatly accelerated aggradation. Channel erosion of straightened channels or rapidly downcutting channels can be reduced by the construction of numerous small dams which incrementally lower the grade of the stream. Natural armoring of the channel which has been disturbed must be restored or replaced. Levee designs must include a consideration of increased erosion potential where the channel is constricted.

Road fills along torrential stream channels should be discouraged in critical areas. Where necessary, road fills should be cribbed or composed of adequately sized material to resist erosion. Channel crossings in sidehills should include adequate culverts or should be bridged. Periodic maintenance of culverts is recommended to prevent their blockage by debris. Careful land management can greatly reduce the magnitude of slope erosion (see Slope Erosion) and can minimize the potential for hazardous deposition. Where residential construction is anticipated, controls should be placed on development near torrential flood channels; and bridge abutments and channel crossings should be designed in a manner that does not impede streamflow.

Impacts of stream-bank erosion can be minimized by properly locating structures away from areas of potential undercutting or by reinforcing threatened stream banks with riprap. Long-term patterns of meander migration must be considered in areas of long-term use. Logjams and snags in channels may initiate undercutting and should be removed where necessary. Removal of gravel bars is also a means of controlling some local stream-bank erosion. The U.S. Soil Conservation Service and State Soil and Water Conservation Commission have programs aimed at controlling stream-bank erosion.

Earthquakes

General

The shaking of the earth's surface which accompanies the release of energy along faults is called an earthquake. The specific location of the displacement within the earth is called the focus, and the geographic location above the focus on the earth's surface is called the epicenter. The crustal structure and tectonic behavior of the northwestern United States is very complex, and the historic record is short. Knowledge of future tectonic activity and earthquake potential is incomplete.

Intensity and magnitude are measures of the energy released by an earthquake. On the modified Mercalli intensity scale, observations of the effects of the quake on the earth's surface serve as indicators of its relative severity. These determinations may be inaccurate because of the observer's distance from the epicenter, the nature of the underlying rocks where the observations are made, and the subjectivity of the viewer. Therefore the Mercalli scale is imprecise. It is widely used, however, because it is universally applicable and requires no equipment. Also, the gathering of numerous observations allows identification and elimination of inconsistent and inaccurate data.

The Richter scale is based on records from seismometers rooted in bed rock. It gives a more direct measure of energy released in an earthquake and is less subject to errors through local variations of the subsurface. Instead of indicating intensity with Roman numerals (I to XII), as on the Mercalli scale, the Richter scale indicates magnitude with decimal numbers (Table 5) on a logarithmic scale. Each digit represents a 10-fold increase in the amplitude of the seismic waves and an approximate 31-fold increase in the amount of energy released. Thus, an earthquake of magnitude 6.0 is 31 times greater than an earthquake of magnitude 5.0. The scale ranges from less than 1 for small quakes to slightly less than 9 for the largest possible quake.

To convert observations on the Mercalli scale to magnitude on the Richter scale, several empirically derived equations are available including:

$$m = 0.43\ I + 2.9 \quad \text{(Stacey, 1969)}$$

$$M_B = (2/3)I + 1 \quad \text{(Gutenberg and Richter, 1965)}$$

M values are Richter magnitudes, and I values are Mercalli intensities. For quakes of low intensity, the Stacey equation gives higher values for magnitude than does the Gutenberg and Richter equation. (Table 6). The Stacey equation is based on shallow quakes and is probably more applicable to the study area, provided numerous reliable observations are available from areas underlain by firm ground.

Earthquake potential

The potential for future earthquakes can be estimated on the basis of the historic seismic record, calculations based on the dimensions of active surface faults, and calculations based on knowledge of rock strength. No information is available on rock strength in the study area and no active faults are exposed at the surface (see Structure). Accordingly, estimates of future seismicity are based almost entirely on the historic record, which is very short and possibly misleading.

The largest historic earthquakes in the study area were of Mercalli intensity VI in central Wasco County and Mercalli intensity IV at The Dalles and Hood River (Table 6). Earthquakes with epicenters outside the study area have been felt with intensities as high as V at Rufus and VI at Parkdale (Table 6). Estimates of the largest possible earthquake for the study area include a Mercalli VII quake presented in the Uniform Building Code and a Richter 6.5 quake (I= VII to VIII) postulated by Portland General Electric (1974a). The Portland General Electric estimate is probably too high when applied strictly to the study area, because it was formulated for the entire Umatilla Plateau and included consideration of active surface faults far removed from the study area. A maximum possible quake of Mercalli VII is here adopted for the study area.

Ground accelerations resulting from earthquakes are a key consideration in the design of structures. Quakes of Richter magnitude 6.0 to 6.9 with epicenters 100 kilometers or more distant will have associated with them ground accelerations of 10 percent of g or less (Page and others, 1975). G is acceleration of gravity, and 1 g = 32.2 ft/sec^2. Quakes of Richter magnitude 5.0 to 5.9 (I= VI to VII) with epicenters in the study area may have associated with them accelerations as high as 50 percent of g . On the basis of limited data and without the aid of detailed local analyses, Algermissen and Perkins (1976) show that quake-induced rock accelerations in the study area will be less than 4 percent of g for any given 50-year interval. This estimate is regarded as too low because it does not address the issue of maximum probable earthquake, and it is based on too limited data in the lower magnitude ranges. It does, however, give a reasonable estimate of the accelerations to be expected from most earthquakes.

Impacts and recommendations

An earthquake of Mercalli VII causes slight damage to well-designed and well-built buildings, slight to moderate damage to well-built structures with variable design, and considerable damage to poorly built and poorly designed buildings (Table 5). Ground failures may include ground cracking on thick sloping colluvium and talus, liquefaction in areas of ground-water discharge and thick soil, and local rockfall and rockslide along steep cliffs. Intensities as high as VII would probably be restricted to areas of poor ground conditions in the event of the largest possible earthquake in the study area. In areas of solid bed rock, intensities would probably be VI or less and would possible produce local falling plasrer, chimney damage, and settling of fill. Evernden and others (1973) show that, in the historic record, maximum

Table 5. Scale of earthquake intensities and magnitudes

Mercalli Intensity	Description of effects	Equiv. Richter magnitude
I	Not felt except by a very few under especially favorable circumstances.	
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.	3.5 to
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.	4.2
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building; standing motor cars rock noticeably.	4.3 to
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. A few instances of cracked plaster; unstable objects overturned. Some disturbance of trees, poles, and other tall objects noticed. Pendulum clocks may stop.	4.8
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	4.9-5.4
VII	Everyone runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary structures, considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.	5.5-6.1
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.	6.2 to
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.	6.9
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.	7.0-7.3
XI	Few if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	7.4-8.1
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.	Max. recorded 8.9

* Adapted from Holmes (1965) and U.S. Geological Survey (1974)

Table 6. Historic earthquakes of northern Hood River, Wasco, and Sherman Counties, Oregon

Date		Intensity and magnitude *	Location
1866	Nov. 24	IV 3.7 Gutenberg and Richter 4.2 Stacey	The Dalles
1866	Dec.	III 3.0 Gutenberg and Richter 3.7 Stacey	The Dalles
1877	Oct. 12 **	III 3.0 Gutenberg and Richter 3.7 Stacey	Cascade Locks **
1892	Feb. 29	IV 3.7 Gutenberg and Richter 4.5 Stacey	The Dalles
1893	July	II 2.3 Gutenberg and Richter 3.7 Stacey	Pleasant Ridge
1902	Dec. 5	II 2.3 Gutenberg and Richter 3.7 Stacey	Hood River
1920	Nov. 28	IV 3.7 Gutenberg and Richter 4.5 Stacey	Hood River
1976	Apr. 12	V, VI 4.8 measured	Maupin, Tygh Valley

* Historic observations in the study area are generally available on the Mercalli scale. Conversion to the Richter scale is provided using the equations of Gutenberg and Richter (1965) and Stacey (1969) to illustrate the range of values possible.

** A larger quake east of Portland on this date is mistakenly located at Cascade Locks in the literature (see Table 7).

Table 7. Distant historic earthquakes affecting the study area

Date		Intensity, magnitude *	Location	Comments
1872	Dec. 15	VI-IX 5.7	Southwest British Columbia	I-II at Pebble Springs in Gilliam County (Portland General Electric, 1974a).
1877	Oct. 12	VII (Portland General Electric, 1975) **	Troutdale-Corbett area probably (Portland General Electric, 1975)	Not felt east of The Dalles (Portland General Electric, 1975); confused with intensity III quake at Cascade Locks by Berg and Baker (1963); Cascade Locks epicenter (Shannon and Wilson, 1975).
1893	Mar. 7	VII 5.7	Umatilla	Damage highly localized and quake felt over restricted area. Inferred intensity may be too high.
1921	Sept. 14	VI 5.0	Walla Walla, Wash.	IV at Pebble Springs in Gilliam County (Portland General Electric, 1974a).
1936	July 15	VII+ 5.8	Milton-Freewater	IV at The Dalles, V at Rufus (Portland General Electric, 1974a); much ground cracking on thick sloping colluvium near epicenter (Coffman and Von Hake, 1973).
1949	Apr. 13	VIII 7.1	Olympia, Wash.	VI at Mount Hood and Parkdale, V at Hood River and The Dalles (Murphy and Ulrich, 1951).
1951	Jan. 7	V 4.3	McNary	
1959		VIII 6.3	Hebgen Lake, Mont.	I-II at Pebble Springs in Gilliam County (Portland General Electric, 1974a).

* Magnitudes calculated using the equation of Gutenberg and Richter (1965).

** An epicentral intensity map developed by Portland General Electric (1975) for this earthquake suggests that the actual magnitude may have been 5.0 or less, in contrast to the higher magnitude of 5.7 suggested by an intensity of VII as listed here and in the literature. The historic intensity recorded in the literature may be too high.

intensities of earthquakes occur in areas of firm or unstable ground, instead of areas of solid bed rock.

Adoption of the relevant provisions of the Uniform Building Code is recommended. These include sections 2313 (wall anchorage), 2314 (general design and construction of structures), 3704 (anchorage of chimneys), and 1807k (anchorage of mechanical and electrical equipment in high-rise structures). It is recommended that all designs involving mass movement or safety factors incorporate a consideration of possible seismic accelerations. The estimates of 4 to 50 percent of 1*g* are not definitive and need refinement based upon more detailed studies. The possibility of damaging ground response to earthquakes is not treated by the Uniform Building Code.

Volcanism

General

Much of the bedrock geology of the study area represents the cumulative result of millions of years of intermittent local volcanic activity. Formations include the Eagle Creek Formation (Tme), the Dalles Formation (Tpd), the Rhododendron Formation (Tpr), and the Cascades Formation (QTv). The Cascades Formation includes many relatively young intracanyon flows, such as those at Parkdale and Underwood, and many young cones, including Mount Hood, Mount St. Helens, and, in the east, McDermid Cone, which is 5 miles south of the mouth of the Deschutes River. In a geologic sense, the study area is an area of active volcanism. From the standpoint of county planning, information that is currently available indicates that potential volcanism is at least of marginal significance.

Recent activity

Mount St. Helens volcano is less than 37,000 years old, and the bulk of the visible cone has formed since 500 B.C. (Crandell and Mullineaux, 1975). The volcano has erupted fairly regularly during the past 4,000 years. Tephra emanating from the cone was spread over parts of northeastern Oregon, Washington, and Alberta, Canada, between 1600 and 2500 B.C. Some tephra deposits in Washington that are traced to Mount St. Helens are less than 500 years old. Between 1600 and 1700 A.D. a dacitic dome formed on the cone; and in 1831 Mount St. Helens ash was spread as far north as Mount Rainier. In the mid-1800's a series of eruptions spread ash as far east as The Dalles.

Mount Hood is less active than Mount St. Helens but does have numerous fumaroles and hot spots near its peak. A large plug emerged from the crater 1,700 years ago (Wise, 1968) and spread hot debris-fan material to the south and west. Six post-glacial flows are also recognized (Shannon and Wilson, 1976). Lawrence (1948) suggests a minor ash eruption occurred in the early 1800's near Cloud Cap Inn. A magnitude 4 earthquake which occurred December 14, 1974 with a focus 2 to 4 kilometers below the surface in the Mount Hood area was of the type associated with upward-migrating magma and may signal the filling of a magma chamber at depth (Shannon and Wilson, 1976).

A review of the volcanic activity of the Cascades indicates that Cascades volcanism can be grouped into three major types. These are 1) quiet lava flows with minor ash eruptions, 2) bimodal eruptions of basaltic and silicic lavas along with intermittent violent ash eruptions and satellite lava flows, and 3) catastrophic eruptions of ash which essentially mark the end of volcanic activity for a peak. The eruption of Mount Mazama 7,000 years ago spread 6 to 8 cubic miles of ash over an area of 350,000 square miles. Mount Hood belongs to the second category of volcanic eruptions.

Future activity

The prediction of volcanic activity is an area of only very recent research. Little geophysical information is available for detailed analyses of either Mount Hood or Mount St. Helens, and no data is available to correlate with actual eruptions or with other volcanoes. The geologist is limited to a primarily historical approach to prediction, which is clearly inadequate in predicting specific events. Specific statements given here will need further refinement or modification as more data accumulates.

Future volcanic activity at Mount Hood and Mount St. Helens will include lava eruptions, hot debris flows, and ash falls. The closest point in the study area to either cone is approximately 10 miles, and the major concern to planning is the potential for ash falls. Graphs developed by Crandell and Mullineaux (1976) indicate that points as far distant from Mount St. Helens as The Dalles are subject to ash falls of 1 cm every 100 years, a few cm every 500 to 1,000 years, and greater than 10 cm every 2,000 to 5,000 years. Winds that are directed toward the study area 10 to 20 percent of the time tend to decrease the probability for ash fall by a factor of 5 to 10. Although this projection is based on very few samples, it does provide a general idea of the types of effects to be expected from future eruptions of Mount St. Helens. Similar studies for Mount Hood are not available.

Impacts and recommendations

An ash fall in the study area possibly would increase acidity and turbidity of runoff. Because most communities derive their water supply from springs or wells, the effect would be minimal. During thick ash falls, storm sewers would become clogged and would require flushing. The remote possibility of flows entering the Upper Hood River Valley does not warrant planning consideration on the basis of presently available information. More precise recommendations are not possible without more long-range geophysical data and detailed analyses of the historic volcanic activity of Mount Hood. Dwight Crandell, of the U. S. Geological Survey, is presently conducting a study of Mount Hood volcanism.

GEOLOGIC HAZARDS OF COMMUNITIES

General

In this chapter, the geologic hazards of the 12 major communities of the study area are mapped and briefly discussed. The maps are of larger scale than that of the regional maps, and the text and maps include additional historic data and field observations. The information provided here is adequate for community planning in conformance with the general procedures set forth in the Introduction, but it does not supplant the need for on-site investigations in making site-specific decisions.

For general information on geologic units, slope erosion, earthquake potential, volcanic potential, and mitigation of various hazards, the reader is referred back to the appropriate parts of the general text. Flooding distributions on the maps are composite historic floods and are generally equivalent to 1 percent to 2 percent (100- to 50-year) floods.

On the basis of general geologic settings and associated geologic hazards, the communities are grouped into three categories: 1) those of the Columbia River Gorge, 2) those of the Deschutes River drainage, and 3) those of the Deschutes Plateau.

Communities of the Columbia River Gorge

Communities of the Columbia River Gorge include Cascade Locks, Hood River, Mosier, The Dalles, and Rufus. Collectively, mapped hazards include deep bedrock slides, rockfall and rockslide, torrential flooding, and local lowland flooding. The region is characterized by steep basaltic cliffs overlain and underlain by slide-prone units. The slopes were deeply eroded by floods of glacial meltwater near the close of the Pleistocene.

Cascade Locks (Figure 36)

Geologic units exposed at Cascade Locks include lower Miocene volcaniclastic rocks (Tme), Columbia River Basalt (Tcr), Quaternary talus (Qt), and older alluvium (Qoa). Deep bedrock slides in the Miocene volcaniclastic rocks are characterized by irregular topography on a grand scale, displaced bed rock, and irregular drainage. Rudolph Creek and Dry Creek disappear into the slide mass to reappear farther downslope as a series of springs.

Where slide terrain terminates downslope against older alluvium which is well above river level, the ancient slide is no longer active. However, the broken character of the ground, heterogeneous lithology of the slide mass, and abundant shallow ground water promote active sliding along creeks and potential sliding in improperly engineered cuts and developments.

The Ruckel slide, downstream from the Bridge of the Gods, is directly across the Columbia River from the Bonneville slide. As the Columbia River was forced against the south bank during episodes of activity on the Bonneville slide, the Ruckel slide was initiated in response to critical undercutting. Although extensive drainage tunnels have been installed in the slide to minimize secondary sliding along the river, activity on the lower parts of the slide continues, causing minor dislocation of the railroad track.

Mass movement in the steep slopes south of Cascade Locks includes rockfall and rockslide. Talus accumulating at the bases of cliffs is hazardous in terms of shallow subsurface flow of ground water, low cutbank stability, and potential for periodic earthflow or debris flow activity. The extent of mass movement hazards and geologic units east of Cascade Locks is shown on the regional geologic maps. Budgetary restrictions precluded more detailed investigation of this area in the present investigation.

Flood hazards include minor lowland flooding along the Columbia River and at the mouth of Herman Creek and occasional torrential flooding along Dry Creek and Rudolph Creek. General recommendations

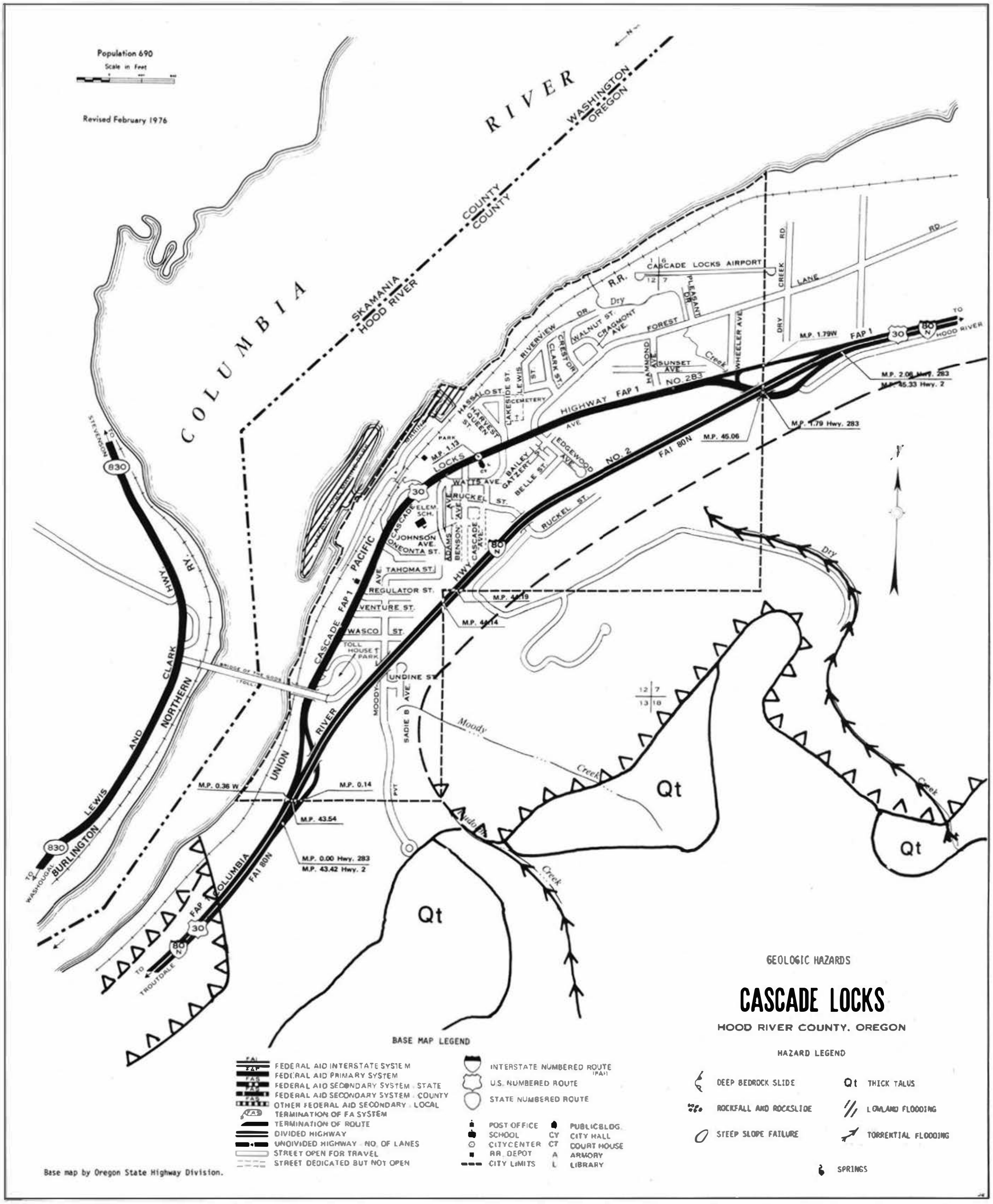


Figure 36. Geologic hazards of Cascade Locks and vicinity.

for flooding and mass-movement hazards are provided in the general text. Development on lower parts of the Ruckel slide area should be avoided, pending detailed study. Development on the inactive deep-slide terrain upslope and to the southeast and east of Cascade Locks should proceed on the basis of site-specific engineering investigations to assure that areas of active sliding of a secondary nature are avoided and that slide-related hazards of low cutbank stability, poor drainage, and variable foundation strength are adequately handled.

Hood River (Figure 37)

Bedrock geologic units at Hood River include local exposures of the Troutdale Formation (Tpt) and cliffs and flat-lying areas of Columbia River Basalt (Tcr). The Quaternary older alluvium of the Hood River Valley (Qoah) immediately overlies the Columbia River Basalt in most areas and consists of a basal coarse boulder conglomerate, a thin horizon of yellow fluvial sand, and more than 100 feet of poorly sorted glacial outwash. Parts of the unit may be equivalent to the Troutdale Formation, and detailed stratigraphic relationships are not defined. Locally Quaternary alluvium (Qal) overlies the older alluvium as along Indian Creek.

Mass-movement potential is generally minimal and is restricted to steep high slopes developed in Quaternary older alluvium (Qoah) in the eastern parts of town. In December 1964, a failure in a road-cut blocked Serpentine Drive for several days. Construction should be avoided in areas of ground-water discharge. Adherence to the grading provisions of the Uniform Building Code should be adequate for avoiding mass movement.

The threat of stream flooding to the community of Hood River is minimal. In the flood of 1964, the gaging station near the mouth of Hood River was destroyed. Damage to surrounding areas is reviewed under Stream Flooding. A protective floodwall lines the railroad tracks along the east side of town. Indian Creek poses a threat of flooding only to low-lying areas of small extent. To minimize flooding, the culverts beneath the Hood River highway should be maintained free of debris.

Local flooding of streets and residences in town by uncontrolled runoff can be avoided by the installation of adequate storm sewer facilities in areas of new development. Unsewered streets in areas of steep slope are a hazard to downslope residences and streets in times of high runoff.

Septic tank failures occur in areas of perched ground water or impermeable soil horizons. Within the Quaternary older alluvium of the Hood River Valley (Qoah), no mappable geologic features were identified that could be related to potential for septic tank failure. Delineation of problem areas requires on-site investigation (see Stream deposits - Older alluvium of the Hood River Valley) and a detailed soils survey (see Stream Flooding - Distribution and magnitude).

Mosier (Figure 38)

Geologic units exposed at Mosier include cliffs of Columbia River Basalt (Tcr), scattered veneers of Pleistocene lake deposits (Qgs, Ql), and stream terrace alluvium (Qoa) along major streams. Erosive action of the Missoula Flood (see Pleistocene lake deposits) removed talus and surficial units in the area, exposing bare bed rock over large areas. Local deposition by the flood in protected areas produced pockets of sand and gravel at high topographic positions downstream from ridges and knolls.

Mass-movement hazards at Mosier are minimal and are restricted to local areas of rockfall and talus along steep ridges surrounding the community. Flood potential is not a concern because the streams within the city limits occupy deep, steep channels. Torrential flooding and erosion pose minor hazards outside the city limits and should be considered in the design of roadfills and bridge abutments within the flood channels. General recommendations for handling mass-movement hazards are presented elsewhere in the text. Shallow depths to bed rock throughout the community require consideration in the planning of subsurface installations and excavations.

The Dalles (Figure 39)

The Columbia River Basalt (Tcr) forms scablands in lower lying areas in the northwestern parts of The Dalles and cliffs in the northeastern parts of The Dalles. Depths to bed rock are shallow. The Dalles

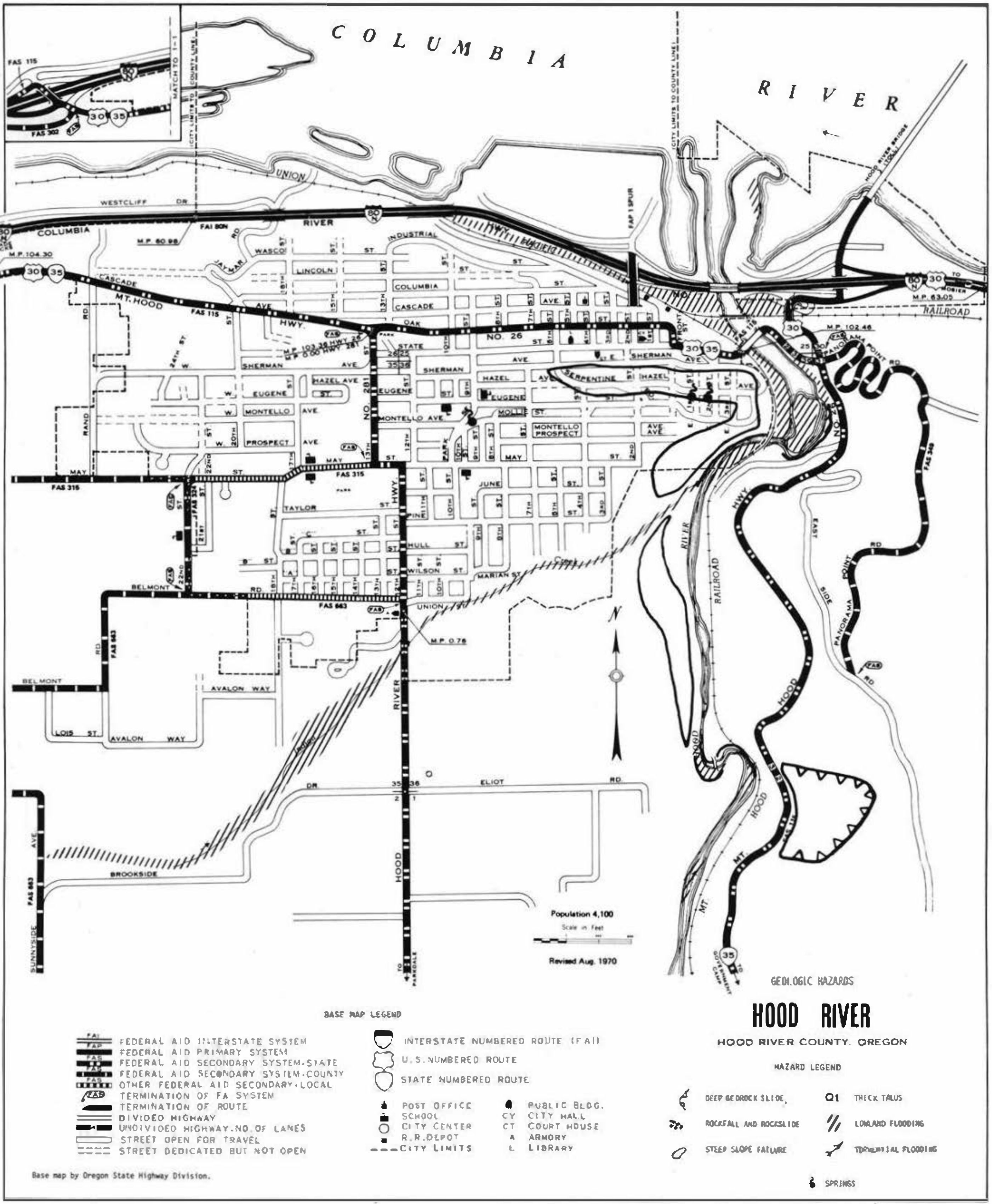


Figure 37. Geologic hazards of Hood River and vicinity.

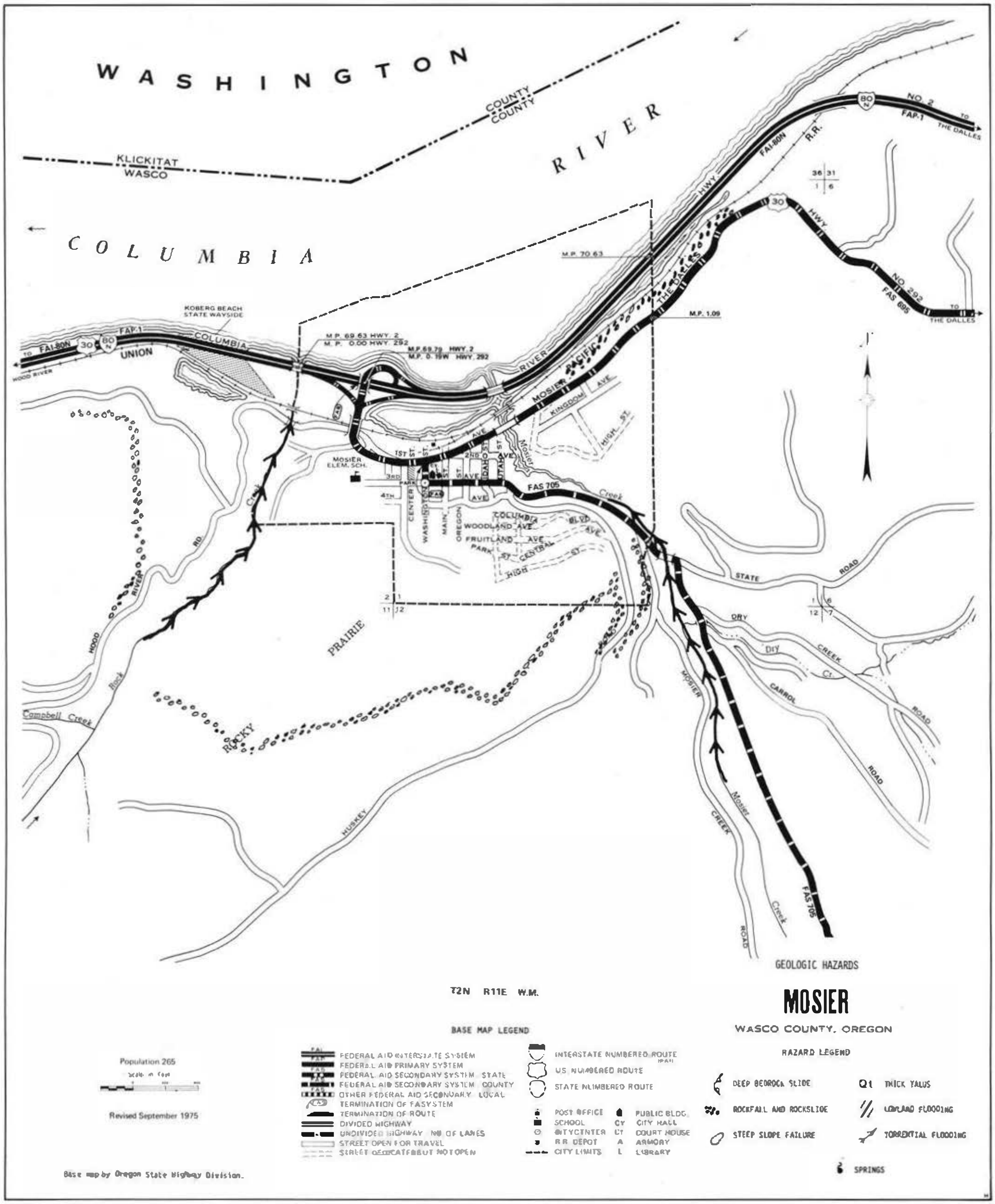


Figure 38. Geologic hazards of Mosier and vicinity.

Formation (Tpd), which consists of hard to soft breccias and river deposits, forms cliffs and pediment surfaces in the Chenoweth area, steep hills overlooking the city between Mill Creek and Threemile Creek, and landslide terrain in the central and eastern parts of The Dalles.

Surficial geologic units include Quaternary older alluvium (Qoa) along streams; Quaternary alluvium (Qal) in flood-prone areas of Chenoweth, Mill, and Threemile Creeks; and talus (Qt) along steep slopes. Distribution of geologic units is indicated on the regional geologic map (see Geologic Map of The Dalles Quadrangle). The contact of the Dalles Formation and Columbia River Basalt is also indicated in Figure 39 (folded, in envelope).

Mass movement in The Dalles includes active sliding in the Scenic Drive-Kelly Avenue area, inactive deep bedrock slides along parts of the cliffs overlooking the Chenoweth District and in the east parts of town, talus at the bases of cliffs, and rockfall and rockslides.

The Scenic Drive-Kelly Avenue slide area is approximately 4 blocks wide and 8 blocks long. It consists of several small slump blocks which are clearly defined in the south part of the slide but which are much less distinct in the north, where they form gently sloping terrain. Slide features are obscured by urban development, and recent movement is delineated primarily by damage to man-made structures (Figures 40 and 41).

The slide area is historically a region of ground-water discharge (Piper, 1932, p. 149) and was vegetated by willows and similar vegetation prior to development (Ron Bailey, 1976, oral communication). It is characterized by gentle northerly dips on north-facing slopes and located immediately above the contact of the Dalles Formation with the Columbia River Basalt. The slopes may have been oversteepened by the Missoula Flood or other erosive activity of the ancient Columbia River.

The potential for sliding is produced by geologic factors and aggravated by acts of man which increase the amount of water in the ground, such as lawn watering, extensive irrigation of upslope orchards, and blocking of springs by the construction of houses and roads. Dealing with the slide is made difficult both by the high density of development and also by the present lack of detailed information regarding the mechanics and rates of sliding and the distribution of actual ground deformation. Possibly more information could be obtained by sponsoring a master's thesis or a doctoral dissertation, by approaching LCDC for grant support, or by getting involved in future Federal pilot investigations of urban landslide problems, should such studies materialize. Engineering solutions must be keyed to site-specific conditions on the ground and may include closer control of water infiltration, the dewatering of parts of the slide, the use of innovative foundation designs for new structures, and the banning of construction in highly critical areas.

Deep bedrock failures are evident east of Dry Hollow in terrain analogous to that of the Scenic Drive-Kelly Avenue slide. The region is approximately $1\frac{1}{2}$ miles long and up to 1 mile wide and is characterized by a series of large slump blocks in the south and hummocky terrain in the north. The slides are located in the Dalles Formation immediately above the contact with the Columbia River Basalt. Gentle northerly dips, incompetent lithology of parts of the Dalles Formation, location above a possibly impermeable horizon of the Columbia River Basalt, and oversteepening by the Columbia River increase the possibility of sliding. To avoid sliding, future developments must 1) provide adequate facilities for all runoff to assure that local increased infiltration does not occur, 2) avoid plugging springs, and 3) require engineering reports for all large developments. Curbs and roads in densely developed areas along Oregon Street show dislocations possibly related to reactivated sliding.

Controlled flow and pool elevations along the Columbia River have significantly reduced the threat of flooding so that repetition of historic major floods (Figure 23) is no longer considered likely. Flooding along lesser streams is limited to the lower reaches of Chenoweth Creek, where the Grange and Chenoweth Trailer Park were flooded in 1964; the lower reaches of Mill Creek, where a residential district was partially flooded in the 1964 flood; and the lower reaches of Threemile Creek (Figure 39).

Local runoff poses a threat of flooding over large areas, because of shallow depths to impermeable bed rock and consequent low infiltration capacities. In the Chenoweth District and to the north, soils are nonexistent or thin over the Dalles Formation and are thin over Columbia River Basalt. Inadequate storm sewers direct some runoff into poorly maintained ditches along the freeway and the tracks. A regional approach is needed to assure proper disposal of storm runoff without menace to surrounding areas. Dry wells into the Dalles Formation are generally not recommended because they increase the potential for sliding. Dry wells into the Columbia River Basalt would dispose of runoff but might threaten water quality of underground aquifers.

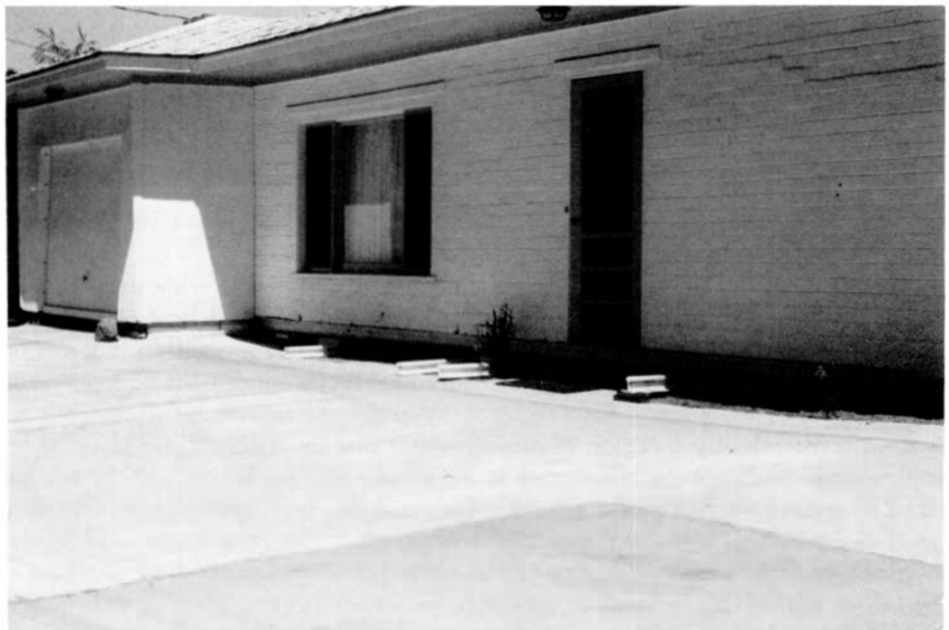


Figure 40. House in The Dalles placed on tracks to minimize structural damage due to sliding.

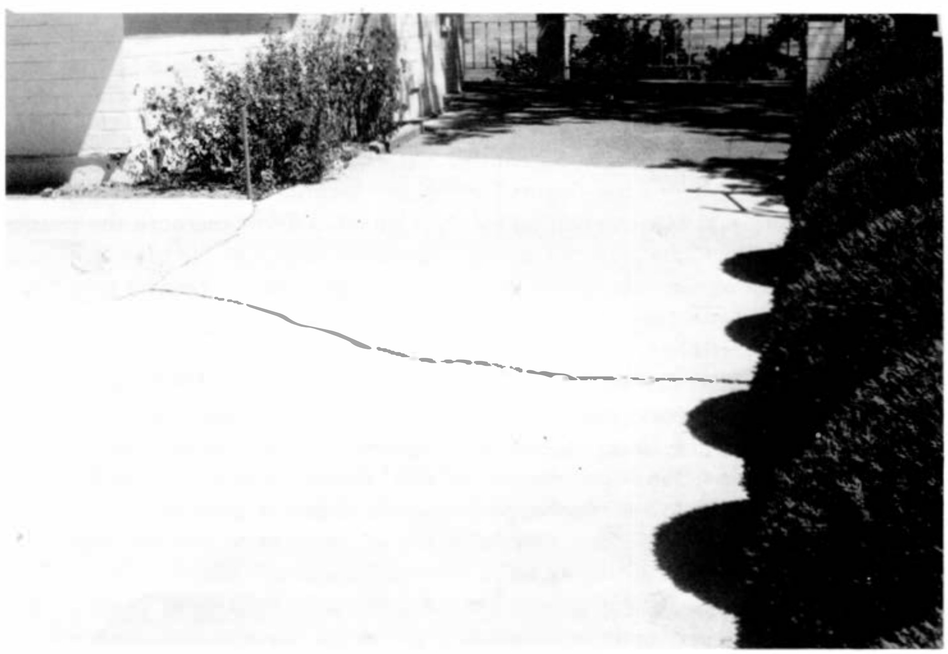


Figure 41. Ongoing slide activity has damaged driveway of house shown in Figure 40.

Ephemeral stream channels in The Dalles area have potential for flash flooding during thunderstorms or rapid snow melts. Dry Hollow has a history of flash floods and was responsible for the death of one person in 1939 and the flooding of numerous residences in 1948. Presently the channel is located along Dry Hollow Road and passes beneath the road near 14th Avenue. Culverts are poorly maintained and apparently were not engineered to handle such floods as the one which occurred in 1948. A repeat of the 1948 thunderstorm would endanger many homes in the Dry Hollow Road area north of 14th Avenue.

Rufus (Figure 42)

Geologic units exposed near Rufus are steep slopes of Columbia River Basalt (Tcr), stream terraces of older alluvium (Qoa), and a complex of surficial deposits which include Quaternary fan deposits (Qaf) of varying ages and sand possibly deposited by the Missoula Flood (included in Qaf). The community of Rufus is situated primarily on fan deposits.

The major geologic hazards at Rufus are inundation, erosion, and deposition associated with torrential flooding. Exceptionally large floods from Gerkling and Scotts Canyons spill over the fan on which the community is located and probably follow random courses over the fan and through the community. Lesser floods of greater frequency which follow the major channels are sensitive to channel modifications and restrictions.

Where coarser deposits of gravel form natural armor over sand and silt (see Stream Erosion and Deposition), disturbances of the surface can increase the potential for erosion.

Torrential flooding eroded part of a trailer park in 1964, spreading sediment and debris through much of the community. The water supply was destroyed and debris was washed over Highway I-80N for a distance of a quarter of a mile. Flooding indicated on the accompanying map is inferred on the basis of topography and published accounts of the 1964 flood. More detailed supplemental analysis based on actual interviews with residents is recommended when funds or staff time become available.

Mass-movement hazards include rockfall and rockslide on steeper slopes surrounding the community and potential failures in poorly engineered cuts in thicker talus. General recommendations for reducing these hazards are provided under the appropriate headings elsewhere in the text.

Communities of the Deschutes River Drainage

Communities of the Deschutes River drainage are Tygh Valley and Maupin. Collectively, mapped hazards include deep bedrock slides, lowland flooding, torrential flooding, and talus. The region is rapidly being eroded by downcutting of the Deschutes River and tributary streams. The result is an abundance of steep-slope-related mass-movement hazards. Geologic maps were not prepared for these communities in this investigation. However, general geology is shown in Waters (1968).

Tygh Valley (Figure 43)

Bedrock geologic units exposed near Tygh Valley include the Columbia River Basalt north of Tygh Creek, the Dalles Formation in the slopes south of Tygh Valley, and lava flows of the Cascades Formation capping the ridges south of Tygh Valley. Surficial geologic units include river alluvium equivalent to Quaternary older alluvium and Quaternary alluvium in the major river valleys. The Dalles Formation consists of tuffaceous river sand, andesitic tuff, and tuff breccias.

Deep bedrock slides underlie the community of Tygh Valley and are present over large areas along the valley of White River and east of the mapped area at Devils Half Acre. The Dalles Formation is the unit which fails. Deep bedrock slides occur where stream erosion undercuts exposures of the Dalles Formation which in turn are overlain by protective caps of younger lava.

The deep bedrock slides at the community of Tygh Valley are middle to late Pleistocene in age and are presently inactive. They are probably prone to localized reactivation in steeper sloping areas. Large-scale developments should follow recommendations based on engineering investigations of shallow subsurface drainage, variable cutbank stability, and variable foundation strengths. In the White River drainage and at Devils Half Acre, the deep slides may still be active in places.

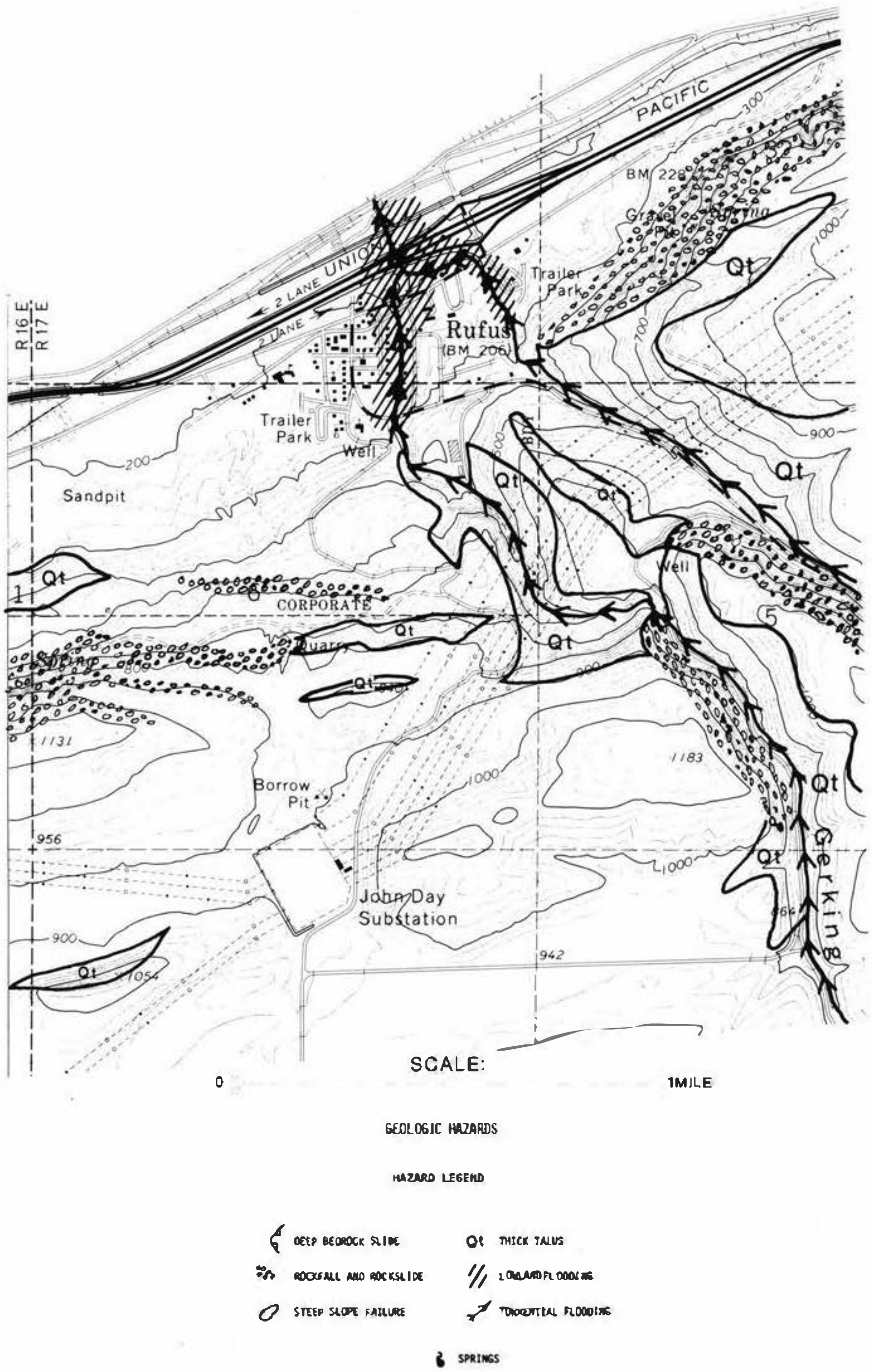


Figure 42. Geologic hazards of Rufus and vicinity.

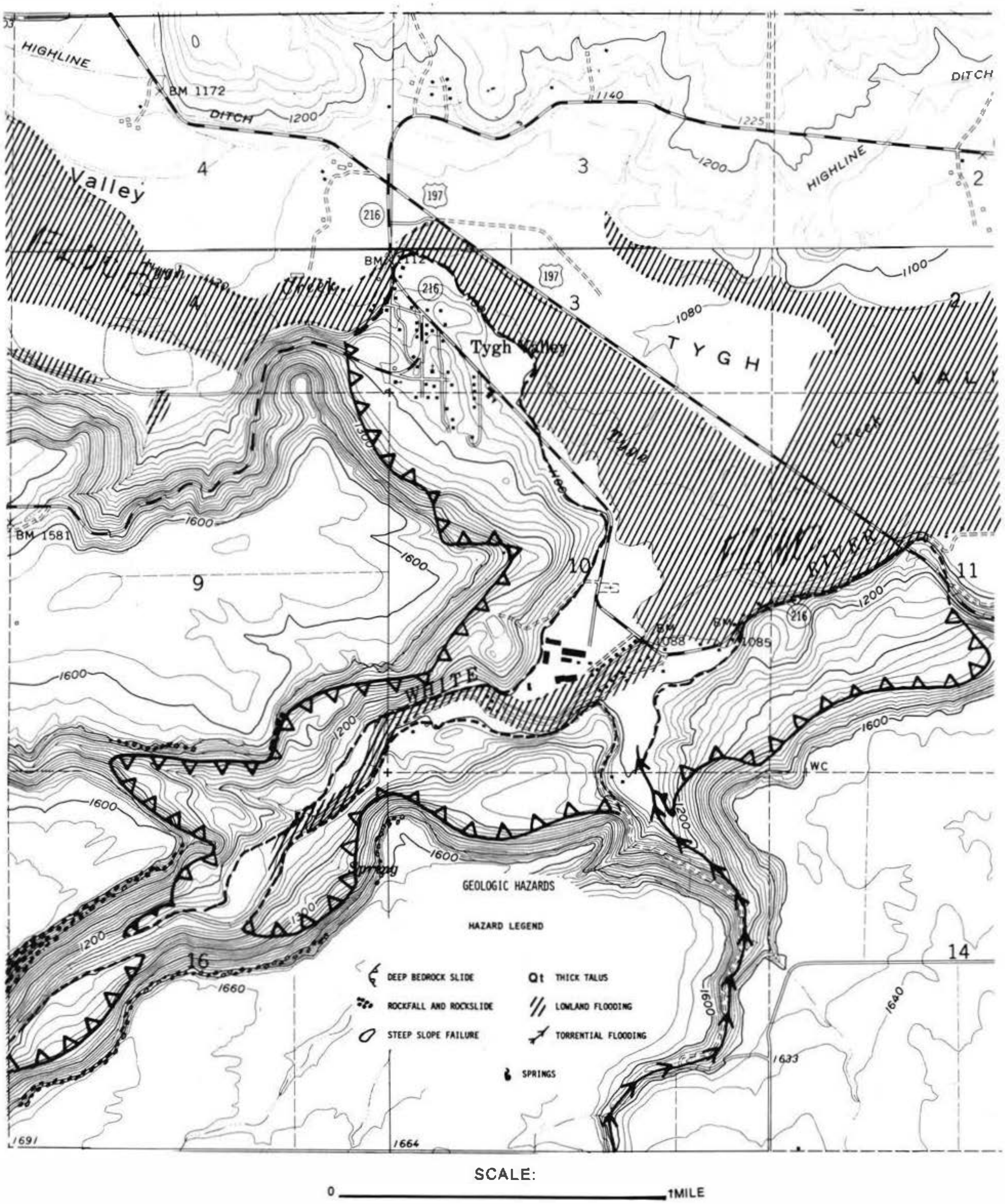


Figure 43. Geologic hazards of Tygh Valley and vicinity.

Flood distributions indicated in Figure 43 for the 1964 flood are based on reconnaissance done by the U. S. Geological Survey and augmented and briefly field checked for this study on the basis of landforms, soil development, and vegetation patterns. During the 1964 flood, the road surface over the White River bridge was covered by water. As shown on the map, Highway 197 restricted much of the flooding to the west half of Tygh Valley and probably aggravated flooding in that area. Recommendations for dealing with flood-prone areas are stated in Stream Flooding.

Maupin (Figure 44)

Bedrock geologic units in the Maupin area include Columbia River Basalt (Tcr) east of the Deschutes River and low on the slopes west of the Deschutes River, Dalles Formation (Tpd) on the middle and upper slopes west of the Deschutes River, and lava flows of the Cascades Formation capping the ridges west of the Deschutes River. In addition, the higher parts of Maupin southwest of the city proper are situated on the remnants of an intracanyon flow of the Cascades Formation. The older parts of the community are located on a bench cut in Columbia River Basalt and covered with a thin veneer of older alluvium.

Flood hazards include torrential flooding in major canyons and localized lowland flooding of alluvial units along the Deschutes River (Figure 44). For example, the 1964 flood washed a barn down Bakeoven Creek and against the Standard Oil building near the confluence with the Deschutes River.

Mass-movement hazards exist in the talus of the Columbia River Basalt east of the Deschutes River and west of the Deschutes River southwest of Maupin. Steep slopes and shallow subsurface flow of ground water in these areas favor shallow debris flows and cutbank failures during the rainy season. North of Maupin in the Spring Creek area, talus overlies the Dalles Formation. Potential hazards include low cutbank stability and landslides, especially near springs. Developers should be guided by engineering investigations of slope stability, ground water, and potential for deep slide activity.

Communities of the Deschutes Plateau

Communities of the Deschutes Plateau include Dufur, Kent, Wasco, Moro, and Grass Valley. Slope-related hazards on the flat upland surface are minimal. Lowland flooding is severe locally. The communities are generally located in the flat bottomlands short distances upstream from narrow, steeper gradient stream segments.

Dufur (Figure 45)

Geologic units in the Dufur area include Columbia River Basalt above the valleys and various alluvial units equivalent to the Quaternary older alluvium and Quaternary alluvium in the valleys. Soils over the Columbia River Basalt are thin along ridge crests and include creep colluvium and wind-blown silt on side slopes.

Mass-movement potential is minimal, and standard grading and shoring practices are recommended in cuts and excavations. Flood potential of the lower lying parts of the Fifteenmile Creek valley is severe. During the 1964 flood, the tavern near the Dufur Bridge, the swimming pool in the Dufur City Park, and streamside areas outside the city limits (Figures 28 and 29) were extensively flooded.

Kent (Figure 46)

Kent is located on flat-lying Columbia River Basalt away from major streams and slopes (Figure 47). There are no flood or slide hazards. The major restriction to development is the shallow depth to bed rock in places as it affects the cost of excavations and the functioning of septic tanks for waste disposal. This restriction is adequately handled by standard septic tank investigations.

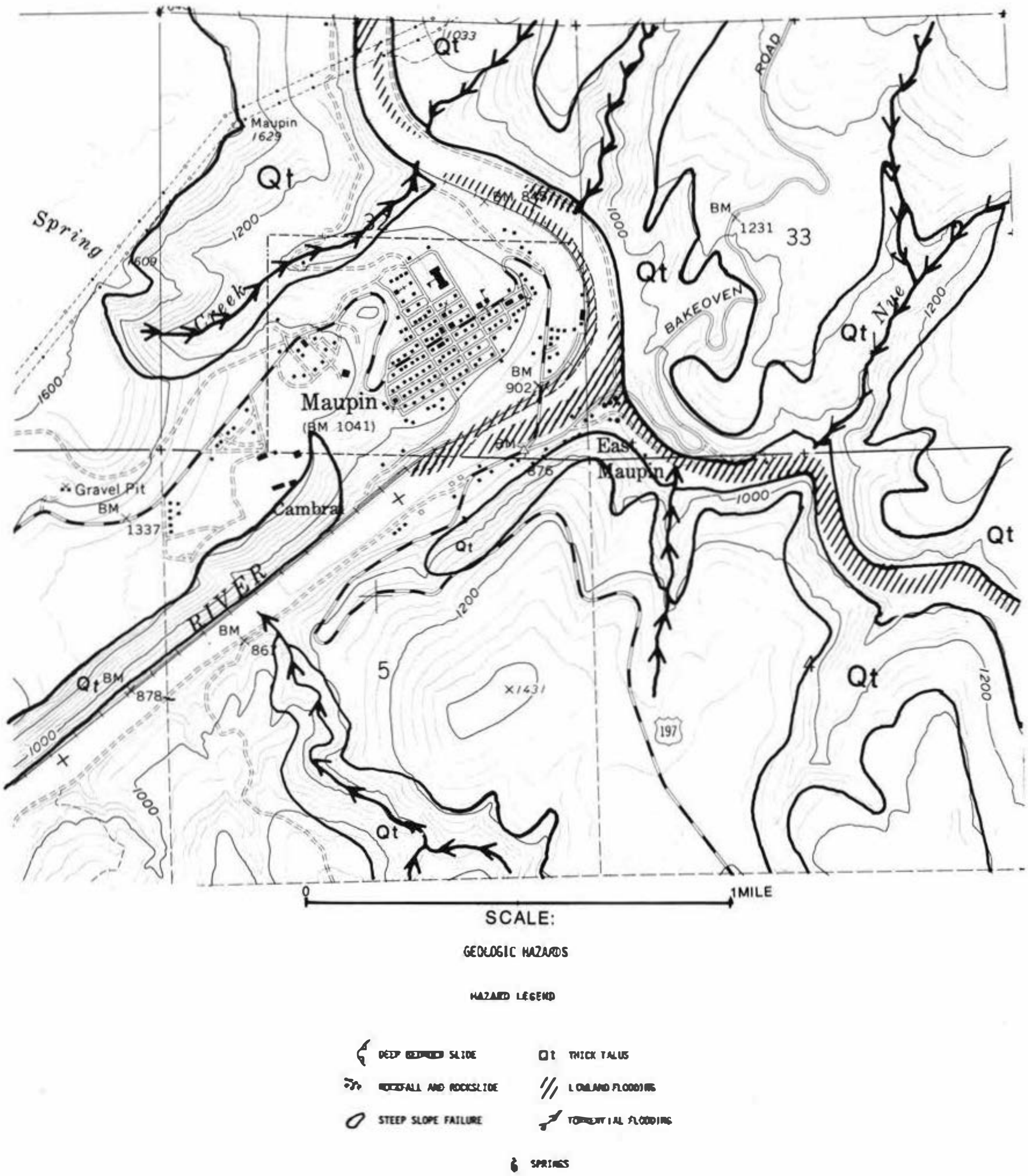


Figure 44. Geologic hazards of Maupin and vicinity.

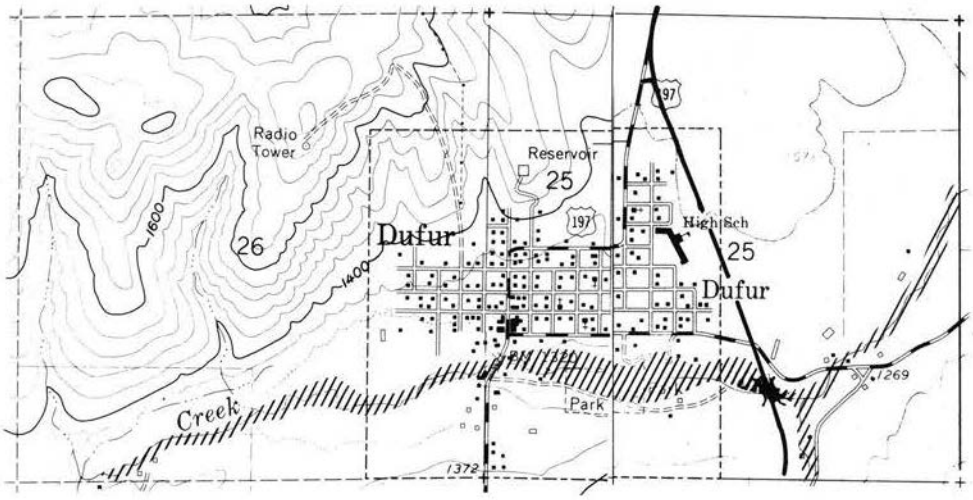


Figure 45. Geologic hazards of Dufur and vicinity.

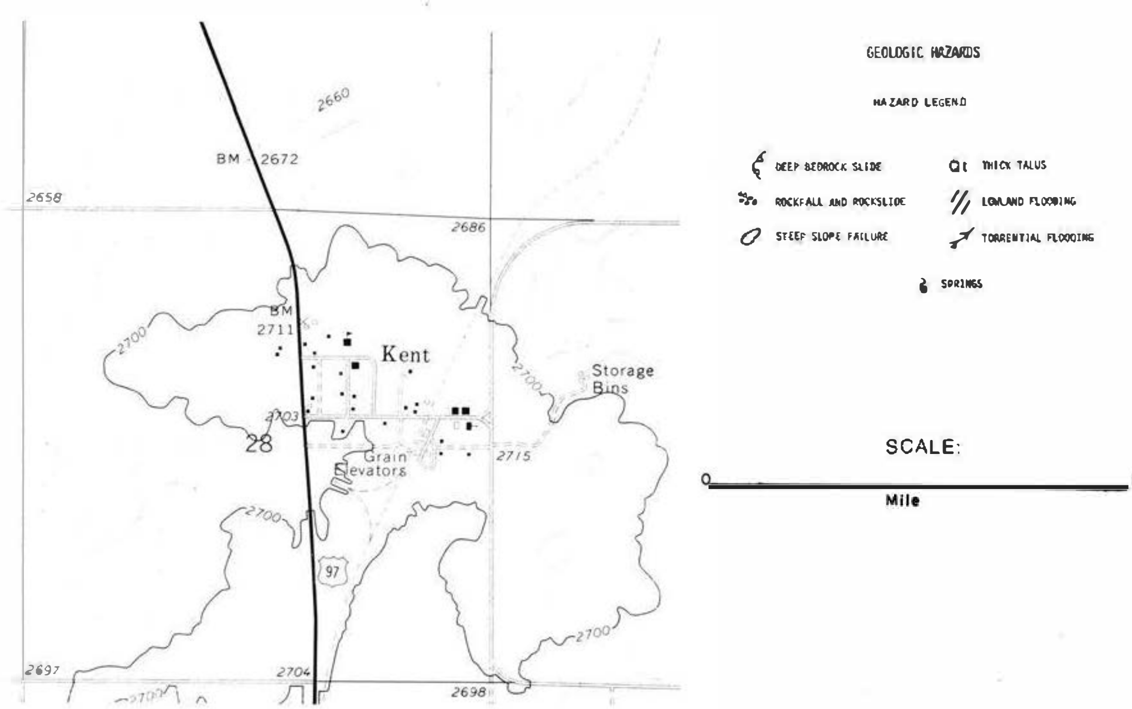


Figure 46. Geologic hazards of Kent and vicinity.

Figure 47. Kent, situated on flat terrain away from streams, is threatened with no geologic hazards but is troubled with shallow depths to bed rock.

Wasco (Figure 48)

Geologic units near Wasco include Columbia River Basalt and lowland alluvial deposits mapped as Quaternary older alluvium and Quaternary alluvium. Mass-movement potential is minimal, and standard grading practices are adequate to avoid slides. Parts of the community are located on shallow soils or bare bed rock. Costs of excavation and potential for septic tank failures are high in these areas.

The potential for flooding is severe in low-lying parts of the community along Spanish Hollow Creek. Flooding indicated in Figure 48 is based upon accounts of the 1964 flood and field examination of the community. It represents a refinement of the 1974 flood map issued by the U. S. Department of Housing and Urban Development.

Much flooding during unusually high discharges of low frequency is caused by inadequate conveyance of flood waters through artificial channels in the community. Culverts under streets vary considerably in cross-sectional area, and abrupt turns in the channel further retard the flow of water. Discharge of the 1964 flood was 575 cfs or more (see Stream Flooding), and the culvert with a cross-sectional area of less than 30 square feet at the intersection of Ellis Avenue and the Sherman County Highway was clearly inadequate. Significant flooding probably occurred when water overflowed the channel and passed through the lower-lying parts of town. Water covered the road for a width of two blocks along the Sherman County Highway and was 2 feet deep in the clothing store between Ellis and Davis Avenues.

The potential for bank overflow during lower discharge floods of higher frequency is augmented by poor maintenance of the channel (Figure 49). Deposits of mud, clumps of grass and cattails, and scattered debris in the channel reduce channel capacity to transmit flood waters through the community.

Assuming favorable cost-benefit ratios, it is recommended that the stream channel be evaluated from an hydraulic engineering standpoint and that appropriate modifications be made, if practical.

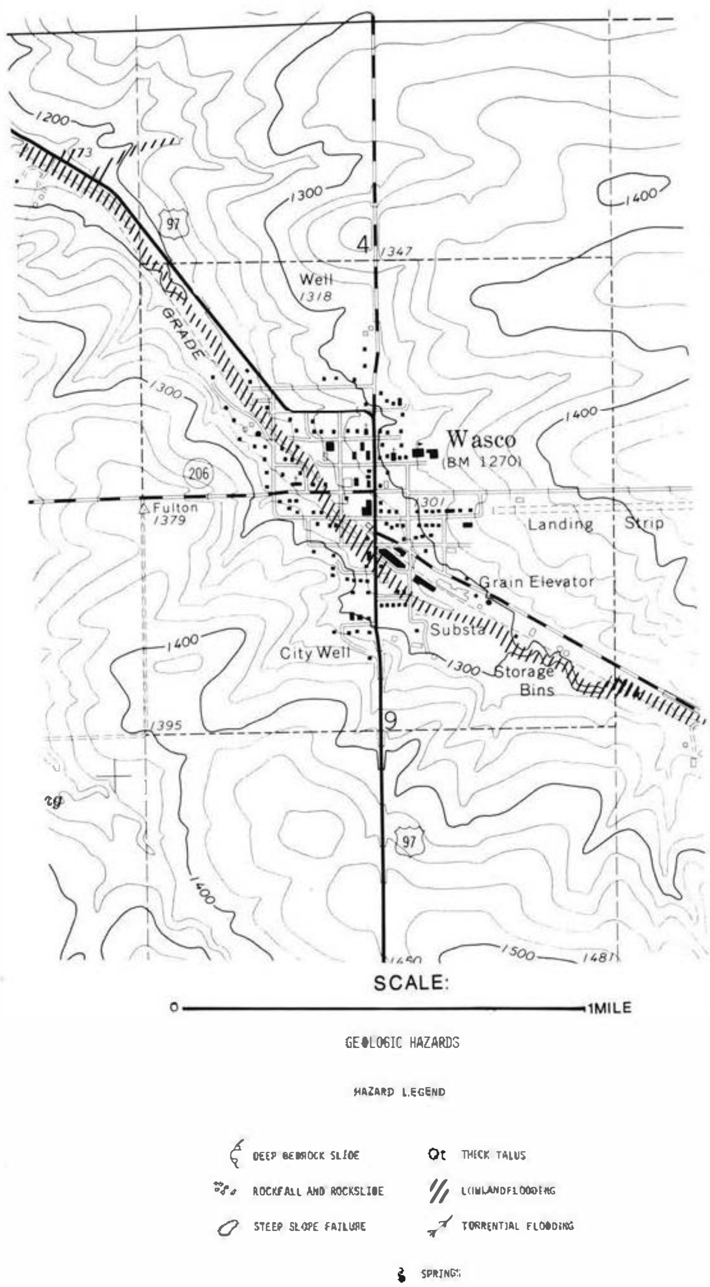


Figure 48. Geologic hazards of Wasco and vicinity.

Figure 49. Poor maintenance of creek channel through Wasco may contribute to flood potential.

Moro (Figure 50)

Geologic units in the Mora area include Columbia River Basalt, which underlies the hills, and stream alluvium along the creek. Slide hazards are negligible if proper grading and shoring practices are followed in excavations and cuts. Flooding along the creek, indicated in Figure 50, is restricted to the lower lying areas along the creek. During the 1964 flood, water flowed over the rood in front of the Mora Lumber and Fuel Company at depths as great as 3 feet. General flood recommendations are provided in the section Stream Flooding.

Gross Valley (Figure 51)

Geologic units in the Grass Valley area include Columbia River Basalt, which underlies the hills, and stream alluvium of varying ages along the creeks. If proper grading and shoring practices are followed in excavations and cuts, slide potential is negligible.

Areas of flooding along the creek are indicated in Figure 51 and are restricted to the lower lying areas along major creeks. Flood-prone areas ore delineated on the basis of published accounts of the 1964 flood and field examination of landforms, vegetation patterns, and soil conditions. Extensive moist ground in the valley bottom north of town indicates frequent flooding and high ground-water conditions.

During the flood of 1964, water was 10 inches deep in Field's Confectionary Store. Water was one foot deep at Dunlop's Service Station. The dike lining the east bank of the creek at the school ployfield near the north end of town may divert flood waters onto the other bank. General flood recommendations are provided under Stream Flooding.

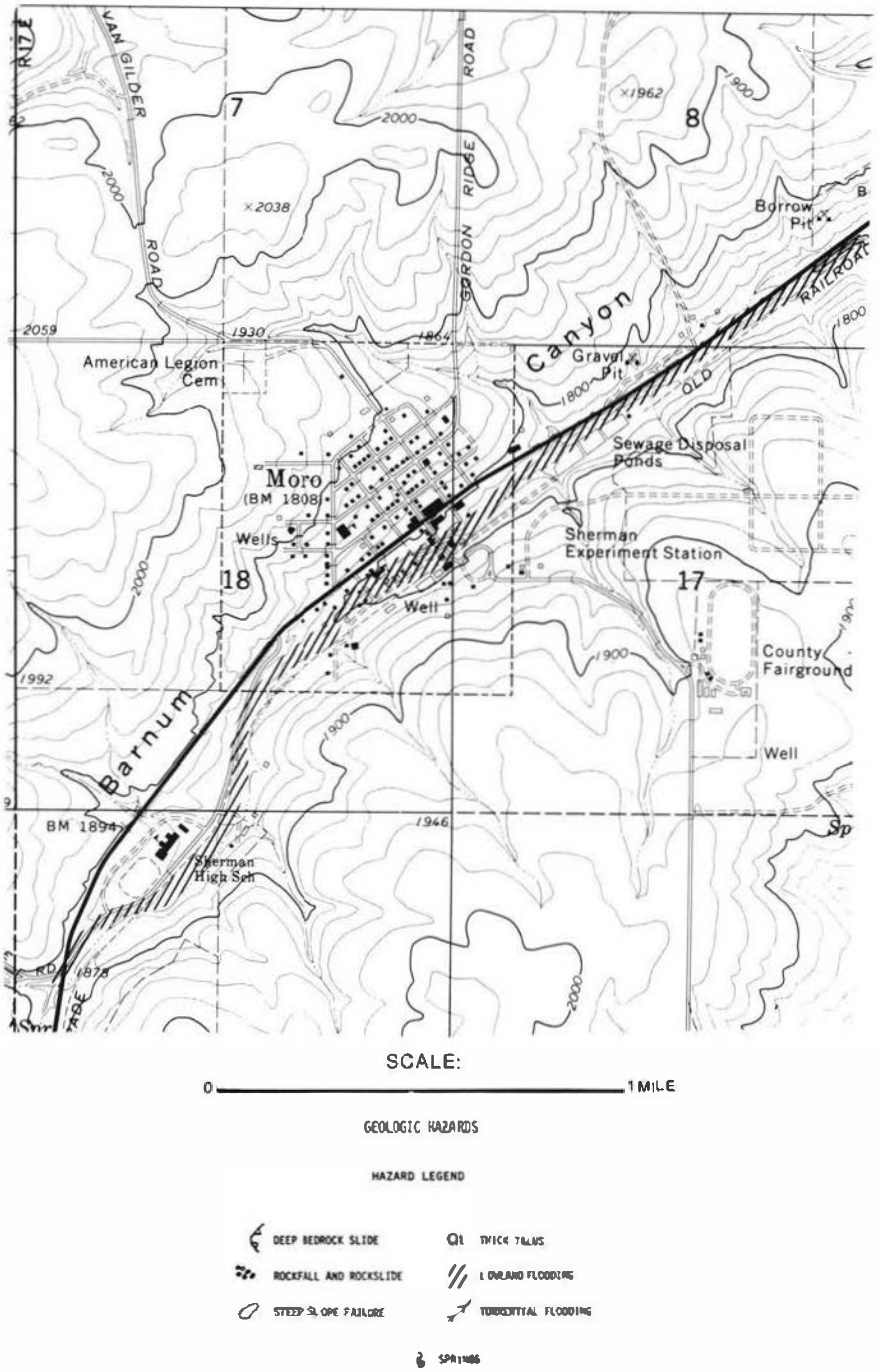


Figure 50. Geologic hazards of Moro and vicinity.

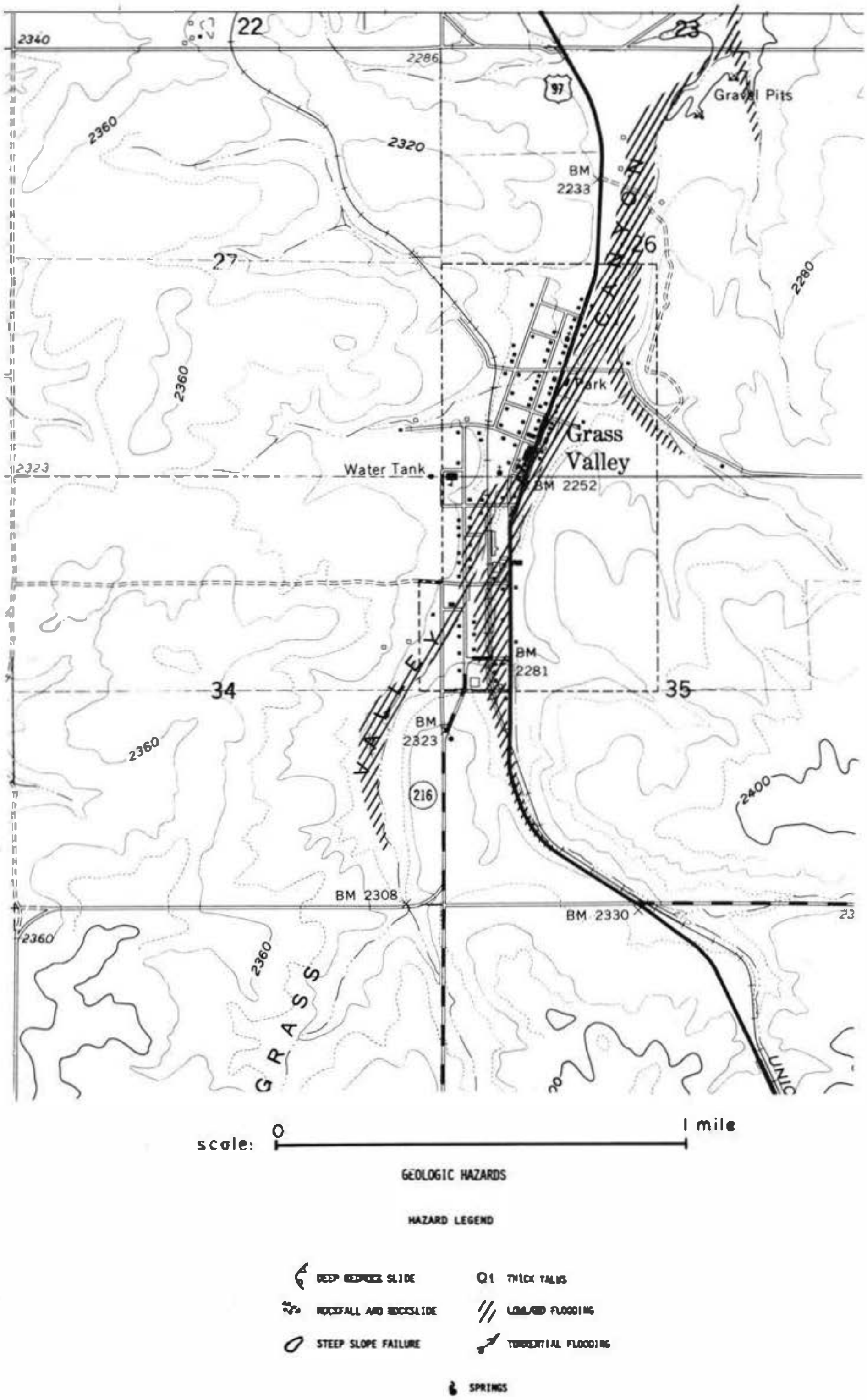


Figure 51. Geologic hazards of Grass Valley and vicinity.

SUMMARY

Use of This Bulletin

This bulletin provides planners in northern Hood River, Wasco, and Sherman Counties with needed information on geologic hazards in their respective areas. The material is reconnaissance, however, subject to refinement based on additional investigations. The maps represent average conditions on the ground; and on-site examination is required for site-specific evaluation.

The bulletin is organized and cross-referenced to facilitate easy use. The maps and tables interrelate the various hazards and systematically present information about them. The text is divided into sections dealing with specific topics and is structured around the formats of the map legends. The resulting hazards analysis has a potential for a wide variety of uses including preliminary site evaluations, land use capability analyses for comprehensive planning or other purposes, projection of data, and policy formulation.

Geography

The study area encompasses the northern parts of Hood River, Wasco, and western Sherman Counties and also includes small areas around major communities to the south, including Dufur, Tygh Valley, Maupin, Moro, Grass Valley, and Kent. Total areal extent is approximately 550 square miles. Major physiographic regions of the study area are the Columbia River Gorge, the Cascade Range, the Hood River Valley, and the dissected plateaus east of The Dalles.

Population of the incorporated communities of the study area has remained basically unchanged in recent years, except for Hood River and The Dalles, which show steady growth. Projections for the counties as a whole indicate continued growth for Hood River and Wasco Counties and redistribution of population from southern Sherman County to northern Sherman County.

Geology

A total of 21 geologic units are recognized - eight surficial deposits of relatively young age, and 13 bedrock stratigraphic units of primarily volcanic origin. The bedrock units include Eocene volcanic rock (Ohanapecosh Formation), early Miocene volcaniclastic rock (Eagle Creek Formation), Miocene flood basalts (Columbia River Basalt), Pliocene Columbia River deposits (Troutdale Formation), Pliocene volcanic rocks (Rhododendron Formation, Dalles Formation), High Cascades volcanic rock (Cascades Formation, including numerous flow units with local names), and Quaternary and Pliocene intrusive rocks. Local use limitations in the bedrock geologic units generally are mass movement, erosion, and conditions related to thin soils.

Major structures include the Dalles-Umatilla syncline, Hood River fault, Cascade Range anticline, the Chenoweth fault, and the Laurel fault. All exposed folds and faults in the study area are probably mid-Pleistocene or older. Ongoing deformation is at depth and involves structures not exposed at the surface.

Surficial geologic units include Pleistocene lake deposits (gravel, sand, and silt), Quaternary stream deposits (older alluvium of Hood River Valley, older alluvium, alluvial fan deposits, and alluvium), slide deposits (thick talus), and wind deposits (silt and sand). Local use limitations include flooding, stream erosion and deposition, and blowing sand. Over large areas, Pleistocene floods removed soil and loose material, leaving hard impermeable bed rock at the surface.

Geologic Hazards

Geologic processes that adversely affect the activities of man or threaten his safety or welfare ore geologic hazards. Their mitigation or treatment should be based on consideration of causes and potential impacts and should be flexible to allow for variations in social, political, and economic setting.

Mass movement

Mass movement includes deep bedrock slumps controlled primarily by faults and large joints in the Columbia River Basalt and by bedding planes and rock type in the Dalles Formation and the Eagle Creek Formation. Impacts are variable, depending on land use and the present level of slide activity, and may include personal injury and immediate or long term destruction of property or buildings.

Other types of mass movement include shallow earthflow and slump on steep slopes and in the heads of valleys, steep-slope failures (rockfall and rockslide) in the Columbia River Gorge and along steep valleys, soil creep, and general areas of potential future mass movement. Use limitations are highly variable and should be determined on an individual basis in consideration of the nature and magnitude of the hazard. Controlled development and engineering practice keyed to the specific causes and characteristics of particular slides are generally recommended.

Slope erosion

Slope erosion is the removal of soil or weathered bed rock by sheet wash, rill erosion, or gully erosion and is controlled primarily by slope and land use or soil cover. Slope erosion in agricultural areas is adequately handled by the U. S. Soil Conservation Service. Soil erosion in areas of urbanization can lead to loss of topsoil, increased runoff, degradation of streams or water supplies, and clogging of storm sewers. Of critical concern to the planner is the anticipation and control of slope erosion in areas of construction.

Stream flooding

Flood-prone areas were delineated on the basis of incomplete records of past historic floods, landforms, soils, vegetation patterns, and other natural features. Floods on the Columbia River are now largely controlled, so repetition of the floods of 1894 and 1948 is not likely. The flood of 1964 inflicted severe damage on all drainages of the study area, washing out bridges, silting cropland, and inundating lowland areas. Floods result from warm rains, melting snow, and random thunderstorms; and the low flow of most streams in the summer, which provides a marked contrast to true flood potential, is very misleading to persons not familior with the extreme ranges of streamflow that do occur.

Stream erosion and deposition

Torrential flooding in channels with steep gradients and minimal flood plains results in extreme conditions of channel scour and channel deposition. Hazards include stream-bank erosion, erosion of embankments and bridge abutments, and extensive rapid deposition downstream on alluvial fans. Erosion and deposition in streams with flood plains are less extreme but remain factors to be considered in decisions of stream management including gravel removal, stream-bonk protection, and water impoundment.

Earthquakes

The largest historic earthquake in the study area occurred east of Maupin on April 12, 1976 and was of Mercalli intensity VI. No surface faults are believed to be active. Quakes originating outside the study area have been felt with intensities as high as VI in parts of the study area. A probable maximum earthquake of Mercalli intensity VII is suggested for areas of poor ground conditions in the study area. Quakes of this severity cause slight damage to well-designed and well-built structures and considerable damage to poorly built and poorly designed structures.

Volcanism

Mount St. Helens has undergone a fairly active eruptive history for the past 4,000 years and will erupt in the future. Mount Hood is less active but does exhibit ongoing fumarolic activity and may have erupted as late as the last century. The most probable volcanic activity of significance to the study area will be ash fall. The very limited data suggest that the frequency and potential impacts in the study area will be minor.

Geologic Hazards of Communities

On the basis of general geologic settings and associated geologic hazards, the communities of the study area are grouped into three categories: 1) those of the Columbia River Gorge, 2) those of the Deschutes drainage, and 3) those of the Deschutes Plateau. Major geologic hazards of the Columbia River Gorge communities and the Deschutes drainage communities include deep mass movement in geologic units above and below the Columbia River Basalt and stream flooding. Ancient landslides are particularly widespread in Cascade Locks, Tygh Valley, and The Dalles (where land use has reactivated parts of ancient slides). Geologic hazards of the communities of the Deschutes Plateau are generally restricted to stream flooding. Mitigation of the various hazards differs considerably between communities and within individual communities, depending upon local conditions.

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APPENDIX A: THE FORMATION AND CLASSIFICATION OF SOILS

Formation

Unconsolidated mineral material at the Earth's surface is termed soil. Agronomists limit use of the term soil to those materials capable of supporting plant growth. Engineers use the term soil to describe all unconsolidated mineral matter including surficial geologic units. Material in the weathered zone is called soil by geologists. In practice, most soils data is based on material sampled from the weathered zone.

Weathering processes of the Earth's surface include chemical breakdown of minerals, chemical reconstitution to form new minerals (clays), physical disintegration, and leaching. During the initial stages of weathering, the composition of the parent material is the dominant factor in determining the soil type in the weathered zone. Climate determines the kinds and rates of chemical processes and the nature of the vegetative cover. Slope intensity influences drainage and mass movement, and slope orientation partly determines the balance of soil-forming processes within a given area. As time progresses, climate becomes increasingly significant in determining soil type.

Soil types at a site vary with depth as a function of varying conditions. The surface (A horizon) is the zone of most intense organic activity, leaching, and downward percolation of fine material. Commonly, iron, carbonates, and clay are removed and deposited in the next lower (B) horizon. This zone may be characterized by relatively high concentrations of silicated clay minerals, iron, or other materials. At greater depths, the C horizon consists of partially weathered and decomposed bed rock. Variations in the balance of the five soil-forming factors (parent rock, climate, topography, vegetation, and time) produce the many variations of soils. Loams, silt loams, and clay loams are most common in the study area.

Classification

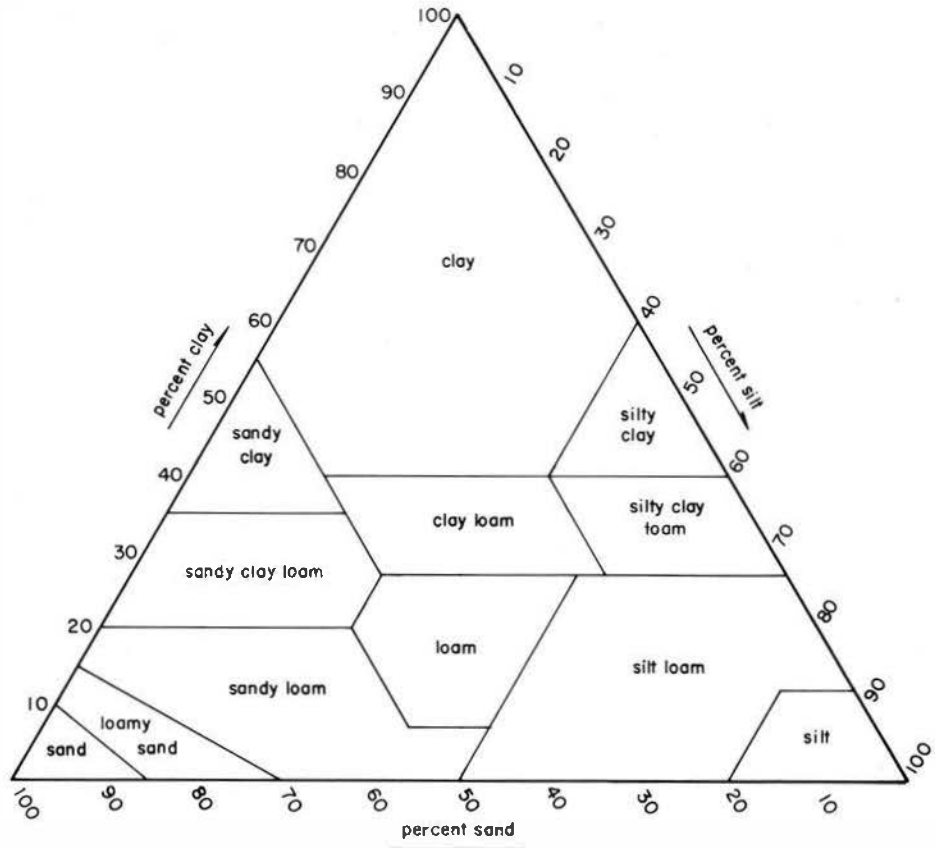
The National Cooperative Soils Survey of the U. S. Department of Agriculture uses the Seventh Approximation System of Soils Classification, in which the soils of the nation are classified into a seven-level hierarchy based upon 1) regional climate, 2) physical setting, 3) uniformity and types of horizons, 4) relationships of horizons, 5) textural and compositional features related to plant growth potential, 6) parent material and genetic horizons, and 7) surface texture.

Soils mapping done according to the U. S. Department of Agriculture system is based primarily on grain size distribution (Appendix B) and addresses items 6 and 7 above. Thus, the Walla Walla silt loam develops on a parent material of loess on gentle slopes and consists of silt loam at the surface. The Seventh Approximation System provides a means of relating soils maps in different areas and of generating reconnaissance soils maps on small scales.

The Unified Soils Classification System (Appendix C), used by the U. S. Army Corps of Engineers and the U. S. Bureau of Reclamation, is more rigorous and places emphasis on the engineering properties of soils, including plasticity index (a measure of water content at which a soil behaves plastically), liquid limit (a measure of water content at which a soil behaves as a liquid), and organic content.

The American Association of State Highway Officials System (Appendix D) is used to classify soils according to those properties that affect use in highway construction and maintenance. Comparison of the particle-size boundaries recognized by the three systems is given in Appendix E. Correlations between the three systems are general. Accurate determination of the behavior of a soil in each system requires testing.

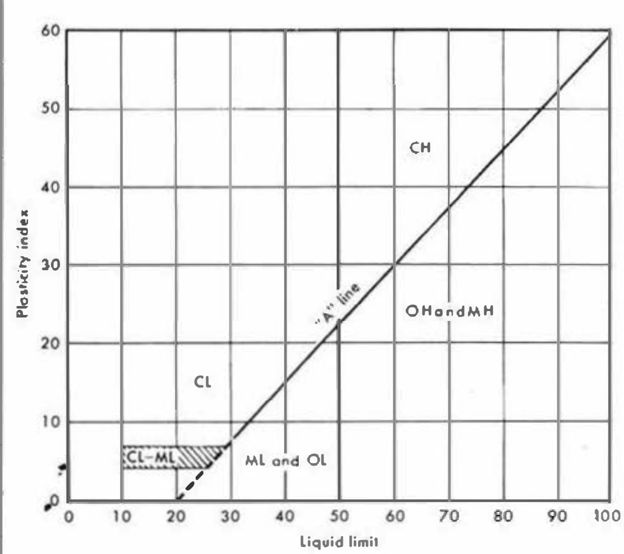
APPENDIX B. GUIDE FOR THE TEXTURAL CLASSIFICATION OF SOILS



Texture	Dry feel	Moist feel	Moist shine	½"-1" wide, 1/8" thick moist plasticity (ribbon)	Moist 2"+ long plasticity (wire) 1/8"
Sand	Individual grains seen and felt	Individual grains seen and felt	None	Will not ribbon	Will not wire
Sandy loam	Individual grains appear dirty	Individual grains appear dirty	None	Will not ribbon	Will not wire
Loam	Gritty, floury feel	Gritty, smooth slick	Faint dull	Very weak ribbon, broken appearance	Very weak wire in broken segments
Silt loam	Soft and floury	Smooth slick w/ some stickiness	Dull	Ribbon broken appearance	Weak wire easily broken
Clay loam	Slightly hard, little grittiness	Smooth slightly sticky w/some grittiness	Prominent dull	Ribbon barely sustains weight	Wire sustains weight
Silty clay loam	Moderately hard, no grittiness	Smooth sticky, feel some plasticity	Faint	Ribbon sustains weight & careful handling	Wire sustains weight & withstands gentle shaking
Silty clay	Hard, no grittiness	Smooth, sticky plastic, faint fingerprints visible	Shine	Ribbon withstands considerable movement & deformation	Wire withstands considerable shaking and rolling
Clay	Very hard, no grittiness	Smooth very sticky - plastic fingerprints	Bright	Long thin ribbon	Wire withstands shaking, rolling, bending, 1/16"

APPENDIX C. UNIFIED SOIL CLASSIFICATION SYSTEM

Major divisions			Group symbols	Typical names	Laboratory classification criteria		
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 per cent ... GW, GP, SW, SP; More than 12 per cent ... GM, GC, SM, SC; 5 to 12 per cent ... Borderline cases requiring dual symbols**	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM* d / u	Silty gravels, gravel-sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures		Atterburg limits above "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP	Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM* d / u	Silty sands, sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures		Atterburg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half of material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Plasticity Chart (see below)		
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH	Inorganic clays of high plasticity, fat clays			
			OH	Organic clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt	Peat and other highly organic soils			



Plasticity Chart

*Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterburg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

**Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example GW-GC, well-graded gravel-sand mixture with clay binder.

Reprinted from PCA Soil Primer

APPENDIX D. AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS (AASHO) SOILS CLASSIFICATION

General classification			Group symbols	Grain size (sieve)	Atterburg limits for fraction passing No. 40		
					Liquid limit	Plasticity index*	
Granular materials Less than 35% is smaller than No. 200 sieve	Stone fragments gravel and sand	A-1	A-1-a	50% max. passes No. 10 30% max. passes No. 40 15% max. passes No. 200		Less than 6	Good to excellent subgrade
			A-1-6	50% max. passes No. 40 25% max. passes No. 200			
	Fine sand	A-3	A-3	50% min. passes No. 40 10% max. passes No. 200		N.P.	
	Silty or clayey gravel and sand	A-2	A-2-4	35% max. passes No. 200	Less than 40	Less than 10	
			A-2-5		Greater than 40	Less than 10	
			A-2-6		Less than 40	Greater than 10	
			A-2-7		Greater than 40	Greater than 10	
Silt-clay materials More than 35% is smaller than No. 200 sieve	Silty soils	A-4	A-4	Greater than 35% passes No. 200	Less than 40	Less than 10	Poor to fair subgrade
		A-5	A-5		Greater than 40	Less than 10	
	Clayey soils	A-6	A-6		Less than 40	Greater than 10	
		A-7	A-7-5 and A-7-6		Greater than 40	Greater than 10	

*The difference between liquid limit and plastic limit; the range of water content through which the soil behaves plasticly.

APPENDIX E. COMPARISON OF THREE SYSTEMS OF PARTICLE-SIZE CLASSIFICATION

American Association of State Highway Officials - soil classification	Colloids	Clay	Silt	Fine sand	Coarse sand	Fine gravel	Medium gravel	Coarse gravel	Boulders	
U.S. Department of Agriculture - soil classification	Clay	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand	Fine gravel	Coarse gravel	Cobbles
Unified soil classification U.S. Army Corps of Engineers Bureau of Reclamation, Dept. of Interior	Fines (silt or clay)	Fine sand	Medium sand	Coarse sand	Fine gravel	Coarse gravel	Cobbles			
Sieve sizes - U.S. standard	270 — 200 — 140 — 60 — 40 — 20 — 10 — 4 — 1/2" — 3/4" — 3"									
Particle size - millimeters	.001 .002 .003 .004 .006 .008 .01 .02 .03 .04 .06 .08 .1 .2 .3 .4 .6 .8 1.0 2.0 3.0 4.0 6 8.0 10 20 30 40 60 80									

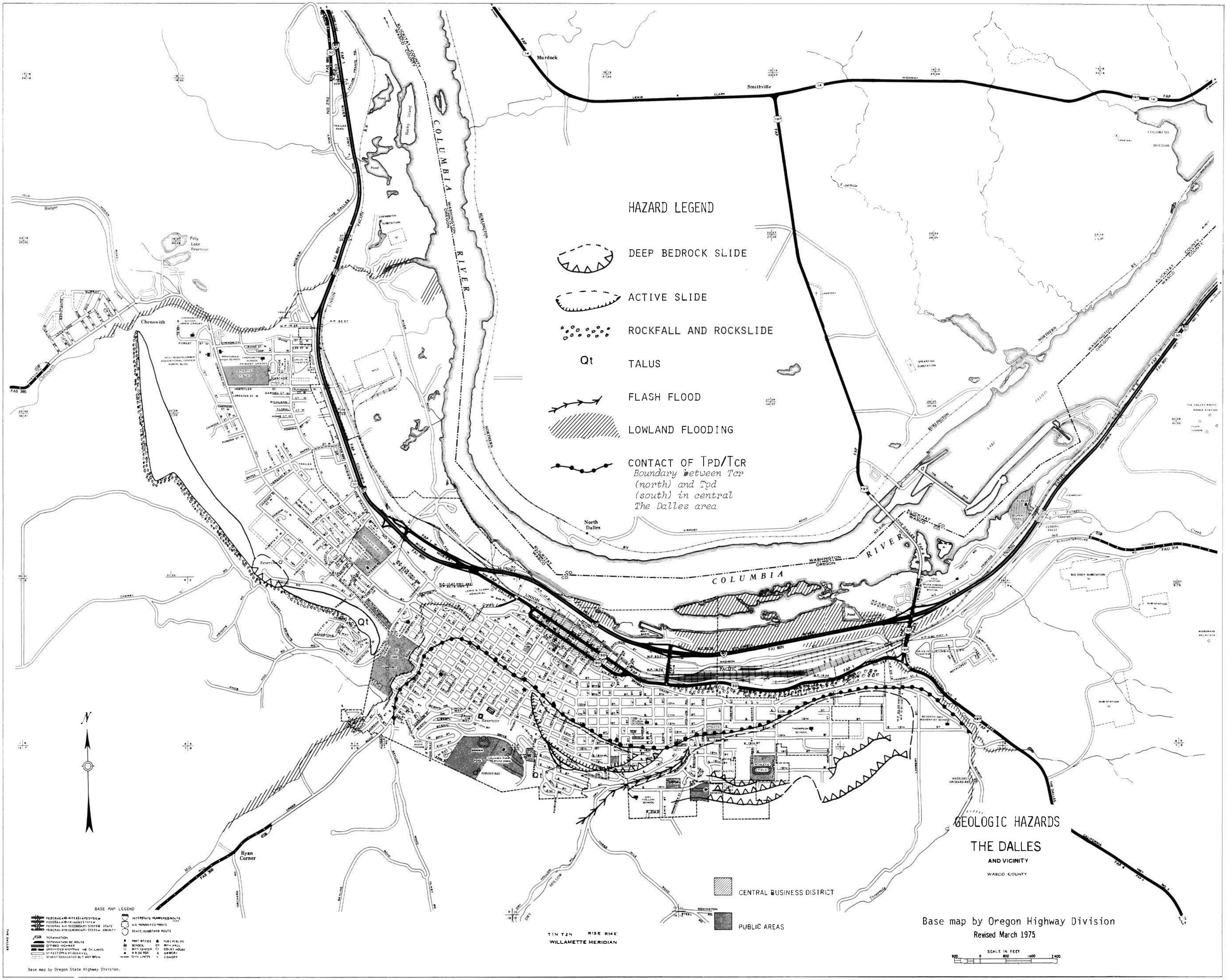


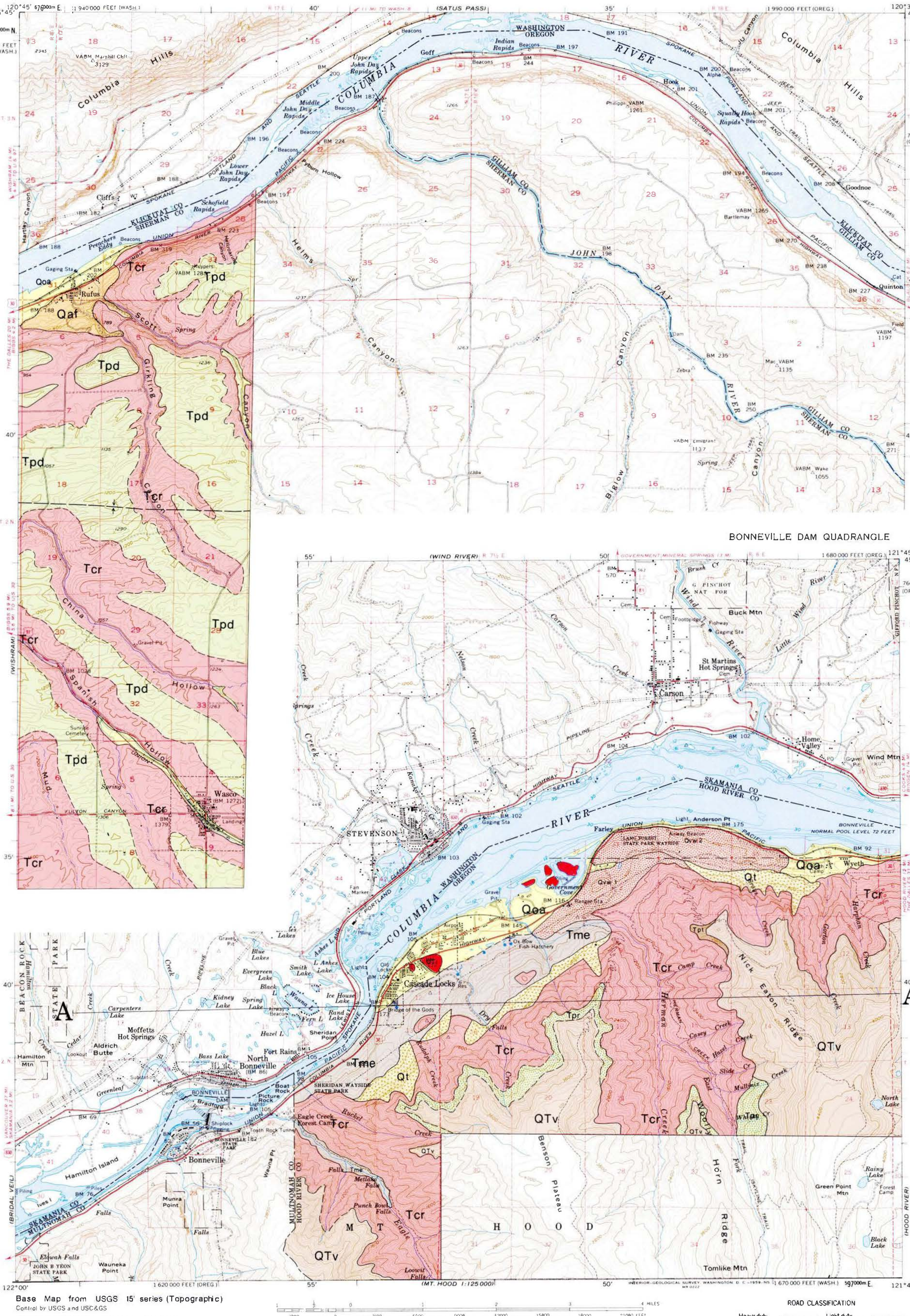
Figure 39. Geologic hazards of The Dalles and vicinity.

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

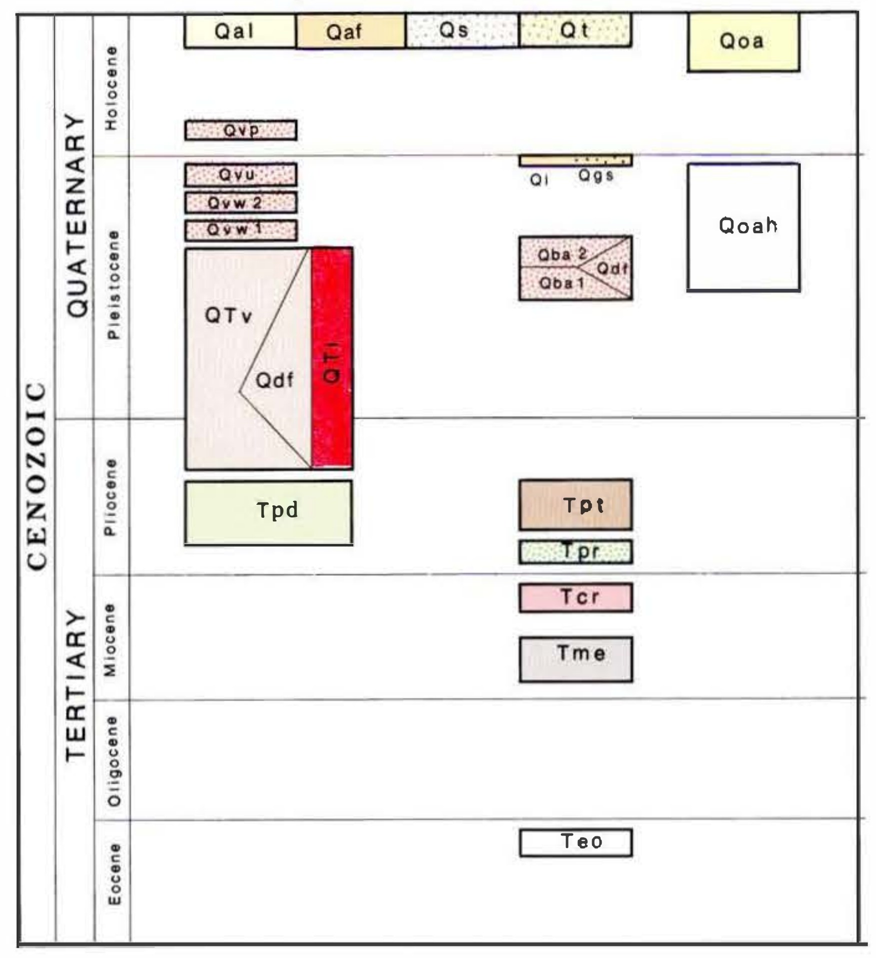
GEOLOGIC MAP of the parts of WASCO & BONNEVILLE DAM QUADRANGLES OREGON

WASCO QUADRANGLE

BONNEVILLE DAM QUADRANGLE



CHRONOLITHOGRAPH
(TIME ROCK CHART)



EXPLANATION

(Boundaries are approximate; statements are general; site evaluations require on-site investigation)

Surficial Geologic Units

Stream deposits:

Qal — Quaternary alluvium: *Unconsolidated gravel, sand, silt, and clay in stream beds and floodplains of major streams; equivalent to part of Qya of Newcomb (1969); not shown along smaller streams owing to limitations of scale; subject to stream flooding.*

Qoa — Quaternary older alluvium: *Unconsolidated gravel, sand, silt, and clay located above floodplains of major streams and as valley fill of smaller stream valleys; equivalent to Qoa and part of Qya of Newcomb (1969); includes several terrace levels of varying ages; generally not subject to flooding except in smaller drainages where scale precludes separate mapping of Qal.*

Qaf — Quaternary alluvial fan deposits: *Unconsolidated, poorly sorted gravel and sand occurring as fan deposits at mouths of torrential flood channels; subject to torrential flooding, erosion, and deposition.*

Qoah — Quaternary older alluvium of Hood River Valley: *Unconsolidated glacial outwash and minor interbedded lacustrine deposits and debris flows filling Hood River Valley; includes basal conglomerate and fluvial sand at Hood River.*

Wind deposits:

Qs — Quaternary eolian sand: *Unconsolidated medium-grained dune sand derived from wind erosion of Pleistocene flood deposits; migrating downslope and eastward in area immediately east of Biggs.*

Slide deposits *(excluding deep bedrock failures and soil failures; see geologic hazards maps):*

Qt — Quaternary thick talus: *Uniformly sloping unconsolidated rock and soil debris accumulating at base of cliffs primarily by rockfall and rock slide; estimated thickness generally greater than 50 feet; numerous associated hazards.*

Pleistocene flood deposits:

Qgs / Ql — Quaternary glacial flood gravel and sand (Qgs) and silt (Ql): *Unconsolidated gravel, sand, and silt scoured from nearby upstream terrain (now scabland) by glacial meltwaters of upper Columbia River drainage and deposited locally in protected areas; also includes unmapped erratics to a maximum elevation of 1150 feet. Much thin loessal material east of The Dalles included in underlying bedrock units.*

Bedrock Geologic Units

High Cascades volcanic rock:

QTv (Qba, Qvw 2, Qvw 1, Qvu, Qvp, Qdf) — Cascades Formation: *Basaltic and andesitic flow rock, agglomerate, tuff breccia, and debris flows of High Cascades volcanic peaks; includes relatively young vents and intracanyon flows in Mount Defiance area and Hood River Valley (Qba), Wind River (Qvw1, Qvw2), Underwood (Qvu), and Parkdale (Qvp) areas; also includes debris flows in Hood River Valley (Qdf) and intracanyon flows (now ridge crests) south and east of The Dalles (QTv); engineering properties and hazards variable. An older Qba unit (Qba1) and a younger unit (Qba2) are mapped near Odell.*

Pliocene volcanic rocks:

Tpd — Dalles Formation: *Thickly bedded andesitic ash-flow tuffs, tuff breccia, agglomerate, and flow rock, with interbedded conglomerate south of Mosier and The Dalles, grading eastward into thinner stream-deposited sands and silts with minor volcanic rock; interbedded with Columbia River conglomerates locally; thick soils east of The Dalles include eolian and lacustrine deposits; large, deep bedrock slumps in places; slump and earthflow potential locally, especially in areas of changing land use.*

Tpr — Rhododendron Formation: *Tuff breccia, agglomerate, and ash of local extent, forming benches between Tcr and Qtv in cliffs of Columbia River Gorge; deeply weathered; local mass movement.*

Pliocene Columbia River deposits *(excluding those mapped as part of Dalles Formation):*

Tpt — Troutdale Formation: *Semi-consolidated conglomerate, yellow grit and sandstone, and pebble beds forming local benches between Tcr and QTv in cliffs of the Columbia River Gorge; contains quartzite pebbles indicative of Columbia River provenance; deeply weathered; local mass movement.*

Miocene flood basalts:

Tcr — Columbia River Basalt: *Extensive flows of dense, dark-gray basaltic lava of upper and middle Yakima Basalt; pillowed lavas, tuffs, and thin interbeds locally; average flow thickness 80 feet; extensive scabland topography at lower elevations; deep, fault-controlled bedrock failures on steep valley sides.*

Early Miocene volcaniclastic rock:

Tme — Eagle Creek Formation: *Hard, stream-deposited sandstone and conglomerate, and semi-consolidated debris flows and tuff breccias derived from scattered volcanic centers north of Columbia River; exposed in uplifted core of Cascade Range; a variety of extensive deep bedrock slumps; stable in places.*

Eocene volcanic rock:

Teo — Ohanapecosh Formation (not exposed in study area): *Impermeable clay-altered and zeolite-cemented volcanic and volcaniclastic rocks and related saprolitic clays; inferred in shallow sub-surface of study area on basis of scattered Ohanapecosh-like material in massive bedrock slumps and nearby exposures on north side of Columbia River; instrumental in generation of massive bedrock slumps in Cascade Locks area.*

Intrusive igneous rock:

QTi — Quaternary and Pliocene intrusive rock: *Wide variety of basaltic and dioritic intrusive rocks which fed QTv vents throughout Quaternary and Pliocene; dense and coarsely jointed in places; includes Shellrock Mountain and quarry rocks east of Cascade Locks; no local vents for Tcr are recognized.*

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- Definite contact
- Approximate contact

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- Concealed fault
- Normal fault *(ball and bar on downthrown side)*

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- Definite anticline
- Definite syncline
- Approximate anticline
- Approximate syncline
- Inferred anticline
- Inferred syncline
- Concealed anticline
- Concealed syncline

Bedding
- Strike and dip of bed
- Strike of vertical bed
- Horizontal bed

Spring

Base Map from USGS 15' series (Topographic)
Control by USGS and USC&GS

Topography from aerial photographs by ER-55 plotter
Aerial photographs taken 1955. Field check 1957

Hydrography compiled from USC&GS chart 6157 (1953)

Polyconic projection. 1927 North American datum
10,000 foot grids based on Oregon coordinate system, north zone, and Washington coordinate system, south zone
1000 meter Universal Transverse Mercator grid ticks, zone 10, shown in blue

Oregon-Washington boundary by interstate agreement December 1956. Subject to ratification

Dashed land lines indicate approximate locations
Land lines unsurveyed in T. 1 N.-R. 7 E., and in parts of T. 2 N.-R. 7 E., T. 1 N.-R. 8 E., and T. 1 S.-R. 7 and 8 E.

Unchecked elevations are shown in brown

APPROXIMATE MEAN DECLINATION, 1957

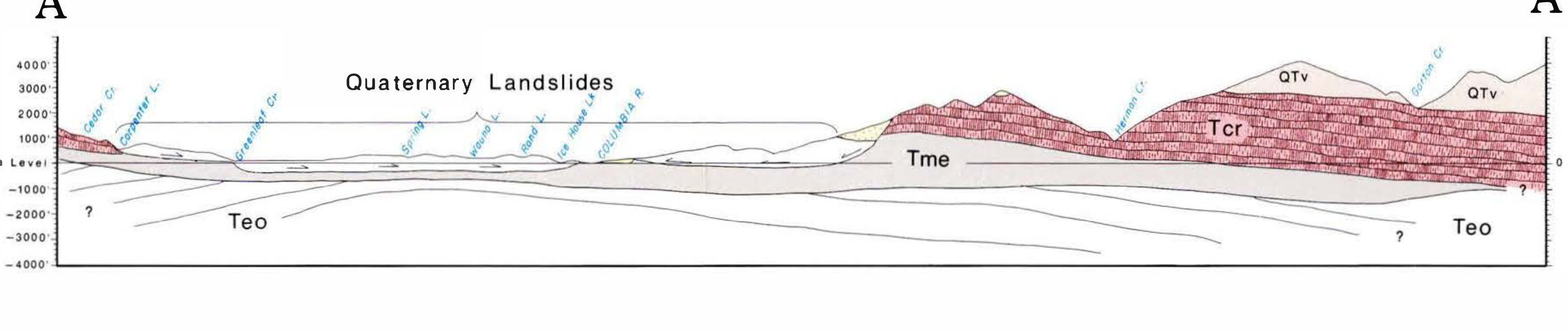
CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS BONNEVILLE NORMAL POOL LEVEL ELEVATION 72 FEET

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

Prepared and Published by the Cartographic Section of the Department of Geology and Mineral Industries R. E. Corcoran, State Geologist, S. R. Renoud, Chief Cartographer.

Geologic Cross Sections



Cartography by S. R. Renoud and C. A. Schumacher, 1977

Bedrock Geology: modified after Allen, 1932 by J. D. Beaulieu, 1977 on the Bonneville Dam sheet; by J. D. Beaulieu, 1977 on the Wasco sheet
Surficial Geology by J. D. Beaulieu, 1977

GEOLOGIC HAZARD MAP of the parts of WASCO & BONNEVILLE DAM QUADRANGLES OREGON

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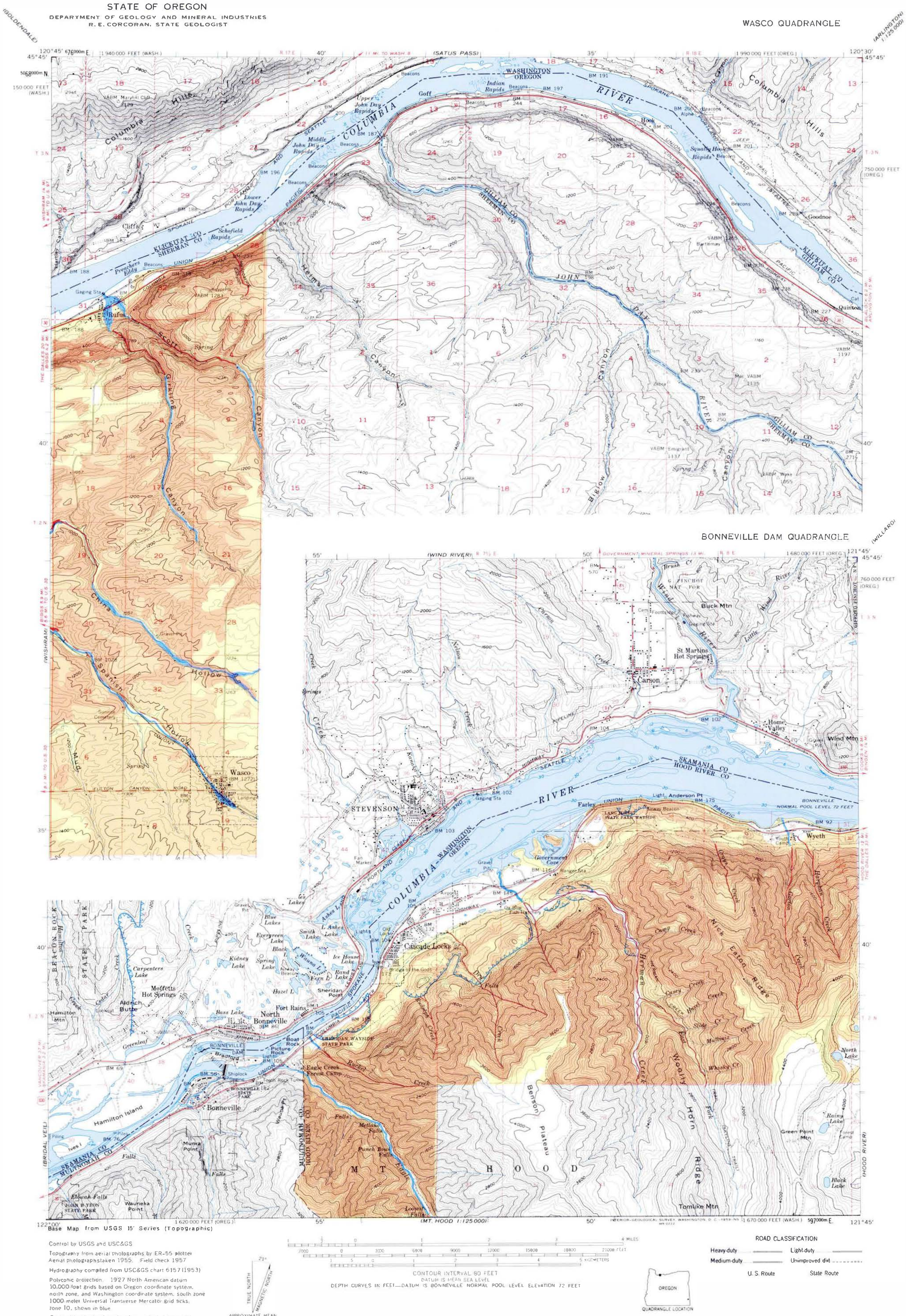

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EXPLANATION

(Boundaries are approximate; statements are general; site evaluations require on-site investigation)

Average (Regional) Slope

Interpreted from maps with scale 1:62,500

0-5% — 0-15% slopes locally; landforms include valley bottomland, some ridge crests, and scablands locally; hazards local and include stream-bank erosion, flooding, and high ground water; land-use potential excellent in areas of minimal hazard.

5-15% — 0-50% slopes locally; landforms include gentle hills and ridge crests; hazards include moderate erosion potential in unvegetated areas; land-use potential good; primarily devoted to agriculture.

15-30% — 0-50% slopes locally; landforms include rolling hills devoted to agriculture; hazards include soil creep and moderate slope erosion potential; land-use potential variable.

30-50% — Greater than 50% slopes locally; landforms include valleys of major streams, volcanic accumulations, and major canyons; hazards include earthflow and slump, severe erosion potential, and creep; land-use potential generally limited to very sparse development and well-managed forestry.

>50% — 50% to vertical locally; landforms include steep canyons, talus, and cliffs in the Cascades and Columbia River Gorge area; local hazards include rockfall, rockslide, debris flow, and severe erosion potential; land-use generally restricted to well-managed forestry and open space.

Geologic Hazards

Mass Movement

Deep bedrock slides: Large downdropped blocks of bedrock both active and inactive; recognized by large-scale topographic irregularities and displacement of bedrock units; distribution generally determined by faults, joints, or incompetent interbeds or formations; possible hazards may include continued sliding, variable foundation strength, variable cutbank stability, poor drainage, and others; potential for development highly variable.

Earthflow and slump topography (areas less than 10-20 acres not shown): Moderately sloping terrain with irregularities of slope, drainage, or soil distribution; recent movement, if present, shown by tension cracks, bowed trees, and others; most common in areas of stream-bank erosion or active headward migration of streams; possible hazards may include continued movement, low cutback stability, poor drainage, and others; development possible locally, but generally may reactivate or accelerate sliding.

Steep slope mass movement: Areas subject to localized debris flow, rockfall, or rockslide; specific locations a function of rock type and structure, jointing, soil properties, soil thickness, root support, vegetative cover, and others; mitigation may include structural solutions, drainage control, and appropriate land-use and forest-management practices.

Thick talus: Uniformly sloping rock and soil debris accumulating at base of cliffs primarily by rockfall and rockslide; associated hazards include shallow subsurface runoff, low cutbank stability especially in wet season, and debris flows either in talus or emanating from upslope canyons; deep cuts and development generally not recommended.

Potential future mass movement: In addition to active slides, areas of highest potential for future mass movement through improper or changing land use include faults in Tcr, moderately sloping to steeply sloping or gently dipping Tpd in areas of increased infiltration, cuts in deep talus and steep slopes of unconsolidated material, and steep slopes in devegetated areas; delineation requires detailed mapping on larger scale than that of this study.

Flooding

Lowland flooding: Areas for which historic flooding is interpreted on basis of surficial unit distribution, soils, landforms, driftwood, and protective structures; minor flooding along smaller streams not shown owing to limitations of scale; statistical flood distributions not available.

Torrential flooding: Areas of high probability for floods characterized by rapidly flowing water with high channel and stream-bank erosion potential in narrow canyons with little or no floodplain; generally restricted to short, high-gradient streams flowing through steep terrain of high relief into Columbia River; channel deposits generally very coarse, angular, and poorly sorted.

Erosion

Slope erosion: Loss of soil material by moving water on slopes; favored by sandy or silty soils, lack of consolidation, slope gradient, slope length, and absence of vegetation or other protective cover; removes valuable topsoil and causes deposition downslope; may cause siltation of streams, municipal water supplies, or other structures or developments; wide variety of engineering and land management techniques for control.

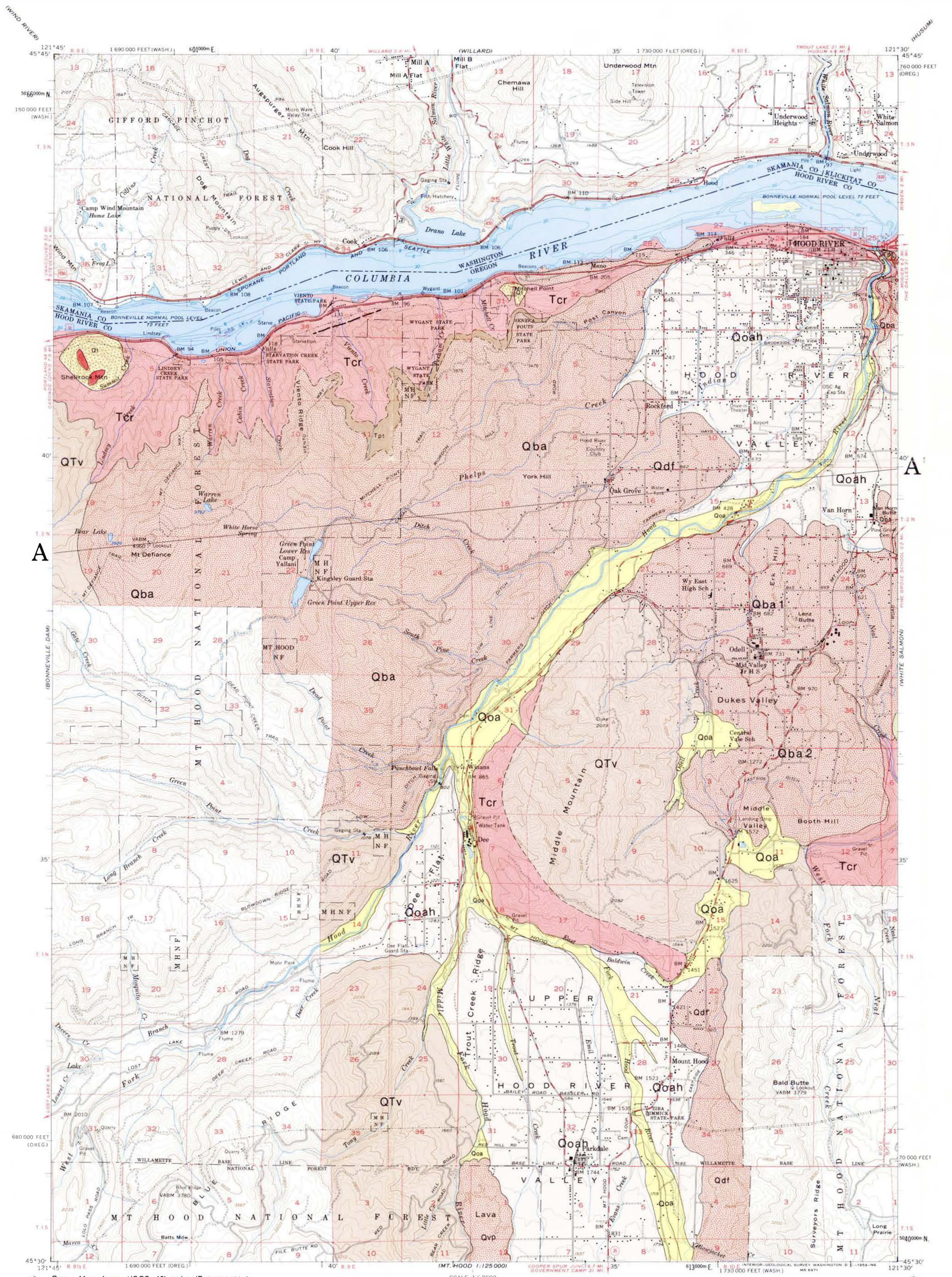
Critical stream-bank erosion (not including torrential flood channels): Undercutting and caving of river and stream banks by stream action; restricted primarily to outer bends of meanders on larger streams; characterized by steep slopes, deep water near shore, and actively growing bar or bars on inner bend; mitigation may include riprap, channel modification, and land-use restrictions depending on local hydraulics, desired land use, and erosion rates.

Prepared and Published by the Cartographic Section of the Department of Geology and Mineral Industries R. E. Corcoran, State Geologist, S. R. Renoud, Chief Cartographer.

Geologic Hazards by J. D. Beaulieu, 1977
Cartography and Slope Interpretation by C. A. Schumacher, 1977
Edited by S. R. Renoud, 1977

GEOLOGIC MAP of the HOOD RIVER QUADRANGLE OREGON

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



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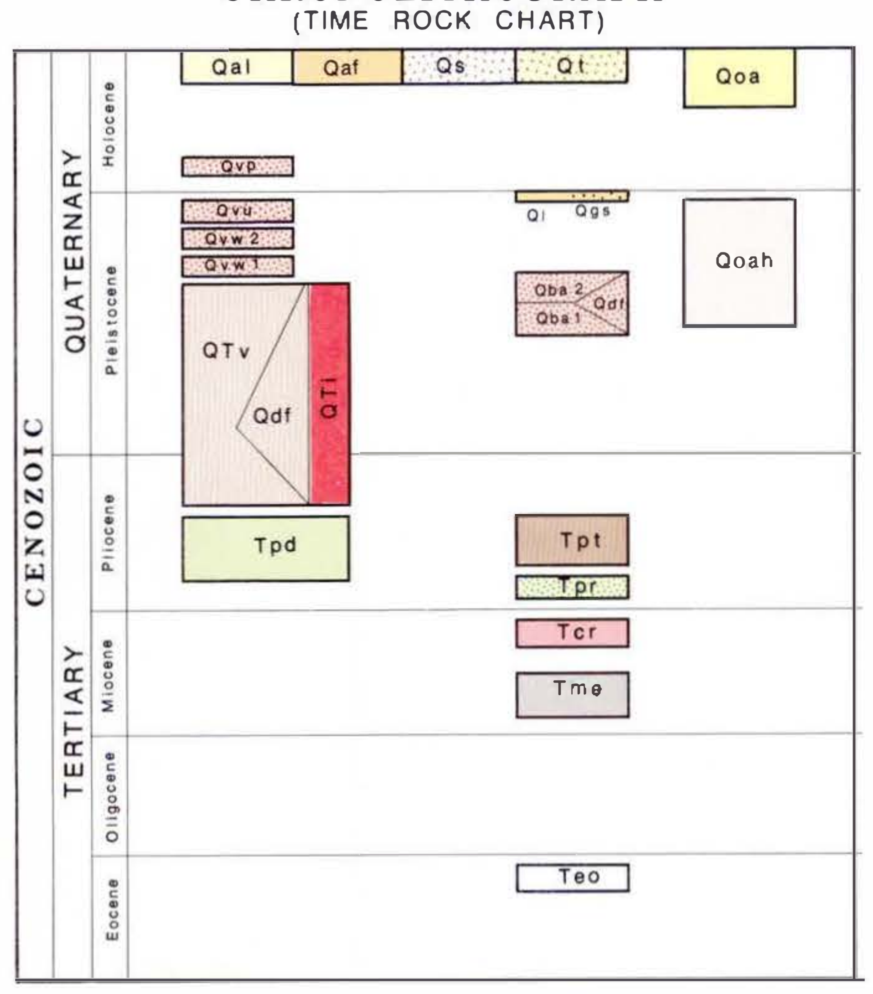

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- Strike and dip of bed
- Strike of vertical bed
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Base Map from USGS 15' series (Topographic)

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Red tint indicates areas in which only landmark buildings are shown

Dashed land lines indicate approximate locations

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TRUE NORTH — MAGNETIC NORTH — 21°
APPROXIMATE MEAN DECLINATION, 1957

SCALE 1:62500

1 ½ 0 1 2 3 4 MILES
3000 0 3000 6000 9000 12000 15000 18000 21000 FEET
1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 80 FEET
DOTTED LINES REPRESENT 40-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS BONNEVILLE NORMAL POOL LEVEL ELEVATION 72 FEET

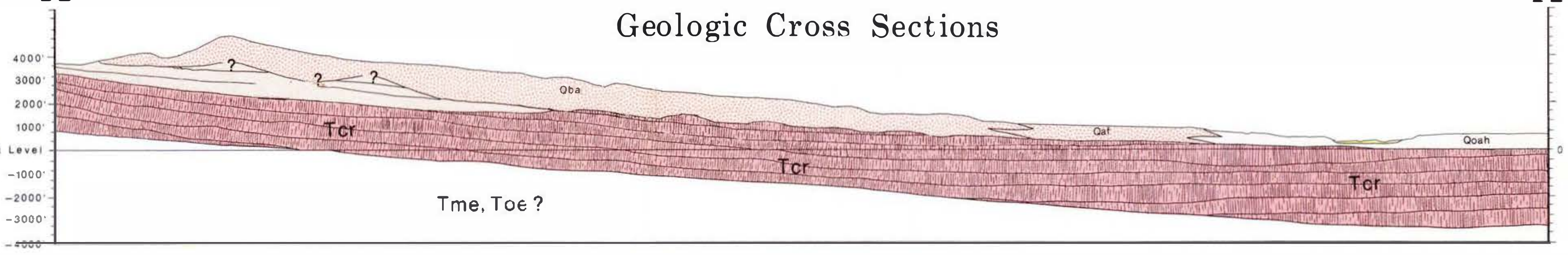
ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

OREGON
QUADRANGLE LOCATION

Prepared and Published by the Cartographic Section of the Department of Geology and Mineral Industries R. E. Corcoran, State Geologist, S. R. Renoud, Chief Cartographer.

A — A'

Geologic Cross Sections



Cartography by S. R. Renoud and C. A. Schumacher, 1977

Bedrock Geology modified after Waters, 1973 and Sceva, 1966 by J.D. Beaulieu, 1977
Surficial Geology by J. D. Beaulieu, 1977

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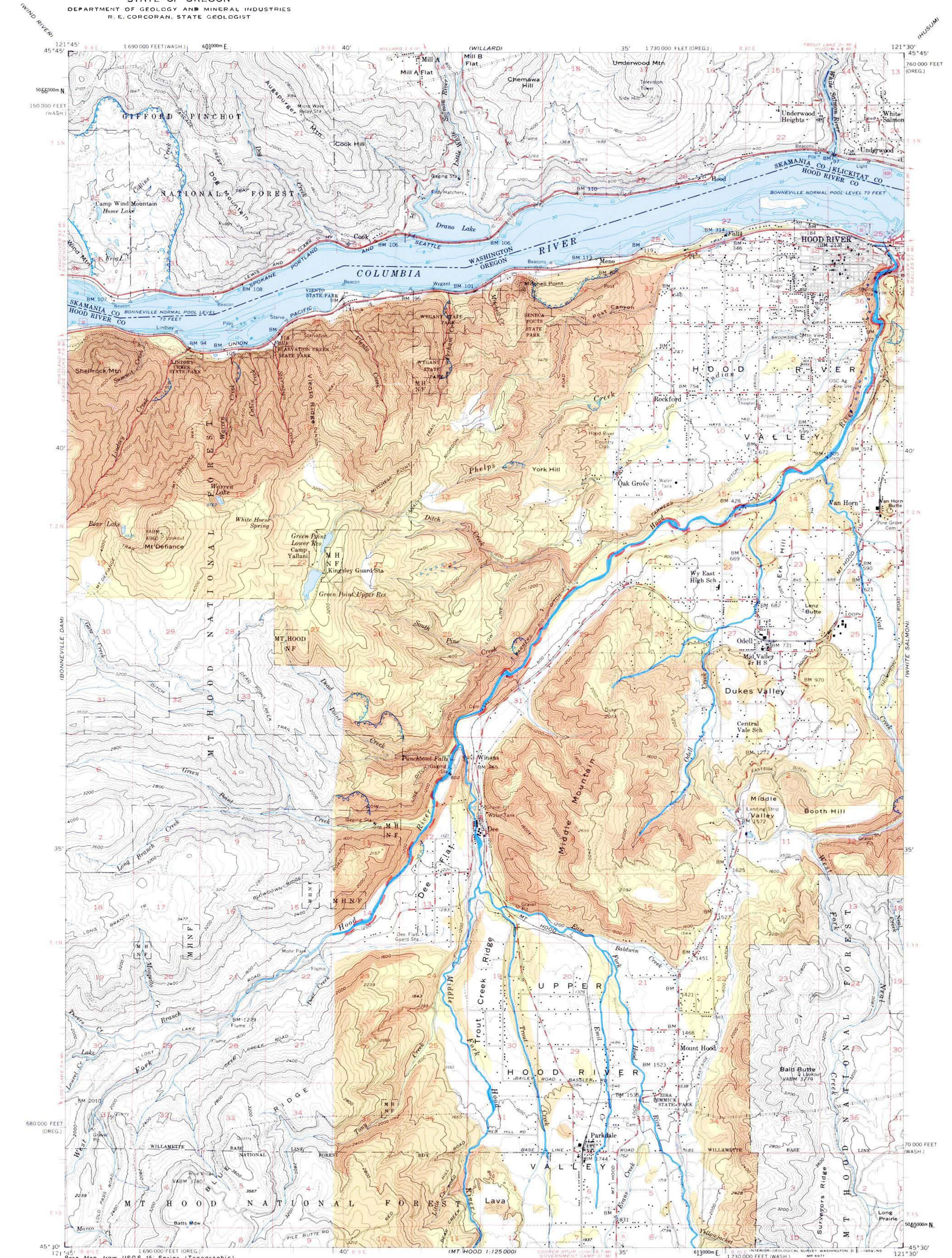
R. E. CORCORAN, STATE GEOLOGIST



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15-30% 0-50% slopes locally; landforms include rolling hills devoted to agriculture; hazards include soil creep and moderate slope erosion potential; land-use potential variable.

30-50% Greater than 50% slopes locally; landforms include valleys of major streams, volcanic accumulations, and major canyons; hazards include earthflow and slump, severe erosion potential, and creep; land-use potential generally limited to very sparse development and well-managed forestry.

>50% 50% to vertical locally; landforms include steep canyons, talus, and cliffs in the Cascades and Columbia River Gorge area; local hazards include rockfall, rockslide, debris flow, and severe erosion potential; land-use generally restricted to well-managed forestry and open space.

Geologic Hazards

Mass Movement

Deep bedrock slides: Large downdropped blocks of bedrock both active and inactive; recognized by large-scale topographic irregularities and displacement of bedrock units; distribution generally determined by faults, joints, or incompetent interbeds or formations; possible hazards may include continued sliding, variable foundation strength, variable cutbank stability, poor drainage, and others; potential for development highly variable.

Earthflow and slump topography (areas less than 10-20 acres not shown): Moderately sloping terrain with irregularities of slope, drainage, or soil distribution; recent movement, if present, shown by tension cracks, bowed trees, and others; most common in areas of stream-bank erosion or active headward migration of streams; possible hazards may include continued movement, low cutback stability, poor drainage, and others; development possible locally, but generally may reactivate or accelerate sliding.

Steep slope mass movement: Areas subject to localized debris flow, rockfall, or rockslide; specific locations a function of rock type and structure, jointing, soil properties, soil thickness, root support, vegetative cover, and others; mitigation may include structural solutions, drainage control, and appropriate land-use and forest-management practices.

Thick talus: Uniformly sloping rock and soil debris accumulating at base of cliffs primarily by rockfall and rockslide; associated hazards include shallow subsurface runoff, low cutbank stability especially in wet season, and debris flows either in talus or emanating from upslope canyons; deep cuts and development generally not recommended.

Potential future mass movement: In addition to active slides, areas of highest potential for future mass movement through improper or changing land use include faults in Tcr, moderately sloping to steeply sloping or gently dipping Tpd in areas of increased infiltration, cuts in deep talus and steep slopes of unconsolidated material, and steep slopes in devegetated areas; delineation requires detailed mapping on larger scale than that of this study.

Flooding

Lowland flooding: Areas for which historic flooding is interpreted on basis of surficial unit distribution, soils, landforms, driftwood, and protective structures; minor flooding along smaller streams not shown owing to limitations of scale; statistical flood distributions not available.

Torrential flooding: Areas of high probability for floods characterized by rapidly flowing water with high channel and stream-bank erosion potential in narrow canyons with little or no floodplain; generally restricted to short, high-gradient streams flowing through steep terrain of high relief into Columbia River; channel deposits generally very coarse, angular, and poorly sorted.

Erosion

Slope erosion: Loss of soil material by moving water on slopes; favored by sandy or silty soils, lack of consolidation, slope gradient, slope length, and absence of vegetation or other protective cover; removes valuable topsoil and causes deposition downslope; may cause siltation of streams, municipal water supplies, or other structures or developments; wide variety of engineering and land management techniques for control.

Critical stream-bank erosion (not including torrential flood channels): Undercutting and caving of river and stream banks by stream action; restricted primarily to outer bends of meanders on larger streams; characterized by steep slopes, deep water near shore, and actively growing bar or bars on inner bend; mitigation may include riprap, channel modification, and land-use restrictions depending on local hydraulics, desired land use, and erosion rates.

Prepared and Published by the Cartographic Section of the Department of Geology and Mineral Industries R. E. Corcoran, State Geologist, S. R. Renoud, Chief Cartographer.

Geologic Hazards by J. D. Beaulieu, 1977
Cartography and Slope Interpretation by C. A. Schumacher, 1977
Edited by S. R. Renoud, 1977

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

GEOLOGIC MAP of the THE DALLES QUADRANGLE OREGON

Base Map from USGS 15' series (Topographic)

Control by USGS, USC&GS, and State of Oregon

Topography from aerial photographs by ER-55 plotter
Aerial photographs taken 1955. Field check 1957

Polyconic projection. 1927 North American datum
10,000-foot grids based on Oregon coordinate system, north zone, and Washington coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue

Oregon-Washington boundary by interstate agreement December 1956. Subject to ratification

Dashed land lines indicate approximate locations

Hydrography compiled from USC&GS chart 6157 (1953)

Red tint indicates areas in which only landmark buildings are shown

Unchecked elevations are shown in brown

APPROXIMATE MEAN DECLINATION, 1957

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS BONNEVILLE NORMAL POOL LEVEL

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route

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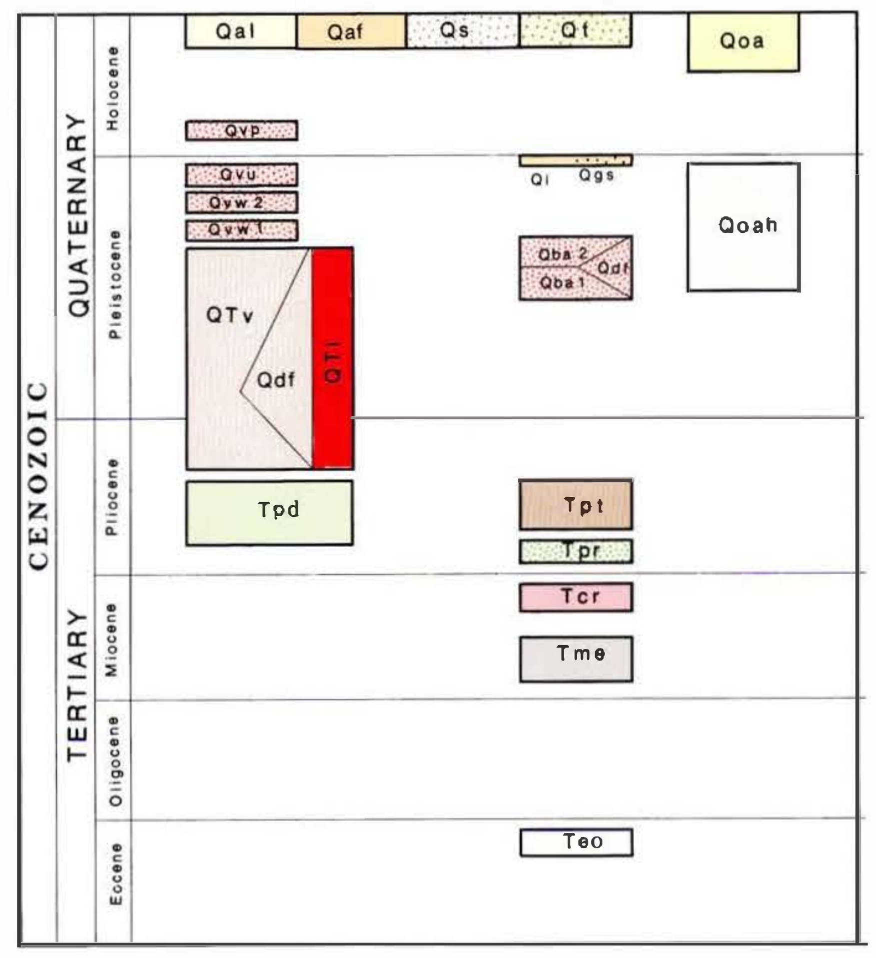
CHRONOLITHOGRAPH
(TIME ROCK CHART)



EXPLANATION

(Boundaries are approximate; statements are general; site evaluations require on-site investigation)

Surficial Geologic Units

Stream deposits:

Qal Quaternary alluvium: *Unconsolidated gravel, sand, silt, and clay in stream beds and floodplains of major streams; equivalent to part of Qya of Newcomb (1969); not shown along smaller streams owing to limitations of scale; subject to stream flooding.*

Qoa Quaternary older alluvium: *Unconsolidated gravel, sand, silt, and clay located above floodplains of major streams and as valley fill of smaller stream valleys; equivalent to Qoa and part of Qya of Newcomb (1969); includes several terrace levels of varying ages; generally not subject to flooding except in smaller drainages where scale precludes separate mapping of Qal.*

Qaf Quaternary alluvial fan deposits: *Unconsolidated, poorly sorted gravel and sand occurring as fan deposits at mouths of torrential flood channels; subject to torrential flooding, erosion, and deposition.*

Qoah Quaternary older alluvium of Hood River Valley: *Unconsolidated glacial outwash and minor interbedded lacustrine deposits and debris flows filling Hood River Valley; includes basal conglomerate and fluvial sand at Hood River.*

Wind deposits:

Qs Quaternary eolian sand: *Unconsolidated medium-grained dune sand derived from wind erosion of Pleistocene flood deposits; migrating downslope and eastward in area immediately east of Biggs.*

Slide deposits *(excluding deep bedrock failures and soil failures; see geologic hazards maps):*

Qt Quaternary thick talus: *Uniformly sloping unconsolidated rock and soil debris accumulating at base of cliffs primarily by rockfall and rock slide; estimated thickness generally greater than 50 feet; numerous associated hazards.*

Pleistocene flood deposits:

Qgs / Ql Quaternary glacial flood gravel and sand (Qgs) and silt (Ql): *Unconsolidated gravel, sand, and silt scoured from nearby upstream terrain (now scabland) by glacial meltwaters of upper Columbia River drainage and deposited locally in protected areas; also includes unmapped erratics to a maximum elevation of 1150 feet. Much thin loessal material east of The Dalles included in underlying bedrock units.*

Bedrock Geologic Units

High Cascades volcanic rock:

QTv (Qba, Qvw 2, Qvw 1, Qvu, Qvp, Qdf) Cascades Formation: *Basaltic and andesitic flow rock, agglomerate, tuff breccia, and debris flows of High Cascades volcanic peaks; includes relatively young vents and intracanyon flows in Mount Defiance area and Hood River Valley (Qba), Wind River (Qvw1, Qvw2), Underwood (Qvu), and Parkdale (Qvp) areas; also includes debris flows in Hood River Valley (Qdf) and intracanyon flows (now ridge crests) south and east of The Dalles (QTv); engineering properties and hazards variable. An older Qba unit (Qba1) and a younger unit (Qba2) are mapped near Odell.*

Pliocene volcanic rocks:

Tpd Dalles Formation: *Thickly bedded andesitic ash-flow tuffs, tuff breccia, agglomerate, and flow rock, with interbedded conglomerate south of Mosier and The Dalles, grading eastward into thinner stream-deposited sands and silts with minor volcanic rock; interbedded with Columbia River conglomerates locally; thick soils east of The Dalles include eolian and lacustrine deposits; large, deep bedrock slumps in places; slump and earthflow potential locally, especially in areas of changing land use.*

Tpr Rhododendron Formation: *Tuff breccia, agglomerate, and ash of local extent, forming benches between Tcr and Qtv in cliffs of Columbia River Gorge; deeply weathered; local mass movement.*

Pliocene Columbia River deposits *(excluding those mapped as part of Dalles Formation):*

Tpt Troutdale Formation: *Semi-consolidated conglomerate, yellow grit and sandstone, and pebble beds forming local benches between Tcr and QTv in cliffs of the Columbia River Gorge; contains quartzite pebbles indicative of Columbia River provenance; deeply weathered; local mass movement.*

Miocene flood basalts:

Tcr Columbia River Basalt: *Extensive flows of dense, dark-gray basaltic lava of upper and middle Yakima Basalt; pillowed lavas, tuffs, and thin interbeds locally; average flow thickness 80 feet; extensive scabland topography at lower elevations; deep, fault-controlled bedrock failures on steep valley sides.*

Early Miocene volcaniclastic rock:

Tme Eagle Creek Formation: *Hard, stream-deposited sandstone and conglomerate, and semi-consolidated debris flows and tuff breccias derived from scattered volcanic centers north of Columbia River; exposed in uplifted core of Cascade Range; a variety of extensive deep bedrock slumps; stable in places.*

Eocene volcanic rock:

Teo Ohanapecosh Formation (*not exposed in study area*): *Impermeable clay-altered and zeolite-cemented volcanic and volcaniclastic rocks and related saprolitic clays; inferred in shallow sub-surface of study area on basis of scattered Ohanapecosh-like material in massive bedrock slumps and nearby exposures on north side of Columbia River; instrumental in generation of massive bedrock slumps in Cascade Locks area.*

Intrusive igneous rock:

QTi Quaternary and Pliocene intrusive rock: *Wide variety of basaltic and dioritic intrusive rocks which fed QTv vents throughout Quaternary and Pliocene; dense and coarsely jointed in places; includes Shellrock Mountain and quarry rocks east of Cascade Locks; no local vents for Tcr are recognized.*

GEOLOGIC SYMBOLS

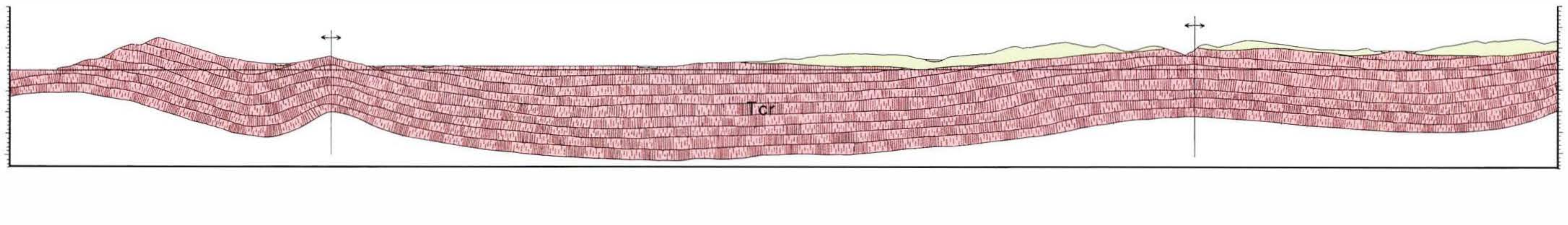
Contacts
- Definite contact
- Approximate contact

Faults
- Definite fault
- Approximate fault
- Inferred fault
- Concealed fault
- Normal fault (ball and bar on downthrown side)

Folds
- Definite anticline
- Definite syncline
- Approximate anticline
- Approximate syncline
- Inferred anticline
- Inferred syncline
- Concealed anticline
- Concealed syncline

Bedding
- Strike and dip of bed
- Strike of vertical bed
- Horizontal bed

- Spring

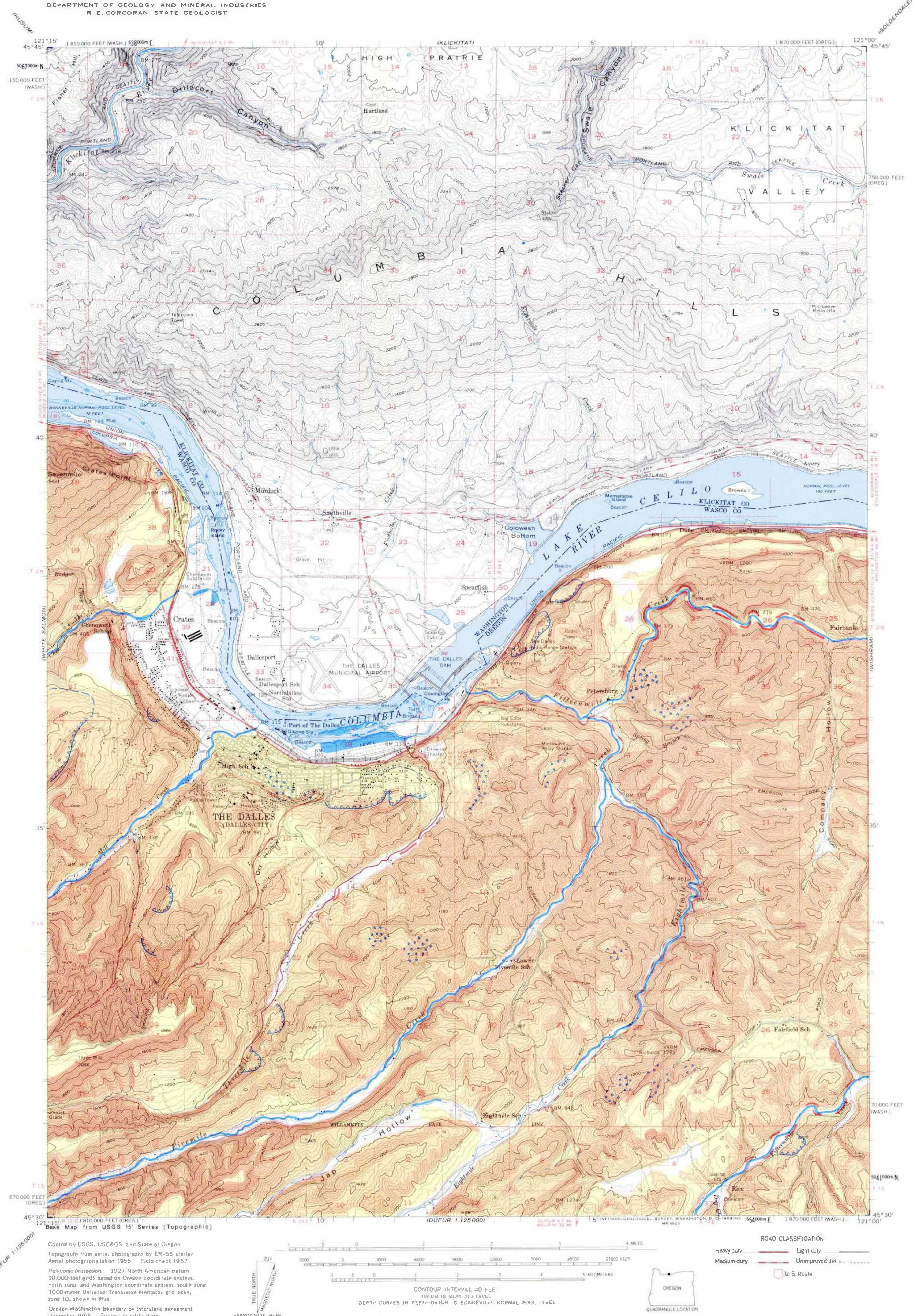


Cartography by S. R. Renoud and C. A. Schumacher, 1977

Bedrock Geology from Newcomb, 1969
Surficial Geology modified after Newcomb, 1969 by J. D. Beaulieu, 1977

GEOLOGIC HAZARD MAP of the THE DALLES QUADRANGLE OREGON

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



Control by USGS, USC&GS, and State of Oregon

Topography from aerial photographs by ER-55 plotter
Aerial photographs taken 1955 Field check 1957

Polyconic projection 1927 North American datum
10,000-foot grids based on Oregon coordinate system, north zone, and Washington coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue

Oregon-Washington boundary by interstate agreement December 1956 Subject to ratification
Dashed land lines indicate approximate locations

Hydrography compiled from USC&GS chart 6157 (1953)

Red tint indicates areas in which only landmark buildings are shown
Unchecked elevations are shown in brown

EXPLANATION

(Boundaries are approximate: statements are general: site evaluations require on-site investigation)

Average (Regional) Slope

Interpreted from maps with scale 1:62,500

0-5%	0-15% slopes locally; landforms include valley bottomland, some ridge crests, and scablands locally; hazards local and include stream-bank erosion, flooding, and high ground water; land-use potential excellent in areas of minimal hazard.
5-15%	0-50% slopes locally; landforms include gentle hills and ridge crests; hazards include moderate erosion potential in unvegetated areas; land-use potential good; primarily devoted to agriculture.
15-30%	0-50% slopes locally; landforms include rolling hills devoted to agriculture; hazards include soil creep and moderate slope erosion potential; land-use potential variable.
30-50%	Greater than 50% slopes locally; landforms include valleys of major streams, volcanic accumulations, and major canyons; hazards include earthflow and slump, severe erosion potential, and creep; land-use potential generally limited to very sparse development and well-managed forestry.
>50%	50% to vertical locally; landforms include steep canyons, talus, and cliffs in the Cascades and Columbia River Gorge area; local hazards include rockfall, rockslide, debris flow, and severe erosion potential; land-use generally restricted to well-managed forestry and open space.

Geologic Hazards

Mass Movement

Deep bedrock slides: Large downdropped blocks of bedrock both active and inactive; recognized by large-scale topographic irregularities and displacement of bedrock units; distribution generally determined by faults, joints, or incompetent interbeds or formations; possible hazards may include continued sliding, variable foundation strength, variable cutbank stability, poor drainage, and others; potential for development highly variable.

Earthflow and slump topography (areas less than 10-20 acres not shown): Moderately sloping terrain with irregularities of slope, drainage, or soil distribution; recent movement, if present, shown by tension cracks, bowed trees, and others; most common in areas of stream-bank erosion or active headward migration of streams; possible hazards may include continued movement, low cutback stability, poor drainage, and others; development possible locally, but generally may reactivate or accelerate sliding.

Steep slope mass movement: Areas subject to localized debris flow, rockfall, or rockslide; specific locations a function of rock type and structure, jointing, soil properties, soil thickness, root support, vegetative cover, and others; mitigation may include structural solutions, drainage control, and appropriate land-use and forest-management practices.

Thick talus: Uniformly sloping rock and soil debris accumulating at base of cliffs primarily by rockfall and rockslide; associated hazards include shallow subsurface runoff, low cutbank stability especially in wet season, and debris flows either in talus or emanating from upslope canyons; deep cuts and development generally not recommended.

Potential future mass movement: In addition to active slides, areas of highest potential for future mass movement through improper or changing land use include faults in Tcr, moderately sloping to steeply sloping or gently dipping Tpd in areas of increased infiltration, cuts in deep talus and steep slopes of unconsolidated material, and steep slopes in devegetated areas; delineation requires detailed mapping on larger scale than that of this study.

Flooding

Lowland flooding: Areas for which historic flooding is interpreted on basis of surficial unit distribution, soils, landforms, driftwood, and protective structures; minor flooding along smaller streams not shown owing to limitations of scale; statistical flood distributions not available.

Torrential flooding: Areas of high probability for floods characterized by rapidly flowing water with high channel and stream-bank erosion potential in narrow canyons with little or no floodplain; generally restricted to short, high-gradient streams flowing through steep terrain of high relief into Columbia River; channel deposits generally very coarse, angular, and poorly sorted.

Erosion

Slope erosion: Loss of soil material by moving water on slopes; favored by sandy or silty soils, lack of consolidation, slope gradient, slope length, and absence of vegetation or other protective cover; removes valuable topsoil and causes deposition downslope; may cause siltation of streams, municipal water supplies, or other structures or developments; wide variety of engineering and land management techniques for control.

Critical stream-bank erosion (not including torrential flood channels): Undercutting and caving of river and stream banks by stream action; restricted primarily to outer bends of meanders on larger streams; characterized by steep slopes, deep water near shore, and actively growing bar or bars on inner bend; mitigation may include riprap, channel modification, and land-use restrictions depending on local hydraulics, desired land use, and erosion rates.

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Geologic Hazards by J. D. Beaulieu, 1977
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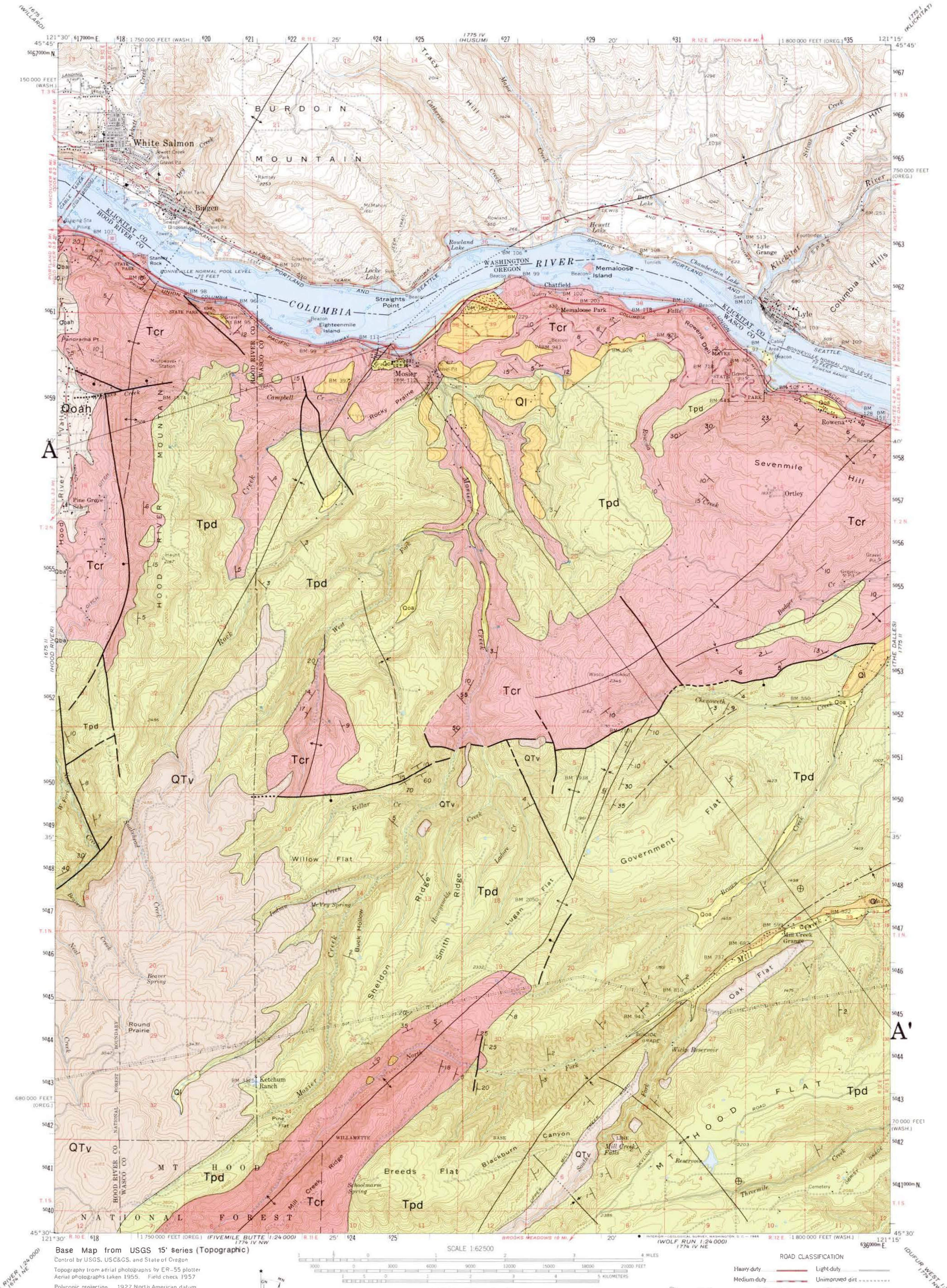
GEOLOGIC MAP of the WHITE SALMON QUADRANGLE OREGON

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



Base Map from USGS 15' series (Topographic)
Control by USGS, USC&GS, and State of Oregon
Topography from aerial photographs by ER–55 plotter. Aerial photographs taken 1955. Field check 1957
Polyconic projection. 1927 North American datum. 10,000-foot grids based on Oregon coordinate system, north zone, and Washington coordinate system, south zone. 1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue
Oregon-Washington boundary by interstate agreement December 1956. Subject to ratification
Hydrography compiled from USC&GS chart 6157 (1953)
Dashed land lines indicate approximate locations
Unchecked elevations are shown in brown

UTM GRID AND 1957 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:62500

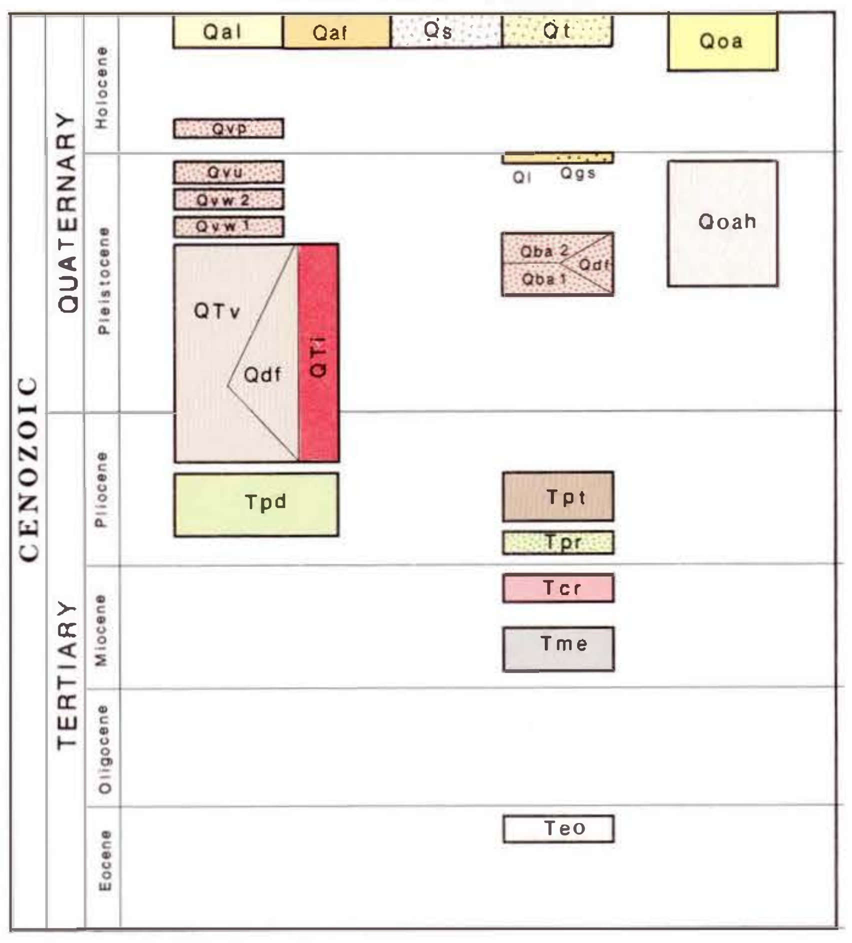
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
DEPTH CURVES 5 FEET—DATUM IS BONNEVILLE NORMAL POOL LEVEL ELEVATION 72 FEET

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

QUADRANGLE LOCATION

Prepared and Published by the Cartographic Section of the Department of Geology and Mineral Industries. R. E. Corcoran, State Geologist, S. R. Renoud, Chief Cartographer.

CHRONOLITHOGRAPH
(TIME ROCK CHART)



EXPLANATION

(Boundaries are approximate; statements are general; site evaluations require on-site investigation)

Surficial Geologic Units

Stream deposits:

Qal — Quaternary alluvium: *Unconsolidated gravel, sand, silt, and clay in stream beds and floodplains of major streams; equivalent to part of Qya of Newcomb (1969); not shown along smaller streams owing to limitations of scale; subject to stream flooding.*

Qoa — Quaternary older alluvium: *Unconsolidated gravel, sand, silt, and clay located above floodplains of major streams and as valley fill of smaller stream valleys; equivalent to Qoa and part of Qya of Newcomb (1969); includes several terrace levels of varying ages; generally not subject to flooding except in smaller drainages where scale precludes separate mapping of Qal.*

Qaf — Quaternary alluvial fan deposits: *Unconsolidated, poorly sorted gravel and sand occurring as fan deposits at mouths of torrential flood channels; subject to torrential flooding, erosion, and deposition.*

Qoah — Quaternary older alluvium of Hood River Valley: *Unconsolidated glacial outwash and minor interbedded lacustrine deposits and debris flows filling Hood River Valley; includes basal conglomerate and fluvial sand at Hood River.*

Wind deposits:

Qs — Quaternary eolian sand: *Unconsolidated medium-grained dune sand derived from wind erosion of Pleistocene flood deposits; migrating downslope and eastward in area immediately east of Biggs.*

Slide deposits *(excluding deep bedrock failures and soil failures; see geologic hazards maps):*

Qt — Quaternary thick talus: *Uniformly sloping unconsolidated rock and soil debris accumulating at base of cliffs primarily by rockfall and rock slide; estimated thickness generally greater than 50 feet; numerous associated hazards.*

Pleistocene flood deposits:

Qgs / Ql — Quaternary glacial flood gravel and sand (Qgs) and silt (Ql): *Unconsolidated gravel, sand, and silt scoured from nearby upstream terrain (now scabland) by glacial meltwaters of upper Columbia River drainage and deposited locally in protected areas; also includes unmapped erratics to a maximum elevation of 1150 feet. Much thin loessal material east of The Dalles included in underlying bedrock units.*

Bedrock Geologic Units

High Cascades volcanic rock:

QTv (Qba, Qvw 2, Qvw 1, Qvu, Qvp, Qdf) — Cascades Formation: *Basaltic and andesitic flow rock, agglomerate, tuff breccia, and debris flows of High Cascades volcanic peaks; includes relatively young vents and intracanyon flows in Mount Defiance area and Hood River Valley (Qba), Wind River (Qvw1, Qvw2), Underwood (Qvu), and Parkdale (Qvp) areas; also includes debris flows in Hood River Valley (Qdf) and intracanyon flows (now ridge crests) south and east of The Dalles (QTv); engineering properties and hazards variable. An older Qba unit (Qba1) and a younger unit (Qba2) are mapped near Odell.*

Pliocene volcanic rocks:

Tpd — Dalles Formation: *Thickly bedded andesitic ash-flow tuffs, tuff breccia, agglomerate, and flow rock, with interbedded conglomerate south of Mosier and The Dalles, grading eastward into thinner stream-deposited sands and silts with minor volcanic rock; interbedded with Columbia River conglomerates locally; thick soils east of The Dalles include eolian and lacustrine deposits; large, deep bedrock slumps in places; slump and earthflow potential locally, especially in areas of changing land use.*

Tpr — Rhododendron Formation: *Tuff breccia, agglomerate, and ash of local extent, forming benches between Tcr and QTv in cliffs of Columbia River Gorge; deeply weathered; local mass movement.*

Pliocene Columbia River deposits *(excluding those mapped as part of Dalles Formation):*

Tpt — Troutdale Formation: *Semi-consolidated conglomerate, yellow grit and sandstone, and pebble beds forming local benches between Tcr and QTv in cliffs of the Columbia River Gorge; contains quartzite pebbles indicative of Columbia River provenance; deeply weathered; local mass movement.*

Miocene flood basalts:

Tcr — Columbia River Basalt: *Extensive flows of dense, dark-gray basaltic lava of upper and middle Yakima Basalt; pillowed lavas, tuffs, and thin interbeds locally; average flow thickness 80 feet; extensive scabland topography at lower elevations; deep, fault-controlled bedrock failures on steep valley sides.*

Early Miocene volcaniclastic rock:

Tme — Eagle Creek Formation: *Hard, stream-deposited sandstone and conglomerate, and semi-consolidated debris flows and tuff breccias derived from scattered volcanic centers north of Columbia River; exposed in uplifted core of Cascade Range; a variety of extensive deep bedrock slumps; stable in places.*

Eocene volcanic rock:

Teo — Ohanapecosh Formation (*not exposed in study area*): *Impermeable clay-altered and zeolite-cemented volcanic and volcaniclastic rocks and related saprolitic clays; inferred in shallow sub-surface of study area on basis of scattered Ohanapecosh-like material in massive bedrock slumps and nearby exposures on north side of Columbia River; instrumental in generation of massive bedrock slumps in Cascade Locks area.*

Intrusive igneous rock:

QTi — Quaternary and Pliocene intrusive rock: *Wide variety of basaltic and dioritic intrusive rocks which fed QTv vents throughout Quaternary and Pliocene; dense and coarsely jointed in places; includes Shellrock Mountain and quarry rocks east of Cascade Locks; no local vents for Tcr are recognized.*

GEOLOGIC SYMBOLS

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Faults
- Definite fault
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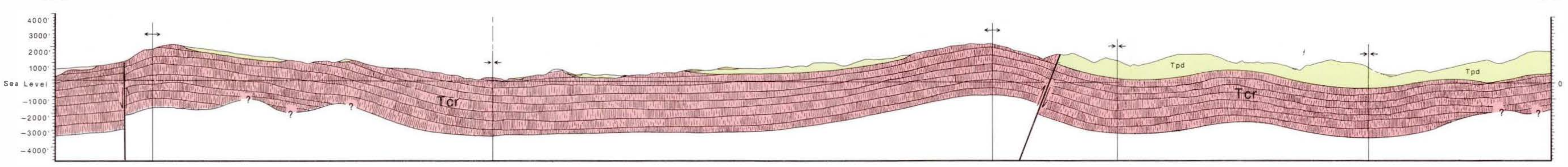
- Approximate syncline
- Inferred anticline
- Inferred syncline
- Concealed anticline
- Concealed syncline

Bedding
- Strike and dip of bed
- Strike of vertical bed
- Horizontal bed

Spring

Geologic Cross Sections



Cartography by S. R. Renoud and C. A. Schumacher, 1977

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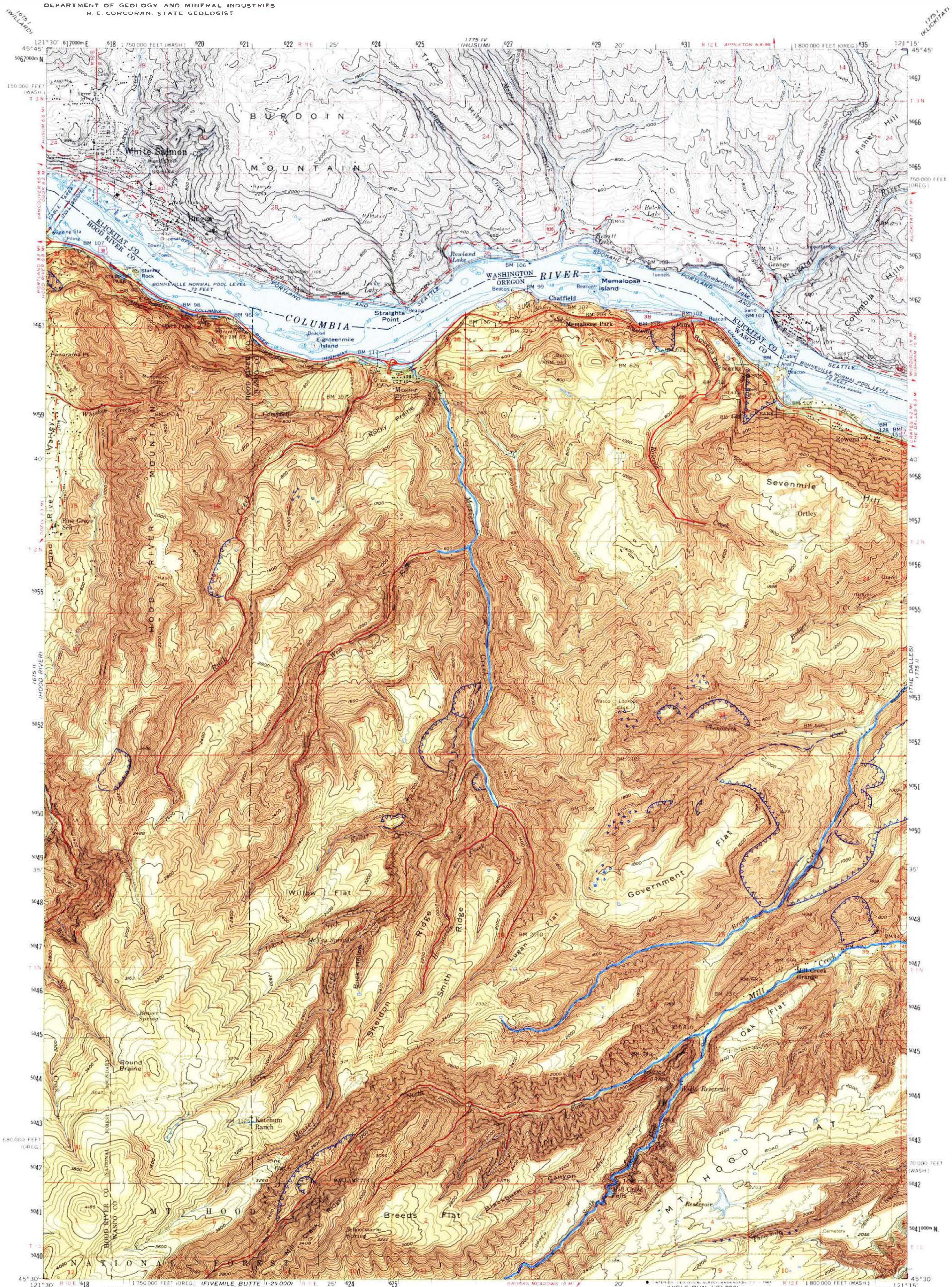
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST



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CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
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ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

QUADRANGLE LOCATION

EXPLANATION

(Boundaries are approximate; statements are general; site evaluations require on-site investigation)

Average (Regional) Slope

Interpreted from maps with scale 1:62,500

0-5% — 0-15% slopes locally; landforms include valley bottomland, some ridge crests, and scablands locally; hazards local and include stream-bank erosion, flooding, and high ground water; land-use potential excellent in areas of minimal hazard.

5-15% — 0-50% slopes locally; landforms include gentle hills and ridge crests; hazards include moderate erosion potential in unvegetated areas; land-use potential good; primarily devoted to agriculture.

15-30% — 0-50% slopes locally; landforms include rolling hills devoted to agriculture; hazards include soil creep and moderate slope erosion potential; land-use potential variable.

30-50% — Greater than 50% slopes locally; landforms include valleys of major streams, volcanic accumulations, and major canyons; hazards include earthflow and slump, severe erosion potential, and creep; land-use potential generally limited to very sparse development and well-managed forestry.

>50% — 50% to vertical locally; landforms include steep canyons, talus, and cliffs in the Cascades and Columbia River Gorge area; local hazards include rockfall, rockslide, debris flow, and severe erosion potential; land-use generally restricted to well-managed forestry and open space.

Geologic Hazards

Mass Movement

Deep bedrock slides: Large downdropped blocks of bedrock both active and inactive; recognized by large-scale topographic irregularities and displacement of bedrock units; distribution generally determined by faults, joints, or incompetent interbeds or formations; possible hazards may include continued sliding, variable foundation strength, variable cutbank stability, poor drainage, and others; potential for development highly variable.

Earthflow and slump topography (areas less than 10-20 acres not shown): Moderately sloping terrain with irregularities of slope, drainage, or soil distribution; recent movement, if present, shown by tension cracks, bowed trees, and others; most common in areas of stream-bank erosion or active headward migration of streams; possible hazards may include continued movement, low cutback stability, poor drainage, and others; development possible locally, but generally may reactivate or accelerate sliding.

Steep slope mass movement: Areas subject to localized debris flow, rockfall, or rockslide; specific locations a function of rock type and structure, jointing, soil properties, soil thickness, root support, vegetative cover, and others; mitigation may include structural solutions, drainage control, and appropriate land-use and forest-management practices.

Thick talus: Uniformly sloping rock and soil debris accumulating at base of cliffs primarily by rockfall and rockslide; associated hazards include shallow subsurface runoff, low cutbank stability especially in wet season, and debris flows either in talus or emanating from upslope canyons; deep cuts and development generally not recommended.

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Slope erosion: Loss of soil material by moving water on slopes; favored by sandy or silty soils, lack of consolidation, slope gradient, slope length, and absence of vegetation or other protective cover; removes valuable topsoil and causes deposition downslope; may cause siltation of streams, municipal water supplies, or other structures or developments; wide variety of engineering and land management techniques for control.

Critical stream-bank erosion (not including torrential flood channels): Undercutting and caving of river and stream banks by stream action; restricted primarily to outer bends of meanders on larger streams; characterized by steep slopes, deep water near shore, and actively growing bar or bars on inner bend; mitigation may include riprap, channel modification, and land-use restrictions depending on local hydraulics, desired land use, and erosion rates.

Prepared and Published by the Cartographic Section of the Department of Geology and Mineral Industries R. E. Corcoran, State Geologist, S. R. Renoud, Chief Cartographer.

Geologic Hazards by J. D. Beaulieu, 1977
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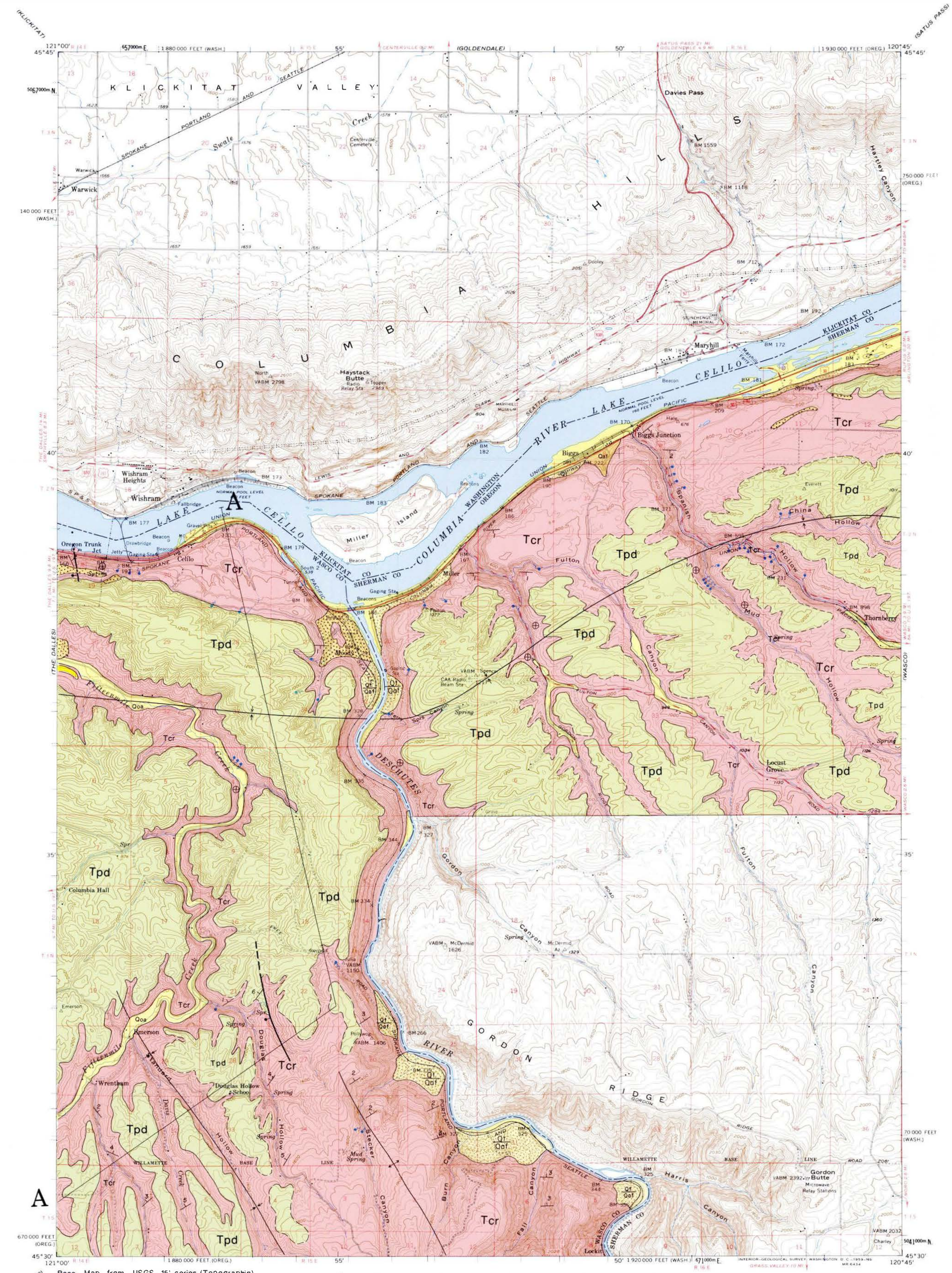
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST

GEOLOGIC MAP of the WISHRAM QUADRANGLE OREGON



Base Map from USGS 15' series (Topographic)
Control by USGS, USC&GS, USCE and State of Oregon
Topography from aerial photographs by ER-55 plotter
Aerial photographs taken 1955. Field check 1957
Polyconic projection. 1927 North American datum
10,000-foot grids based on Oregon coordinate system, north zone, and Washington coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue
Oregon-Washington boundary by interstate agreement December 1956. Subject to ratification

APPROXIMATE MEAN DECLINATION, 1957

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route

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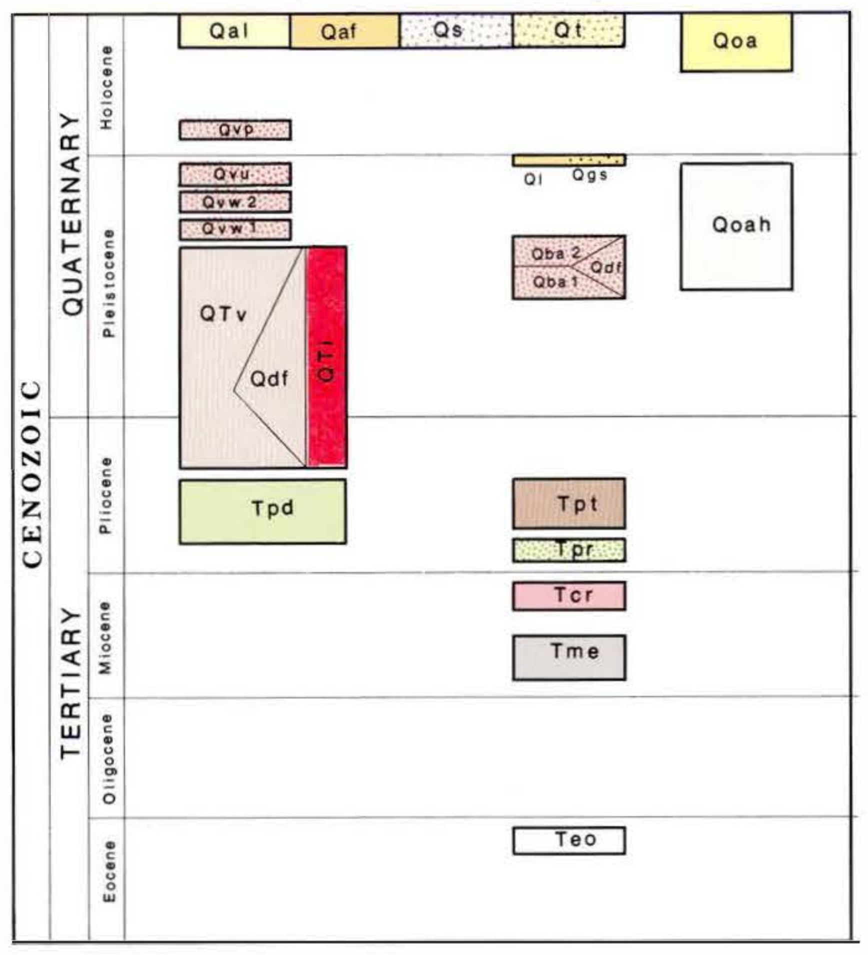
CHRONOLITHOGRAPH
(TIME ROCK CHART)



EXPLANATION

(Boundaries are approximate; statements are general; site evaluations require on-site investigation)

Surficial Geologic Units

Stream deposits:

Qal — Quaternary alluvium: *Unconsolidated gravel, sand, silt, and clay in stream beds and floodplains of major streams; equivalent to part of Qya of Newcomb (1969); not shown along smaller streams owing to limitations of scale; subject to stream flooding.*

Qoa — Quaternary older alluvium: *Unconsolidated gravel, sand, silt, and clay located above floodplains of major streams and as valley fill of smaller stream valleys; equivalent to Qoa and part of Qya of Newcomb (1969); includes several terrace levels of varying ages; generally not subject to flooding except in smaller drainages where scale precludes separate mapping of Qal.*

Qaf — Quaternary alluvial fan deposits: *Unconsolidated, poorly sorted gravel and sand occurring as fan deposits at mouths of torrential flood channels; subject to torrential flooding, erosion, and deposition.*

Qoah — Quaternary older alluvium of Hood River Valley: *Unconsolidated glacial outwash and minor interbedded lacustrine deposits and debris flows filling Hood River Valley; includes basal conglomerate and fluvial sand at Hood River.*

Wind deposits:

Qs — Quaternary eolian sand: *Unconsolidated medium-grained dune sand derived from wind erosion of Pleistocene flood deposits; migrating downslope and eastward in area immediately east of Biggs.*

Slide deposits *(excluding deep bedrock failures and soil failures; see geologic hazards maps):*

Qt — Quaternary thick talus: *Uniformly sloping unconsolidated rock and soil debris accumulating at base of cliffs primarily by rockfall and rock slide; estimated thickness generally greater than 50 feet; numerous associated hazards.*

Pleistocene flood deposits:

Qgs / Ql — Quaternary glacial flood gravel and sand (Qgs) and silt (Ql): *Unconsolidated gravel, sand, and silt scoured from nearby upstream terrain (now scabland) by glacial meltwaters of upper Columbia River drainage and deposited locally in protected areas; also includes unmapped erratics to a maximum elevation of 1150 feet. Much thin loessal material east of The Dalles included in underlying bedrock units.*

Bedrock Geologic Units

High Cascades volcanic rock:

QTv (Qba, Qvw 2, Qvw 1, Qvu, Qvp, Qdf) — Cascades Formation: *Basaltic and andesitic flow rock, agglomerate, tuff breccia, and debris flows of High Cascades volcanic peaks; includes relatively young vents and intracanyon flows in Mount Defiance area and Hood River Valley (Qba), Wind River (Qvw1, Qvw2), Underwood (Qvu), and Parkdale (Qvp) areas; also includes debris flows in Hood River Valley (Qdf) and intracanyon flows (now ridge crests) south and east of The Dalles (QTv); engineering properties and hazards variable. An older Qba unit (Qba1) and a younger unit (Qba2) are mapped near Odell.*

Pliocene volcanic rocks:

Tpd — Dalles Formation: *Thickly bedded andesitic ash-flow tuffs, tuff breccia, agglomerate, and flow rock, with interbedded conglomerate south of Mosier and The Dalles, grading eastward into thinner stream-deposited sands and silts with minor volcanic rock; interbedded with Columbia River conglomerates locally; thick soils east of The Dalles include eolian and lacustrine deposits; large, deep bedrock slumps in places; slump and earthflow potential locally, especially in areas of changing land use.*

Tpr — Rhododendron Formation: *Tuff breccia, agglomerate, and ash of local extent, forming benches between Tcr and Qtv in cliffs of Columbia River Gorge; deeply weathered; local mass movement.*

Pliocene Columbia River deposits *(excluding those mapped as part of Dalles Formation):*

Tpt — Troutdale Formation: *Semi-consolidated conglomerate, yellow grit and sandstone, and pebble beds forming local benches between Tcr and QTv in cliffs of the Columbia River Gorge; contains quartzite pebbles indicative of Columbia River provenance; deeply weathered; local mass movement.*

Miocene flood basalts:

Tcr — Columbia River Basalt: *Extensive flows of dense, dark-gray basaltic lava of upper and middle Yakima Basalt; pillowed lavas, tuffs, and thin interbeds locally; average flow thickness 80 feet; extensive scabland topography at lower elevations; deep, fault-controlled bedrock failures on steep valley sides.*

Early Miocene volcaniclastic rock:

Tme — Eagle Creek Formation: *Hard, stream-deposited sandstone and conglomerate, and semi-consolidated debris flows and tuff breccias derived from scattered volcanic centers north of Columbia River; exposed in uplifted core of Cascade Range; a variety of extensive deep bedrock slumps; stable in places.*

Eocene volcanic rock:

Teo — Ohanapecosh Formation (not exposed in study area): *Impermeable clay-altered and zeolite-cemented volcanic and volcaniclastic rocks and related saprolitic clays; inferred in shallow sub-surface of study area on basis of scattered Ohanapecosh-like material in massive bedrock slumps and nearby exposures on north side of Columbia River; instrumental in generation of massive bedrock slumps in Cascade Locks area.*

Intrusive igneous rock:

QTi — Quaternary and Pliocene intrusive rock: *Wide variety of basaltic and dioritic intrusive rocks which fed QTv vents throughout Quaternary and Pliocene; dense and coarsely jointed in places; includes Shellrock Mountain and quarry rocks east of Cascade Locks; no local vents for Tcr are recognized.*

GEOLOGIC SYMBOLS

Contacts
- Definite contact
- Approximate contact

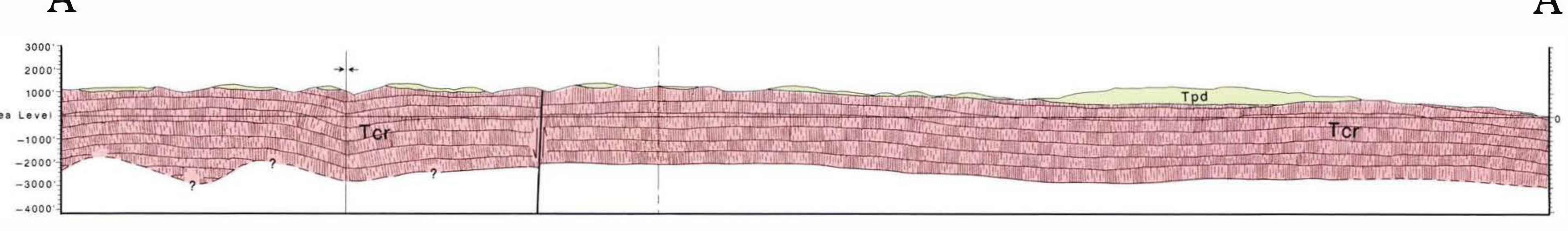
Faults
- Definite fault
- Approximate fault
- Inferred fault
- Concealed fault
- Normal fault *(ball and bar on downthrown side)*

Folds
- Definite anticline
- Definite syncline
- Approximate anticline
- Approximate syncline
- Inferred anticline
- Inferred syncline
- Concealed anticline
- Concealed syncline

Bedding
- Strike and dip of bed
- Strike of vertical bed
- Horizontal bed

Spring

Geologic Cross Sections



Cartography by S. R. Renoud and C. A. Schumacher, 1977

Bedrock Geology from Newcomb, 1969
Surficial Geology modified after Newcomb, 1969 by J. D. Beaulieu, 1977

GEOLOGIC HAZARD MAP *of the* WISHRAM QUADRANGLE OREGON

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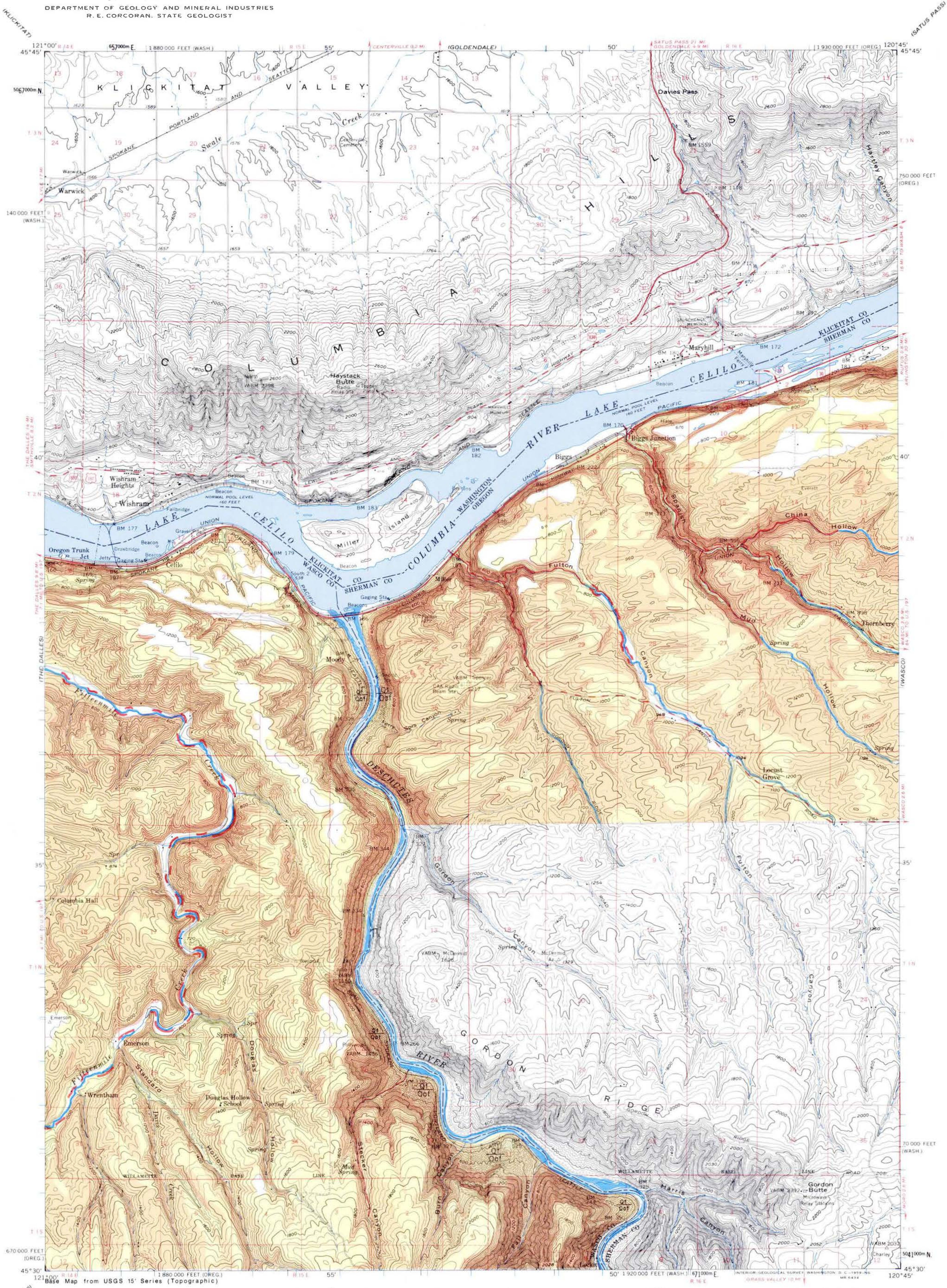

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EXPLANATION

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Average (Regional) Slope

Interpreted from maps with scale 1:62,500

0-5% 0-15% slopes locally; landforms include valley bottomland, some ridge crests, and scablands locally; hazards local and include stream-bank erosion, flooding, and high ground water; land-use potential excellent in areas of minimal hazard.

5-15% 0-50% slopes locally; landforms include gentle hills and ridge crests; hazards include moderate erosion potential in unvegetated areas; land-use potential good; primarily devoted to agriculture.

15-30% 0-50% slopes locally; landforms include rolling hills devoted to agriculture; hazards include soil creep and moderate slope erosion potential; land-use potential variable.

30-50% Greater than 50% slopes locally; landforms include valleys of major streams, volcanic accumulations, and major canyons; hazards include earthflow and slump, severe erosion potential, and creep; land-use potential generally limited to very sparse development and well-managed forestry.

>50% 50% to vertical locally; landforms include steep canyons, talus, and cliffs in the Cascades and Columbia River Gorge area; local hazards include rockfall, rockslide, debris flow, and severe erosion potential; land-use generally restricted to well-managed forestry and open space.

Geologic Hazards

Mass Movement

Deep bedrock slides: Large downdropped blocks of bedrock both active and inactive; recognized by large-scale topographic irregularities and displacement of bedrock units; distribution generally determined by faults, joints, or incompetent interbeds or formations; possible hazards may include continued sliding, variable foundation strength, variable cutbank stability, poor drainage, and others; potential for development highly variable.

Earthflow and slump topography (areas less than 10-20 acres not shown): Moderately sloping terrain with irregularities of slope, drainage, or soil distribution; recent movement, if present, shown by tension cracks, bowed trees, and others; most common in areas of stream-bank erosion or active headward migration of streams; possible hazards may include continued movement, low cutback stability, poor drainage, and others; development possible locally, but generally may reactivate or accelerate sliding.

Steep slope mass movement: Areas subject to localized debris flow, rockfall, or rockslide; specific locations a function of rock type and structure, jointing, soil properties, soil thickness, root support, vegetative cover, and others; mitigation may include structural solutions, drainage control, and appropriate land-use and forest-management practices.

Thick talus: Uniformly sloping rock and soil debris accumulating at base of cliffs primarily by rockfall and rockslide; associated hazards include shallow subsurface runoff, low cutbank stability especially in wet season, and debris flows either in talus or emanating from upslope canyons; deep cuts and development generally not recommended.

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