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FIELD TRIP GUIDE TO THE H. J. ANDREWS EXPERIMENTAL FOREST

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International Symposium on Erosion and Sedimentation in the Pacific Rim

August 2, 1987

The field trip today will provide an opportunity to view current research at the H. J. Andrews Experimental Forest on a variety of erosion and sedimentation processes and problems in forested mountain landscapes. Since its establishment as an Experimental Forest in 1948, the H. J. Andrews Forest has become one of the primary sites for basic and applied forest ecosystem studies in the United States. Today, we will look at studies of small watershed hydrology and sediment transport under varying land use practices, larger watershed investigations of channel morphology and valley floor development, hillslope studies of debris flows and earthflows, and long-term ecological experiments on log decomposition and nutrient cycling.

Underlying much of the work at the Andrews is our view of geomorphic processes and landforms as major determinants of the structure of aquatic and terrestrial ecosystems over broad spatial and temporal scales. Multiple disturbances by fire, debris flow, and flooding have left their mark on both the physical landscape and patterns of forest vegetation. Because our trees are long-lived, they provide a record many centuries long of forest-wide disturbance and climatic fluctuation. We thus have the rare opportunity to interpret how geomorphic processes operate on ecologically-relevant time scales.

At the same time, we recognize biologic systems as modifying the work of geomorphic agents. You will see examples today of interactions between forest and stream and vegetation and hydrology. Several decades of intensive forest management at the Andrews, notably clearcut logging and road building, have provided many opportunities to experimentally manipulate vegetation and observe the resulting changes to physical processes.

Our trip today will take us south towards the head of the Willamette Valley and then east into the Western Cascades along the McKenzie River, a major tributary to the Willamette River (Fig. 1). The road log will emphasize the development of Quaternary and Recent landforms in both of these physiographic regions. Our first stop will be at the Blue River Saddle Dam (Site 1), approximately 1-1/2 hours from Corvallis.

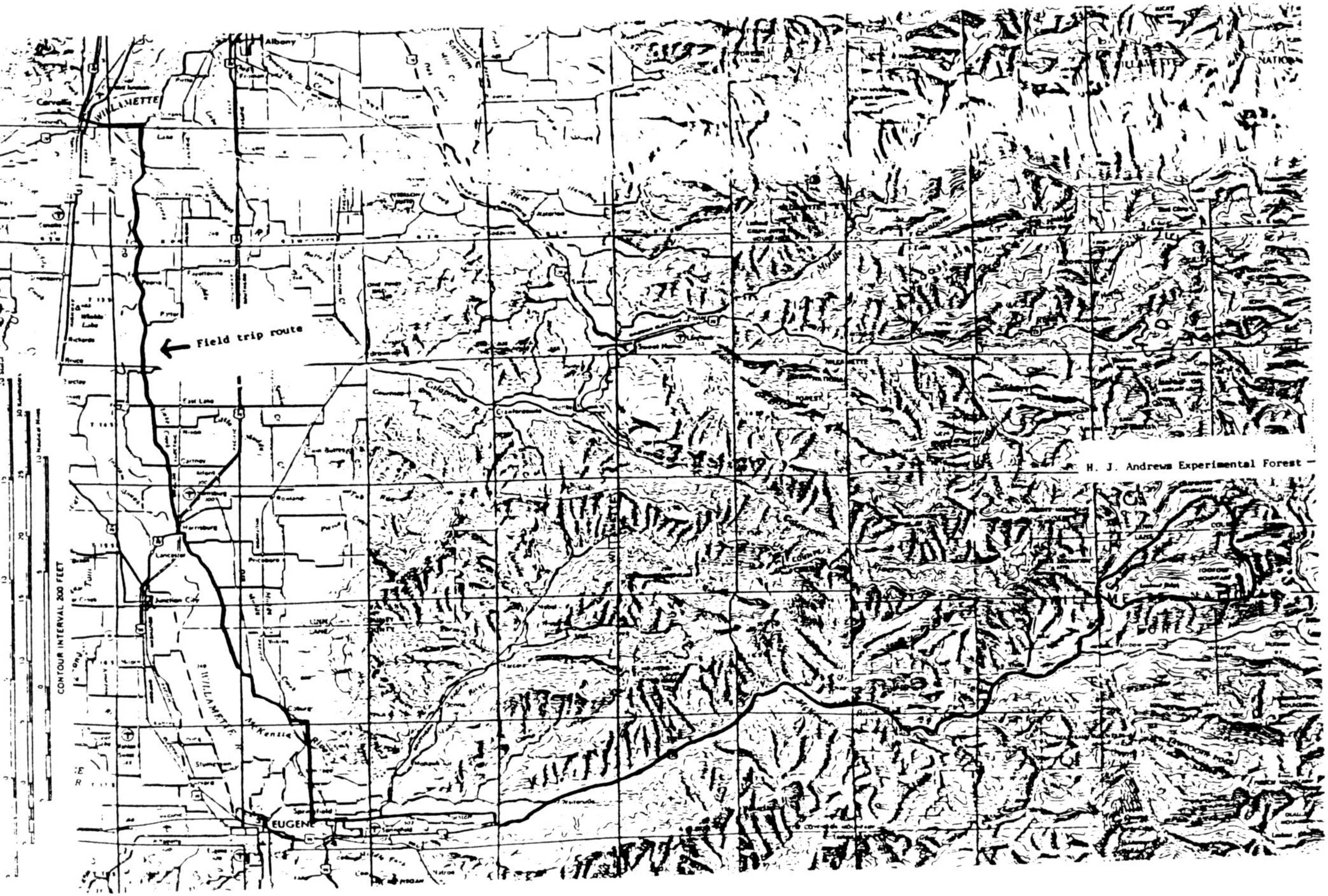

 Figure 1. Location map showing field trip route to H. J. Andrews Experimental Forest.

ROAD LOG: CORVALLIS TO H. J. ANDREWS EXPERIMENTAL FOREST
Gordon E. Grant

Mileage for the road log begins at the west end of the Willamette River bridge on Harrison Street in Corvallis.

Mileage:

0.0 Cross the Willamette River and proceed east on Highway 34. The Willamette River system drains the Cascade and Coast Ranges north into the Columbia at Portland where it is the 12th largest river in the United States in terms of discharge. At Corvallis, the drainage area is approximately 11,200 km2. We will generally be following the river's course south during the first half of the trip.

0.5 This area was inundated during the flood of December, 1964, a flood of epic proportions throughout the Pacific Northwest.

1.1 Turn right at small grocery onto Peoria Rd.

The overall impression of the Willamette Valley is of an extensive flat-lying surface bordered by the Coast Range to the west and the Western Cascade foothills to the east. Closer inspection reveals multiple surfaces generally paralleling the north-south trend of the main Willamette and the east-west trend of its major tributaries. These surfaces are particularly well-expressed on the Peoria Rd.

The surfaces and their underlying stratigraphy record an unusual history of valley floor filling due to catastrophic glacial outburst floods (jokulhlaups) in the Columbia River system. Repeated outburst flooding from Lake Missoula during the late Pleistocene resulted in periodic formation of a backwater lake and deposition of lacustrine sediments within the Willamette Valley. In the southern part of the valley, these deposits appear as horizontally-bedded silts and sands up to 15 m thick with occasional pebble, gravel, and boulder erratics of foreign provenance in the upper part of the formation; These deposits are known collectively as the Willamette Formation (Balster and Parsons 1968) and they volumetrically represent most of the valley fill above the present channel of the Willamette River. A sediment budget for the Willamette system would thus be dominated by allocthonous material.

It is not clear just how many times the Willamette was inundated. While Waitt (1980, 1985) argues that approximately 40 floods occurred within the Columbia system as Lake Missoula repeatedly filled and breached with an average inter-flood interval of 150 years, the thick rhythmite beds that make up most of the Willamette Formation display no evidence of time intervals between depositional episodes. Truncation and erosion of the upper rhythmites and deposition of boulder erratics argues for at least two major flooding phases (McDowell and Roberts 1987).

There is not a one-to-one relationship between lithostratigraphic units and geomorphic surfaces within the valley. In a classic study of soil/geomorphic surface relations, Balster and Parsons (1968) recognized and mapped 15 Quaternary surfaces of varying origins. We will encounter five of these surfaces over the next 40 miles.

3.0 Proceed south on Peoria Rd. In this area, the road is on the Ingram surface which represents the higher of two floodplain levels of the Willamette River. Lower areas of this surface, which is typically undulating with a maximum relief of 2-3 m, are commonly inundated by the Willamette during floods; upper parts of this surface are rarely, if ever, flooded and should probably be considered low terraces. Radiocarbon dating from the upper areas indicate partial abandonment of the Ingram surface approximately 550 years ago (Balster and Parsons 1968). During heavy rains, the outline of old river channels incised into this surface can be seen.

4.3 Cross Muddy Creek, a small, sluggish tributary of the Willamette.

5.0 The road rises onto the Calapooya surface. This surface forms the dominant landscape on the valley floor. It is a virtually flat surface into which lower surfaces are incised. Despite its flat aspect, it is not a simple depositional surface but has a complex stratigraphy made up of Willamette Formation units. Balster and Parsons (1968) argue that the Calapooya surface is really erosional/depositional in origin, and represents planation of older backwater deposits by a final large flood that also deposited the erratics; they assign it an age of 13,000 B.P.

6.2 The Horseshoe surface, representing the present floodplain of the Willamette is visible to the right adjacent to the channel.

7.5 Road drops back down to the Ingram surface; the Horseshoe is clearly visible to the right.

8.8 Road rises again to the Calapooya surface. Both the Ingram and Horseshoe surfaces can be seen to the right.

9.7 Peoria Park and boat ramp.

10.1 Peoria store. Note the old church to the right. A century ago Peoria was a major wheat shipping center when shallow-draft steamboats navigated the Willamette River.

11.2 Differences in the morphology of oaks related to cultural practices can be seen in the oak stand to the left. Prior to the coming of white man approximately 150 years ago, most of Willamette Valley and surrounding foothills were covered with prarie grasslands maintained by annual fires set by Indians. Oak stands were limited to isolated, fire-resistant individuals with large crowns. Following institution of fire suppression by whites, oak stands became more dense, seen here as clumped individuals with narrow crowns. As the prarie shifted to oak woodland, shade-tolerant Douglas-fir was able invaded the oak openings and now covers most of the surrounding foothills (Johannessen and others 1971).

11.7 Road is located on Calapooya surface but closely parallels Horseshoe surface to the right.

14.0 Slough. Many of the sloughs that line the Willamette Valley are old main river channels now fed by tributaries and springs.

15.5 At this point the road is located on the Senecal surface. The distinction between the Senecal and Calapooya surfaces is subtle and consists primarily of greater degree of incision by small drainageways on the former. Balster and Parsons (1968) interpret modification of the Calapooya surface as resulting from overland flooding shortly after deposition of the final silt blanket. Others have speculated that incision may have resulted from lake waters draining to the north.

16.3 Mennonite school. A small Mennonite community is located here--note the exceptionally well-tended gardens.

16.9 Good view of the Coast and Cascade Ranges to the west and east, respectively. In the area flanking the Willamette Valley the Coast Range is underlain by shales and sandstones of Eocene age which overlie submarine volcanic flows and breccias. The Coast Range has been uplifted throughout the Tertiary. The two prominent peaks on the skyline are Marys Peak to the north and Roman Nose further south. To the east are the foothills of the Western Cascades, a constructional volcanic platform of early Miocene to late Pliocene age. The Willamette Valley itself is the southern end of a structural depression extending over 2400 km north to British Columbia.

18.3 Old farmhouse on left. Note that many of the older farms were built on the upper surfaces which were not flooded annually.

22.8 Harrisburg. Junction with Hwy 99E; continue straight ahead.

23.3 Turn left at green sign marked 'High School' just before road bends to right.

23.6 Turn right at first stop sign (S. 6th St.)

29.8 Approximate location of the contact between the Senecal and Winkle surfaces. In the southern part of the valley, relief between the Senecal and Winkle surfaces is only 1-2 m; in the northern half of the valley, however, the relief exceeds 20 m. The Winkle surface is incised into the older Calapooya-Senecal surfaces and is characterized by an undulating topography of old, abandoned flood channels. Age of the surface is taken to be mid- to early Holocene (5000-12,000 yrs. B.P.) (McDowell and Roberts 1987); dates reported by Balster and Parsons (1968; pg. 8), however, suggest that sedimentation beneath the Winkle may have begun as early as 34,000 yrs. B.P. McDowell and Roberts (1987, pg. 42) describe changes in channel sinuosity as interpreted from paleochannel scars identified on aerial photographs. They note that channels on the Winkle surface are less sinuous than those on younger (Horseshoe and Ingram) surfaces and generally show a braided pattern. The Senecal surface apparently had channels intermediate in sinuosity between the Winkle and Ingram surfaces.

30.5-31.2 Road is on the Winkle surface; Ingram surface to the right.

32.0 Intrusive volcanic rocks form low rounded buttes to the left.

33.0 Road dips down to Ingram surface.

33.5 Good expression of Horeshoe surface to the right and scarp of Winkle surface to the left.

33.7 Road climbs to Winkle; note the dark green peppermint fields. As you may have noticed, the agriculture of the Willamette valley is distinguished by its diversity. Primary crops include grass seed, hops, wheat, berries, and fruit and nut trees. Blackened fields are due to burning by grass seed farmers to eliminate root rusts and smuts.

34.5 Coburg--notorious speed trap!

34.8 Turn right at stop sign.

35.0 Turn left at grocery (E. Pearl St.); green sign to freeway on right may be hard to see.

35.7 Turn right onto freeway on-ramp towards Eugene.

37.3 Outcrop on the left shows dark volcanic sills (upper Oligocene?) intruding tuffaceous silt and sandstones of the Eugene Formation (early Oligocene). Outcrops such as this one may record the beginning of volcanism that built the Western Cascades.

37.5 Cross McKenzie River. We are on the outskirts of Eugene, Oregon's second largest city (population 125,000).

41.0 Take Exit 194A to Springfield/McKenzie River.

45.9 Weyerhaeuser pulp mill to the right; McKenzie River on the left.

47.8 Turn left at second stoplight onto Highway 126.

51.6 Thurston Bump, a small earthflow complex. Over the years, public works engineers have laid down over 6 m of asphalt fill to maintain the roadbed at elevation.

53.1 Cross the McKenzie River at Hendricks Bridge.

54.2 Good views up the McKenzie River valley. The valley is floored by thick deposits of outwash gravel which have been cut into a series of terraces. No correlation of tributary terraces with main Willamette surfaces has been attempted.

The mountains of the western Cascades which flank the valley on either side are primarily composed of a thick section of volcanic and related intrusive rocks of Miocene age but include some later Pliocene rocks as well, mostly along ridgetops or as intra-canyon flows. Early western Cascade rocks are primarily silicic tuffs and breccias with lesser tholeitic lava flows; later western Cascade rocks are chiefly andesite and basaltic andesite lave flows with tuff interbeds. Most of the relief of the present western Cascades is due to rapid uplift and erosion during the late Miocene and early Pliocene.

54.8 Cross power canal. Water diverted from the McKenzie is conveyed 15 km downstream to a hydroelectric generation facility.

58.4 Good view of lower terrace surfaces to the right.

59.3 Exposure of dark, blocky, olivene-rich basalt overlying reddish breccia. This rock has been mapped as the Little Butte Formation (late Oligocene-early Miocene) by Peck and others (1964). It consists of a series of dacitic to andesitic pyroclastic rocks, including coarse breccias and dark basaltic flow rocks.

61.0 Leaburg power plant. Note the painted bas-relief built by the Works Projects Administration (W.P.A.) during the 1930's.

61.6 Leaburg

62.5 Christmas tree farm on lower terrace surface on right.

63.2 High upper surface on left is actually power canal.

64.1 Recent clearcuts on privately-owned land are visible on the ridgetop to the right.

64.5 Cross power canal.

65.8 Leaburg dam, lake, and power canal diversion.

66.2 Old state fish hatchery on left.

67.5 Goodpasture covered bridge. Bridges constructed during the late 1800's and early 1900's were covered in order to retard rotting of wood timbers.

67.7 Large recent landslide on the left failed during the storm of Feb. 21-22, 1986. The left side of the house on the right of the slide was partially destroyed by the slide which also blocked the road. Derangement of drainage accompanying construction of a small cat road above the slide site in the summer prior to failure may have been a contributing factor. The slide failed again exactly one year after the first failure.

68.2 Vida. Glacial outwash gravels exposed in roadcut on left.

68.5 Gate Creek

69.3 Filbert orchards on both sides of the road.

69.5 Road cut in Little Butte basalt on left.

69.8 Glacial outwash cobbles in sandy-silt matrix overlie weathered breccia on left. Clasts are fresh with 0-1 mm weathering rinds and there is little apparent post-depositional clay formation.

Ice cap glaciation along the crest of the High Cascade platform to the east served as a source area for outlet valley glaciers throughout the Pleistocene; however the extent and sequence of glaciation in the Western Cascades is poorly understood. This is due to heterogeneity of rock types, erosion or redistribution of deposits by fluvial or colluvial processes, and poor exposures. Scott (1977) documents three major Quaternary glaciations on the east side of the Cascades; however, no comparable chronology exists west of the Cascade crest.

71.7 Roadcut on left shows deeply weathered mudflow breccia with 1-2 mm thick weathering rinds overlying basalt in an apparent swale depression. Mudflow is overlain in turn by much fresher colluvium. This deposit is probably an old alluvial fan perched on an upper terrace surface.

73.9 Exposure of dark gabbro in left cutbank.

74.5 Exposure of Nimrod Granite on left. This is one of several small granitic intrusions within the Western Cascades; rocks surrounding these intrusions have often been altered propylitically to zeolite facies metamorphism. Gold mined near the town of Blue River at the turn of the century was associated with the contact aureole of the Nimrod Granite.

75.0 Cutbank on left displays large dune-scale foresets consisting of interbedded, deeply weathered coarse and fine sand with occasional pebble and cobble drop stones. These foresets grade laterally to the west (downriver) into fine-grained, faintly laminated sandy silts showing soft sediment deformation. To the east, the foresets grade into deeply-weathered fluvially-worked cobbles, many of which are clay 'ghosts'. Overlying both the cobbles and the sands are much fresher fluvial deposits. This deposit records at least two periods of alluviation within the lower McKenzie River valley probably associated with glacial periods. Deposition of the foresets probably occurred as a delta built into an ice-dammed lake along the valley margin. Based on the degree of weathering of the underlying deposit, we can speculate that it represents glacial outwash of Hayden Creek age (approximately 50,000 B.P.) or earlier.

75.5 Prospect hole in the Nimrod Granite.

76.3 Greenish propylitic alteration of Nimrod Granite.

76.5 Nimrod store and gas station.

77.7 Large flat on left is probably part of alluvial fan complex coming from a north-side tributary.

78.4 Large 10 m cutbank on left consists of 8 m of grey, fluvially-worked and imbricated cobbles and boulders without substantial weathering overlain by 2 m of brown, mudflow deposit. Source for this mudflow is the small creek in the center of the deposit. At the eastern (upriver) edge of the deposit, one can see interbedding of debris flow and outwash cobbles.

80.1 Finn Rock

80.8 Green volcanic breccia on left.

80.7-81.2 Even-aged stands of alders along the McKenzie River in this area date from the 1964 flood.

81.7 Valley widens, high terraces to left. This area has been interpreted as the lower limit of valley glaciation (Wilson 1981); however, the evidence is inconclusive. Bedrock constriction of the valley floor downstream probably contributed to terrace formation in this area.

82.3 The 1964-aged alder stand is clearly visible across the river on the right on a mid-channel bar. Note the progressively younger trees at the lower end of the bar suggesting that the bar is growing downstream.

82.8 Confluence of Blue River and the McKenzie. The location of this confluence has been affected by ice-damming within the main McKenzie valley, as will be discussed at the first stop.

83.4 Large outcrop of green breccia on left.

85.9 Veer left onto uphill grade at green sign to Blue River Reservoir.

86.8 SITE 1: BLUE RIVER SADDLE DAM.

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H J ANDREWS GEOMORPHOLOGY FIELD TRIP GUIDE

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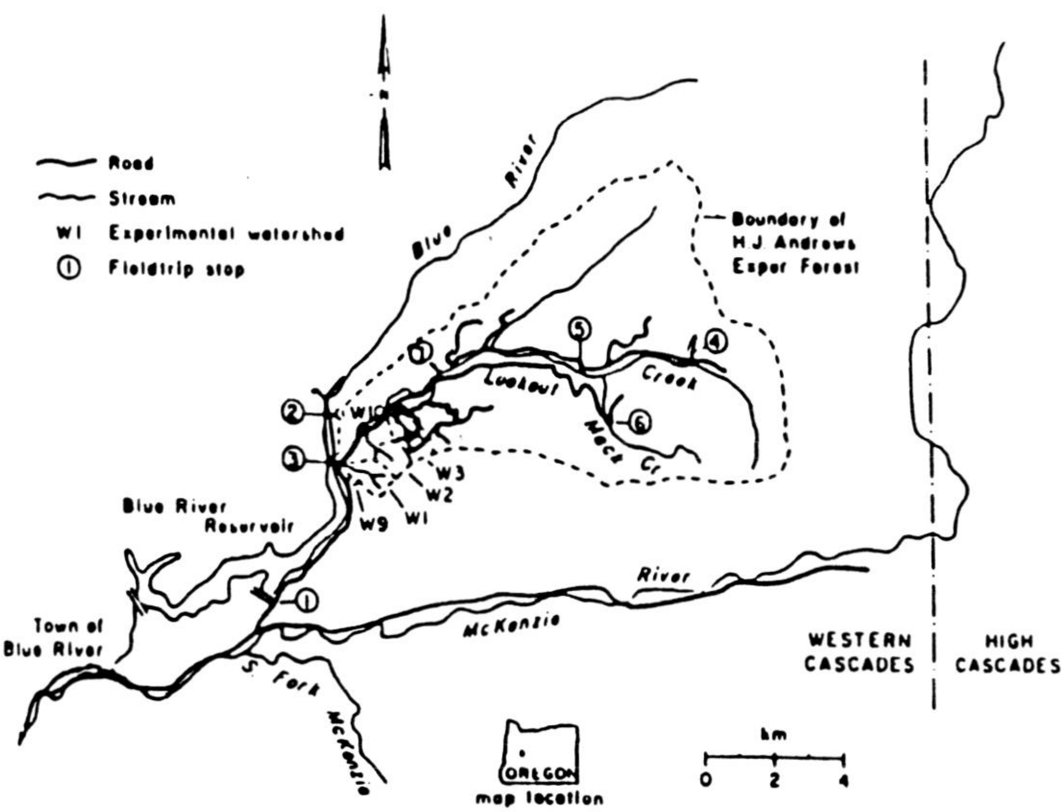


An Introduction to the H. J. Andrews Experimental Forest

The H. J. Andrews Experimental Forest is located in the rugged Cascade Mountains approximately 50 miles (80 km) east of Eugene, Oregon. It is 15,815 acres (6400 hectares) in size and ranges from 1350 feet (412 m) to 5350 feet (1630 m) in elevation. The landscape is deeply dissected and heavily forested. Pristine stands of old-growth forest with dominant trees in excess of 400 years of age cover about 45 percent of the Andrews Forest with the remainder in younger age-class forests; the most common forest types at lower elevations are dominated by Douglas-fir, western hemlock and western red cedar. Going up in elevation, western hemlock is gradually upland by Pacific silver fir, and Douglas-fir and western red cedar decline in importance. Upper elevation stands consist of mixtures of true firs and mountain hemlock. Approximately one third of the Andrews Forest has been logged or manipulated for research as shown in the following table.

Forest Type	Areas in Acres (hectares)		
	Undisturbed	Logged/Manipulated	Total
Low elevation douglas-fir--western hemlock	3363 (1362)	2807 (1136)	6170 (2498)
Mid-elevation transitional	3959 (1603)	1331 (539)	5290 (2142)
Upper elevation true fir-mountain hemlock	2756 (1115)	981 (379)	3737 (1512)
Non-forest types	618 (250)	-- --	618 (250)
Grand Totals	10,696 (4330)	5119 (2072)	15,815 (6402)

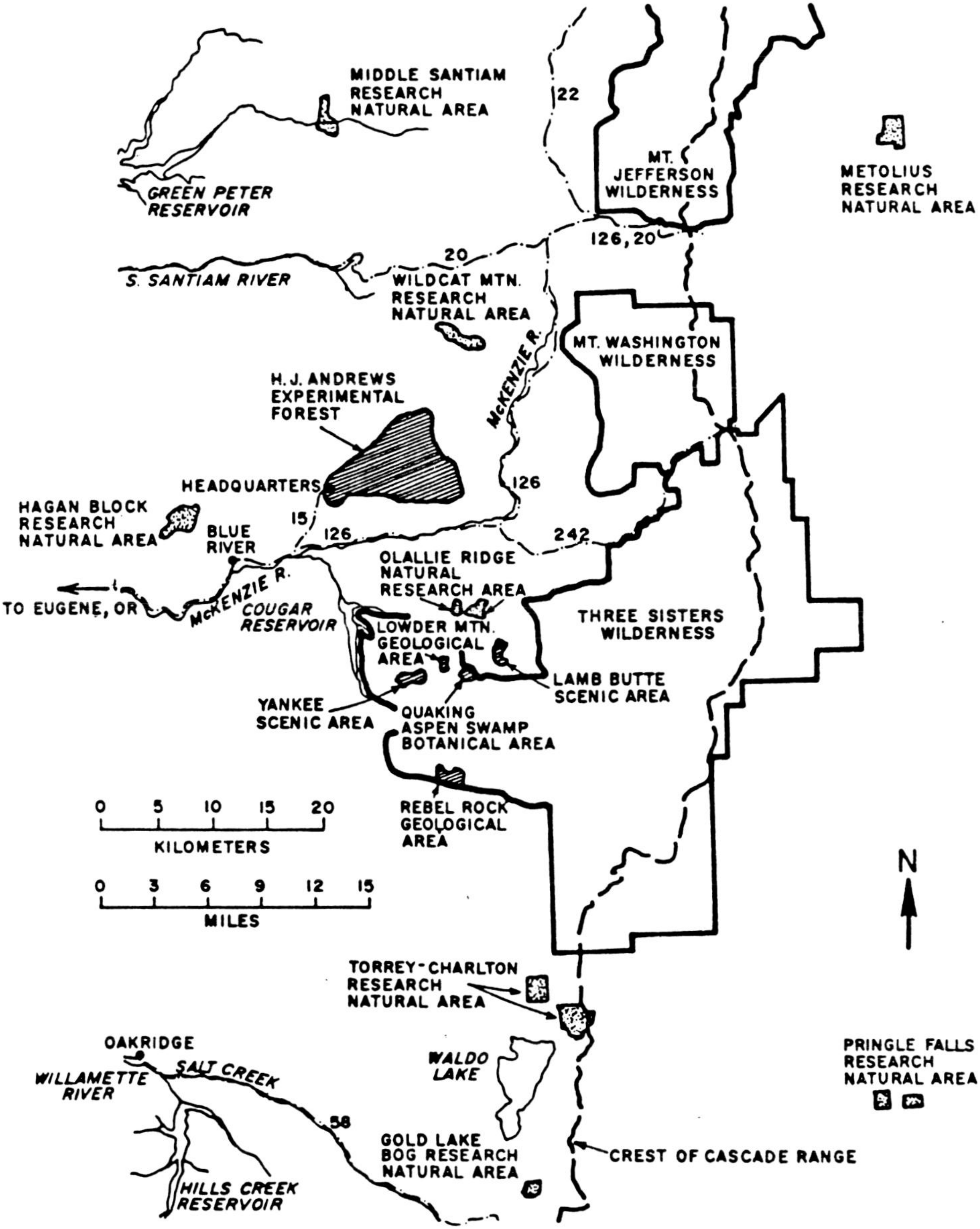
The maritime climate is mild with wet winters and cool, dry summers. Annual precipitation normally exceeds 100 inches (2540 mm) and is concentrated in the winter. Deep snowpacks are common above 3300 feet (1000 m). Little or no rain falls during July and August.

Rapidly flowing mountain streams are the primary type of aquatic ecosystem on the Andrews Forest. Streamflow follows the precipitation pattern with winter maximum flows three orders of magnitude larger than summer minimum. First and second order streams under natural conditions are dominated by coarse woody debris and receive large annual inputs of litter which provide the energy base for the aquatic organisms. Larger order streams have an increasing proportion of the energy base provided by in-stream photosynthesis, but processed organic matter (litter) washed down from the smaller tributaries remains an important part of the energy base.

The Andrews Forest was established by the U.S.D.A. Forest Service in 1948. Research efforts focused on logging and regeneration in the 1950's, shifted to a watershed emphasis in the 1960's and to an ecosystem orientation in the 1970's. Research use of the site expanded rapidly in the 1970's, with National Science Foundation support. In 1977, Oregon State University and the Forest Service agreed to jointly administer the site with the common management objective of enhancing research and educational use. The success of this joint management is apparent in the continuing expansion of the overall program, which includes basin and applied research.

During 1983, 87 scientists and 51 graduate students were involved in research at the Andrews Forest. Fifty-six separately funded projects used the site; if broken down into subprojects, well 100 studies could be listed. Total research expenditure is large, over $1,750,000 during 1983. The major contributors are:

Agency/Source	Amount
National Science Foundation	$ 855,000
Pacific Northwest Forest and Range Exp. Stat.	$ 401,000
Oregon State University	$ 170,000
Bureau of Land Management	$ 110,000
Department of Energy	$ 96,000
Other	$ 121,000
Total	$1,[illegible]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NATURAL AREA
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126, 20
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S. SANTIAM RIVER
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MT. WASHINGTON
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ASPEN SWAMP
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TORREY-CHARLTON
RESEARCH
NATURAL AREA
OAKRIDGE
SALT CREEK
WILLAMETTE
RIVER
WALDO
LAKE
PRINGLE FALLS
RESEARCH
NATURAL AREA
58
GOLD LAKE
BOG RESEARCH
NATURAL AREA
CREST OF CASCADE RANGE
HILLS CREEK
RESERVOIR

GEOLOGY AND GEOMORPHOLOGY

Soils in the area have loamy surface horizons, ranging from silty-clays to sandy and gravelly loams. Because of aggregation of primary soil particles by organic matter and other agents, porosity of surface soils is 60 to 70 percent, over half of which is macropore space (Ranken 1974). Subsoil porosities are also high, ranging from 50 to 60 percent, of which about 20 percent is macropore space. The pore-size distribution of the soil accounts for two important hydrologic properties: (1) all water enters the soil and travels by subsurface flow to streams (Harr, 1977), because soil permeabilities are up to several hundred times greater than rainfall rates, and (2) soil is able to retain 30-40 cm of water in its top 120 cm (Dyrness, 1969) which is an important water source for the dense forest vegetation during the dry summers. These conditions of high soil permeability combined with steep slopes cause headwater streams to respond very quickly to changes in rainfall rate (Harr, 1977).

Bedrock at elevations below about 850 m is composed of a variety of hydrothermally altered volcaniclastic rocks of the late Oligocene to early Miocene Little Butte Formation (Peck et al., 1964, Swanson and James, 1975a). The western end of the Forest is cut by numerous steeply dipping, northwest-trending dikes. Little Butte Formation rocks are overlain by ash flow and basaltic andesite lava flows of the Miocene Sardine Formation which crop out up to elevations of about 1,220 m. Ridge crests along the eastern and southern boundaries of the Forest are capped with thick andesite lava flows with K-Ar ages in the range of about 4 to 6 million years.

Holocene deposition of thin tephra units completes the history of accumulation of volcanic material in the Lookout Creek drainage. Mazama ash with fragments up to about 1 cm diameter rained over the Andrews area about 6,700 radiocarbon years ago. Average thickness of initial airfall deposits was probably on the order of 1 cm. Fine-grained (<1 mm diameter) basaltic tephra erupting from the Sand Mountain area (Taylor 1968) probably fell on portions of the Forest about 3,000 radiocarbon years ago. The Mazama ash, weathered to a distinctive yellow color, fell in sufficient abundance to be a useful time marker in analysis of some geomorphic surfaces in the area.

Landscapes of the Andrews Forests have been sculptured by glacial, fluvial, mass movement, and other hillslope processes (Swanson and James, 1975a). Details of glacial history of the area have been obscured by subsequent erosion and redistribution of glacial landforms and deposits. The origin of bouldery deposits in the area is commonly ambiguous. For example, nearly identical bouldery diamictons can be produced by glacial, volcanic, and mass movement processes; and combinations of these three types of processes may all operate on a single batch of earth material. So the glacial history of these areas of the western Cascades has been poorly kept due to rapid removal of the record by other geomorphic processes and presence of anistropic rock types that do not form neat glacial landforms in the first place.

Despite these difficulties glacial processes have clearly influenced higher elevation, north aspect parts of the Lookout Creek drainage (Crandell, 1965, Swanson and James, 1975a). Cirques were formed by small alpine glaciers on the north side of ridges higher than about 1,370 m elevation. Valley wall and bottom glacial deposits derived from headwaters of the Lookout Creek drainage extend as far down valley as about 660 m elevation. The lower end of Lookout Creek drainage was also influenced by damming of lower Blue River by glacial ice in the main McKenzie River valley (Swanson and James, 1975b). The ice dam backed water up into the mouth of Lookout Creek, causing deposition of fine grained, varved quiet water sediments.

Mass movement processes have created distinctive wide spread landforms. Slump-earthflow features, produced by slow, deep-seated mass movements, cover over 25 percent of the landscape in the lower elevation half of the forest underlain by volcaniclastic rocks (Swanston and Swanson, 1976). The heads of most large earthflow features are located at geologic contacts where hard lava flow bedrock caps softer volcaniclastic rock. About a third of the slump-earthflow areas has been active in the past century based on disrupted growth of trees; and some areas are currently active during each wet season. Even the most active earthflows in the area are heavily forested.

Slump-earthflow areas typically have subdued relief, hummocky ground and deranged drainage systems. Active features have open tension and shear cracks, split and tilted trees, and very irregular drainage patterns and channel cross-section geometry. At low flow stream water goes undergound where crack systems intersect stream channels. On flows that have been dormant for progressively longer periods of time there is less evidence of disrupted vegetation and drainage systems. Some earthflows in the Forest have deposits of Mazama ash in poorly drained depressions, suggesting that the hummocky ground existed 6,700 years ago.

Steep terrain in areas of volcaniclastic bedrock and associated soils has been sculptured largely by debris avalanches. These rapid soil mass movements are initiated from the headward tips of incipient drainage depressions ("hollows" of Dietrich and Dunne, 1978), from streamside areas, and infrequently from smooth slopes. Events are commonly triggered as a result of high precipitation on wet soil conditions, and multiple windthrow of trees may also be a contributing factor on forested sites. Debris avalanches are a major mechanism for transfer of soil from slump-earthflow features to streams. Slump-earthflow movement oversteepens the toes of deep-seated failures and causes them to encroach on streams, thus aggravating bank cutting and debris avalanche potential (Swanson and Swanston, 1977). Debris avalanches also take place on the steep headwall areas of some slump-earthflow features.

Table 1. Experimental watersheds in the H. J. Andrews Experimental Forest. Forests in watersheds 1, 2, 3, 9, and 10 were 400 to 500 year old Douglas-fir—western hemlock stands. Watersheds 6, 7, and 8 were 100-130 year old Douglas-fir stands.

Watershed no.	Area (ha)	Elevation (m) Min.	Elevation (m) Max.	Management history	Water & sediment yield, start of record W[1/]	C	S	B
1	96	460	990	100 percent clearcut (1962-1966)	1953	1962	1957	1957
2	60	530	1,070	Control	1953	1962	1957	1957
3	101	490	1,070	6 percent roads (1959) 25 percent clearcut (1963)	1973	1962	1957	1957
6	13	880	1,010	100 percent clearcut (1974)	1964	1972	1972	--
7	15	910	1,020	100 percent partial cut (1974)	1964	1972	1972	--
8	21	960	1,130	Control	1964	1972	1972	--
9	9	425	700	Control	1967	1969	1969	1973
10	10	425	700	100 percent clearcut (1975)	1967	1969	1969	1973

[1/] W = water discharge; C = water chemistry, typically N, P, K, Ca, Na, Mg; S = suspended sediment, C and S sampled with grab samples and pumping proportional sampler (Fredriksen, 1969); B = bedload sampled in ponding basin.

Table 2. Erosion process studies in the H. J. Andrews Experimental Forest

Erosion process monitoring

Process	Sites	Methods	Duration of record
Creep	Both straight and hummocky slopes	Inclinometer tubes	1969 to present and shorter
Earthflow	One site, upper Lookout Creek	Stake arrays, inclinometer tubes, crackmeter, theodolite survey	1974 to present 1974 to present 1976 to present 1976 to present
Surface erosion	Steep slopes in WS1, WS9, WS10, and other forest sites	Collector boxes, 0.5 and 2.4 m long	1974 to present and shorter
Channel changes	6 sites, small to large streams	Monumented cross-sections	1978 to present

Forest-wide inventories of mass movement processes

Process	Sites	Methods	Duration of record
Debris avalanches	All of Andrews	Ongoing inventory of events 75 m^3	1950 to present
Slump-earthflow	All of Andrews	Field and air photo analysis	Some features 6,700+ yrs.

Small, steep channels in the lower elevation half of the Forest area are also subject to mass movements termed debris torrents. Most debris torrents (82 percent of 38 inventoried events) are initiated as debris avalanches from hillslopes which enter channels and maintain their momentum downstream until they are stopped by obstructions or bends in the channel or simply by decreasing channel gradient (Swanston and Swanson, 1976). Some debris torrents start in channels as a result of flotation of organic debris. Many torrents move through first-order channels and can travel up to a kilometer downstream into lower second- and upper third-order channels. The scouring and exposure of bedrock by debris torrents probably contributes to the incised appearance of many first- through third-order channels in the area. Many small streams are flanked by 2 to 8 m high steep banks of colluvium and bedrock.

Other hillslope processes transport soil from slopes to channels in the Forest, but do not create large scale landforms. Sheetwash and rill erosion are trivial on all but severely disturbed sites due to low precipitation intensities and high infiltration rates. Surface erosion by dry ravel, throughfall and rain drop impact, and freeze-thaw processes is significant on steep slopes. Root throw is also an important soil transport process which does create distinctive, though small scale, landforms. Soil mantle creep and transport of material in solution are subtle, but important, pervasive processes in this terrain.

Fluvial processes, of course, have played important roles in shaping the landscape of Lookout Creek basin. Streams are steep and development of fluvial landforms has been constrained by influences of bedrock, hillslope mass movement processes, and large organic debris derived from adjacent forests. Significant development of flood plains and terraces occurs along streams larger than third-order. Remnants of alluvial fans are located at junctions of smaller streams with fourth- and fifth-order streams (Swanson and James, 1975b). The coarse scale of jointing in the volcanic bedrock produces large clasts that become the boulders and cobbles covering much of the streambed area.

Sediment yield from forested parts of this landscape are at the low end of the range for mountainous terrain. Anderson (1954) estimates 48 T/km^2/yr of suspended sediment yield for the McKenzie River basin, based on samples collected in 1949 and 1950 before much development had occurred. Sediment yield from small forested watersheds in the Forest is about 40 T/km^2/yr composed of dissolved, suspended, and bedload sediment in order of decreasing contribution to total yield (Fredriksen and Harr, 1979, Swanson et al., in press). Removal of vegetation by wildfire and logging results in increased soil

SITE 1. SADDLE DAM OF BLUE RIVER RESERVIOR

This stop provides an overview of the geographic, geologic, and geomorphic setting of the field trip area and environs (Figure 1). To the north we look across the Blue River Reservoir and into the Blue River drainage. We are on a low divide with the westward flowing McKenzie River south of us. The Lookout Creek drainage and the Andrews Experimental Forest meet Blue River at the head of the reservoir.

We are in the western Cascade geologic and physiographic provinces. Bedrock is comprised entirely of Pliocene and older volcanic and subvolcanic intrusive material, and landforms have been shaped by erosional processes. The boundary with the High Cascades lies about 20 km east of this spot. Steeply dipping, north-trending, normal faults which are down-dropped on the east form the boundary. The High Cascades are predominantly a constructional volcanic landscape formed during the past two million years.

During the Pleistocene, Blue River drained directly into the McKenzie River through this saddle dam area (Swanson and James, 1975b). Pre-latest Wisconsin glaciers from the High Cascade platform and from the South Fork McKenzie River basin flowed down the main McKenzie River valley and blocked the mouth of Blue River. This ice dam formed a lake 30+ m higher than maximum reservoir level and diverted the lower Blue River to its present course. Drilling in the saddle dam area by the Corps of Engineers revealed more than 60 m of glacial deposits forming a natural saddle dam below the man-made saddle dam.

Till, outwash, and varved lake sediments are exposed in the dam area. A wood sample from these deposits is more than 40,000 radiocarbon years old. Along the drive up the east side of the reservoir we pass kame terrace deposits on the valley wall above the road. Bedrock exposed in road cuts is predominantly propylitically altered, green, laharic breccias cut by numerous vertical, northwest-trending dikes.

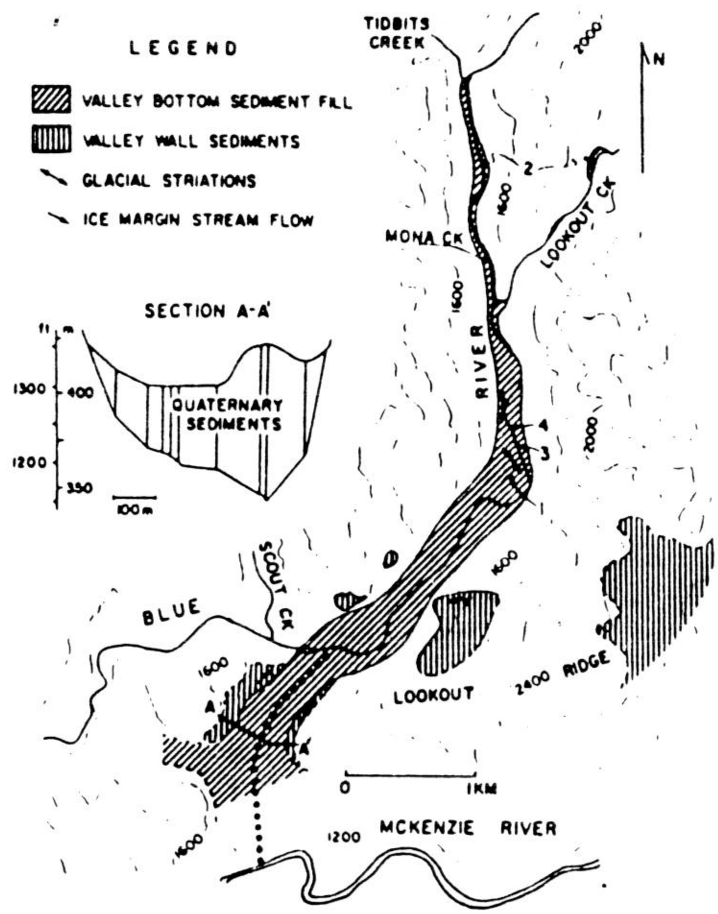


Figure 2 Map showing distribution of fluvial and lacustrine sediments related to glaciation of lower Blue River. Location 1 notes the occurrence of N25W-trending glacial striations. Location 2 marks sedimentary sections in the upper end of the lake, while at location 3 there are good exposures of sediments deposited in the lower portion of the lake. Wood collected from glacio lacustrine sediments at location 4 was dated at >40,000 years b.p. Dotted line shows former course of Blue River. Contours (interval = 400 ft) from U.S. Geological Survey Blue River and McKenzie Bridge 15 ft

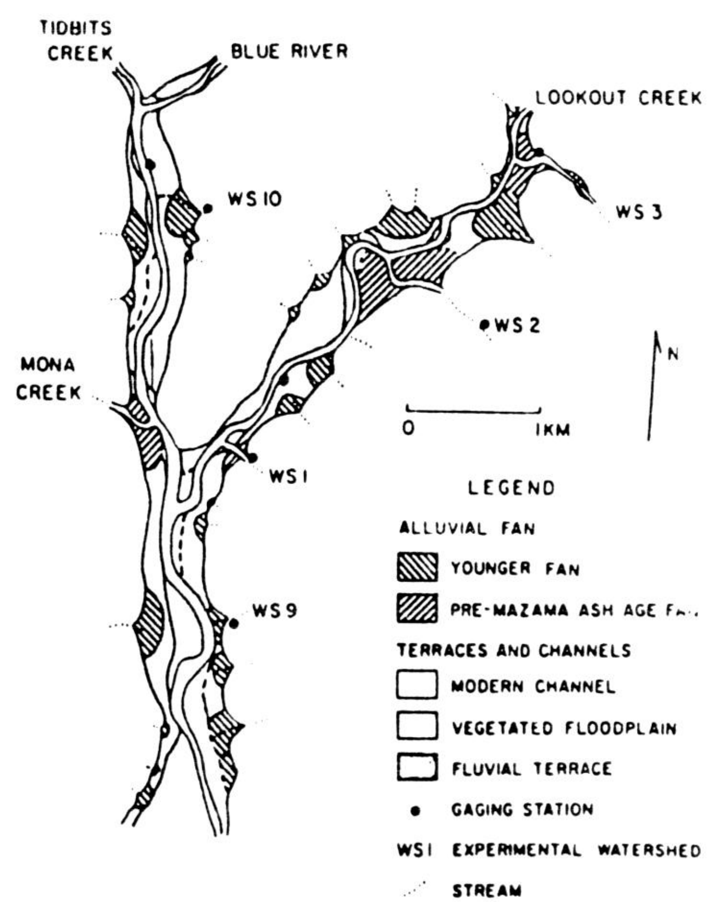


Figure 3 Map of post glacial geomorphic surfaces near the confluence of Blue River and L[illegible] Creek.

SITE 2. WATERSHED 10

Watershed 10 (WS10) has been the principal study site of the Oregon phase of the Coniferous Forest Biome research. This 10 ha watershed is probably the most intensively studied piece of ground of this scale in the western hemisphere. Research since 1969 has examined hydrology, vegetation, nutrient cycling, aquatic biology, and geomorphology under both forested and recovering clearcut conditions. The 400 to 500 year-old stand of Douglas-fir, western hemlock, western redcedar, and other tree species (Grier and Logan, 1978) was clearcut with directional falling with jacks and yarded with a skyline system in the summer of 1975. Heavy residues were yarded to the landing and hauled away or burned there. Limb-sized material was hand-cleaned from the channel and piled above high flow line. The overall logging operation was designed to follow practices used in standard Forest Service operations at that time. Companion WS9 about 1.5 km south is maintained in the forested condition as a control.

Geomorphology research in WS10 is comparing erosion under forested and clearcut recovery conditions. We do this by developing erosion budgets, comprehensive assessments of soil and sediment movement by all significant erosion processes. The soil/sediment routing system is viewed as movement of material down slopes and channels from one temporary storage site to another. Storage sites include shallow depressions on slopes that ultimately fail by debris avalanching (Dietrich and Dunne, 1978) and wedges of sediment stored behind logs in streams. Transfer processes between storage sites range from debris avalanches that typically occur on a few percent of the watershed once every few centuries to watershed-wide persistent processes such as surface erosion and solution transfer (Table 3).

Table 3. Process characteristics and transfer rates of organic and inorganic material to the channel by hillslope processes (T/yr) and export from the channel by channel processes (T/yr) for Watershed 10.

Process	Frequency	Area influenced (% of watershed)	Material transfer: Inorganic	Material transfer: Organic
Hillslope processes				
Solution transfer	Continuous	99	3	0.3
Litterfall	Continuous, seasonal	100	0	0.3
Surface erosion	Continuous	99	0.5	0.3
Creep	Seasonal	99	1.1	0.04
Root throw	1/yr	0.1**	0.1	0.1
Debris avalanche	1/370 yr	1-2**	6	0.4
Slump/earthflow	Seasonal*	5-8%	0	0
TOTAL			10.7	1.4
Channel processes				
Solution transfer	Continuous	1	3.0	0.3
Suspended sediment	Continuous, storm	1	0.7	0.1
Bedload	Storm	1	0.6	0.3
Debris torrent	1/580 yr	1	4.6	0.3
TOTAL			8.9	1.0

*Inactive in past century in Watershed 10

**Area influenced by one event.

An erosion budget has been prepared for Watershed 10 in old-growth forest conditions (Table 3). Methods of generating these estimates are described by Swanson et al. (in press). Such a budget provides a basis for comparing processes. For inorganic matter transport the mass movement processes are very important, although they are estimated to occur less frequently than 1 per 300 years under forest conditions. (Note: there are many difficulties in making these estimates, including the dominance of the 30 year record by events triggered in a single storm of a probable return period much greater than 30 years.) The most persistent process, solution transfer, is also very important.

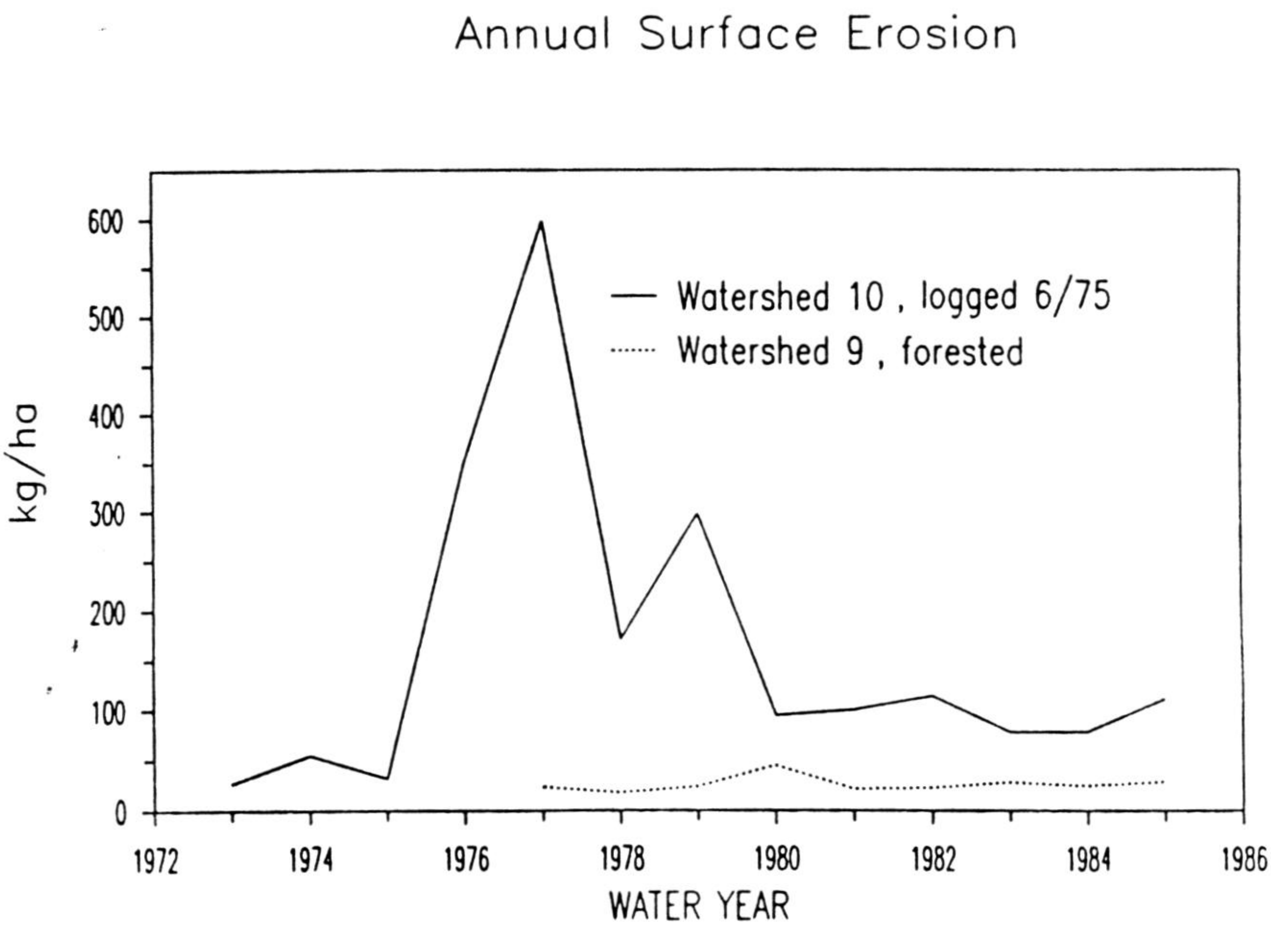
Average annual values (kg ha^{-1} yr^{-1}) for Watersheds 9 (forested) and 10 (clearcut, 1975).

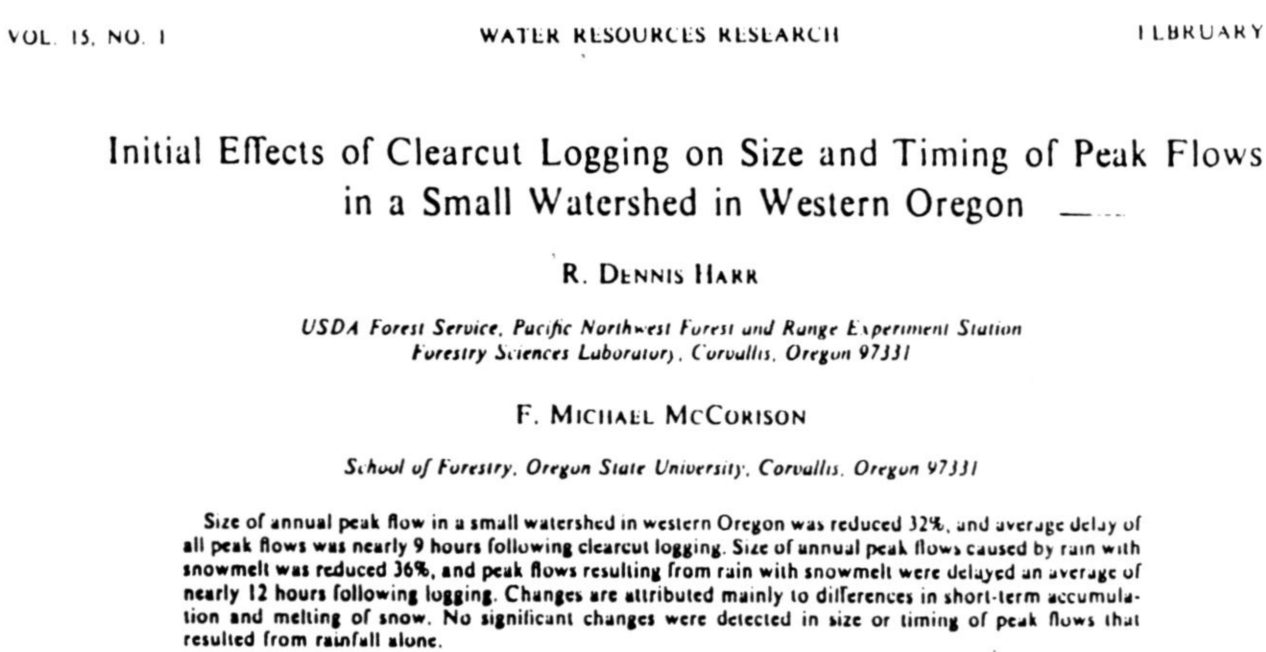
	Watershed 9	Watershed 10	
	1975 - 1986	Pre-logging (est.)	1975 - 1986
Input to channel			
Surface erosion	26	80	199
Debris slide	0	643 (est.)	1300 (actual)
Dissolved load	16	16	17
Export from channel			
Dissolved load	286	332	354
Suspended load	35	70	320
Bedload (basin catch)	14	90	305
Debris flow	0	493 (est.)	6000 (actual)

We are now observing changes in the rate of each erosion process during the post-clearcut recovery period. Each transfer process and storage site in the soil/sediment routing system is regulated by a different combination of vegetative factors. Root strength, for example, affects debris avalanche potential, and presence of an organic litter layer moderates surface erosion. Consequently each erosion process has a different response to clearcutting and revegetation.

Substantial increases in suspended and bedload export occurred following logging. Sediment yield is limited by (1) availability of sediment for transport and (2) availability of flowing water, the transporting medium. Snowmelt peak flows from WS10 were actually delayed and smaller the first winter after logging, but rain generated peak flows were not affected significantly (Harr and McCorison, 1979). Changes were attributed to differences in short term snow accumulation and melt. Increased sediment yield has come from increased availability of material from three sources: (1) material input to the channel during the logging operation itself, predominantly fine organics, (2) sediment that entered the channel and was stored behind large debris before logging, but was released from storage when logs were removed in the yarding operation, and (3) soil from post-logging accelerated hillslope erosion.

Erosion monitoring facilities on the watershed include inclinometer tubes, 0.5 m wide surface erosion collectors along the stream perimeter, 2.4 m wide surface erosion collectors on upslope sites, monumented channel cross-sections, sediment ponding basin, and stream gaging facility with proportional pumping sampler (Fredriksen, 1969) for water chemistry and suspended sediment sampling.





At 0300 February 22, 1986, during high rates of water input caused by heavy rainfall and snowmelt, a debris avalanche occurred in a tributary stream about 70 meters above its confluence with the main WS-10 stream. The original material was augmented by water, soil.and organic debris in and along the main stream and a debris flow was created. The debris flow demolished the gage house and damaged the stilling wells. The mineral and organic debris filled the sediment basin and parking area and spilled over onto the road and down into the forest beyond the road. The main channel was scoured from about 30 meters below the confluence to the flume at the watershed outlet.

The volume of the failure was approximately 300 m^3, originating in a bedrock hollow. The volume of material that left the watershed and was deposited in the sediment basin, on the road and in the forest was estimated to be 700 m^3. Observation along with mapping indicated that as much as 50% of the deposited material was organic (mostly in the form of coarse woody material).

At the time of the debris flow, the stream was flowing at roughly 15 liter/sec/ha or about 5.4 ft^3/sec. Given the rate of hydrograph rise, the stream probably peaked slightly above the the highest rate of flow ever measured at WS-10. WS-9 peaked near 0830, 5 1/2 hours after the debris flow occurred.

The following table shows peak flows that have occurred since stream flow measurements began in 1967:

Before Logging		After Logging	
Jan. 11, 1972	18.95 ((liter/sec)/ha)	Dec. 13, 1977	15.19
Jan. 21, 1972	18.95	Feb. 22, 1986	15.02*
Dec. 5, 1971	15.62	Nov. 25, 1977	14.80
Dec. 4, 1968	14.97	Feb. 7, 1978	13.92
Nov. 8, 1968	11.95	Dec. 6, 1981	12.84
Mar. 2, 1972	11.76	Jan. 12, 1980	11.96
Nov. 26, 1971	11.70	Jan. 8, 1976	11.13
Dec. 9, 1971	11.50	Dec. 2, 1981	11.02
Jan. 5, 1975	8.86	Feb. 14, 1982	10.30
Jan. 28, 1967	8.45	Dec. 25, 1980	9.80

* Stream flow at the time the gage house was destroyed. Flow was undoubtedly much higher during the 4-6 hours after the debris flow occurred.

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Effects of Clearcutting on Rain-on-Snow Runoff in Western Oregon: A New Look at Old Studies

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Results of updating and reanalyzing streamflow data from studies in two experimental watersheds in western Oregon suggest that clearcut logging has altered snow accumulation and melt enough to have increased the size of peak flows caused by snowmelt during rainfall. In a 96-ha clearcut watershed in the transient snow zone, peak flows with return periods of roughly 3-8 years were higher than predicted by prelogging data. In a similarly clearcut 10-ha watershed, sizes of peak flows caused by melting of relatively deep snowpacks during rainfall were also higher after logging. Higher peak flows indicate a higher rate of water delivery to soils, which, in turn, suggests increased potential for both hillslope and channel erosion.

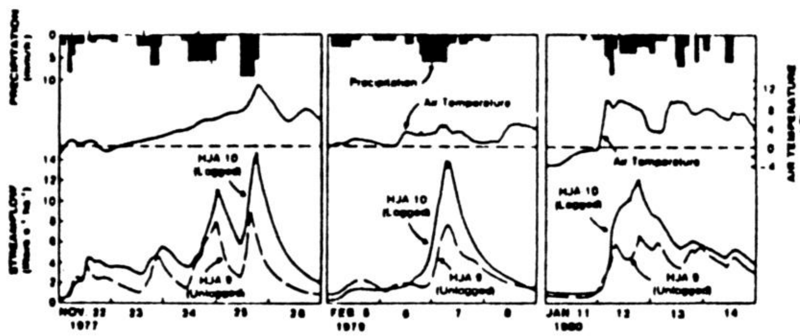


Fig. 5. Streamflow, precipitation, and air temperature associated with selected runoff events in the postlogging period at unlogged watershed HJA-9 and logged HJA-10, H. J. Andrews Experimental Forest, Oregon.

SITE 3. EXPERIMENTAL WATERSHEDS 1, 2, AND 3

These watersheds have long, documented histories of land use, research activities, and erosion (Fredriksen 1963, 1965, 1970, Fredriksen and Harr 1979). WS1 was clearcut between 1962 and 1966 using a skyline yarding system and slash was broadcast burned in a hot fire in 1966. WS3 had clearcuts of 5, 9, and 11 ha logged with high lead cable systems and slash was broadcast burned. Roads totalling 2.66 km were built at three levels in the watershed in 1959. Water and sediment yield, precipitation, and vegetation have been monitored since before logging (Table 1, Fredriksen and Harr, 1979, Dyrness, 1973). WS2 has been maintained as a control.

Vegetation removal caused several changes in streamflow characteristics. Removal of forest vegetation reduced both interception and transpiration, allowing more precipitation to leave the watershed by streamflow rather than evaporation. At WS1 initial increases in annual water yields were 45-50 cm, about 75 percent of which occurred during the winter rainy season (Rothacher 1970). Yield increases are diminishing as revegetation proceeds. Summer flows were increased 3-5 times the first few years after logging, but owing to rapid growth of riparian vegetation, such increases have disappeared (Rothacher, 1971). Changes at WS3 have been smaller because of less extensive logging in that watershed.

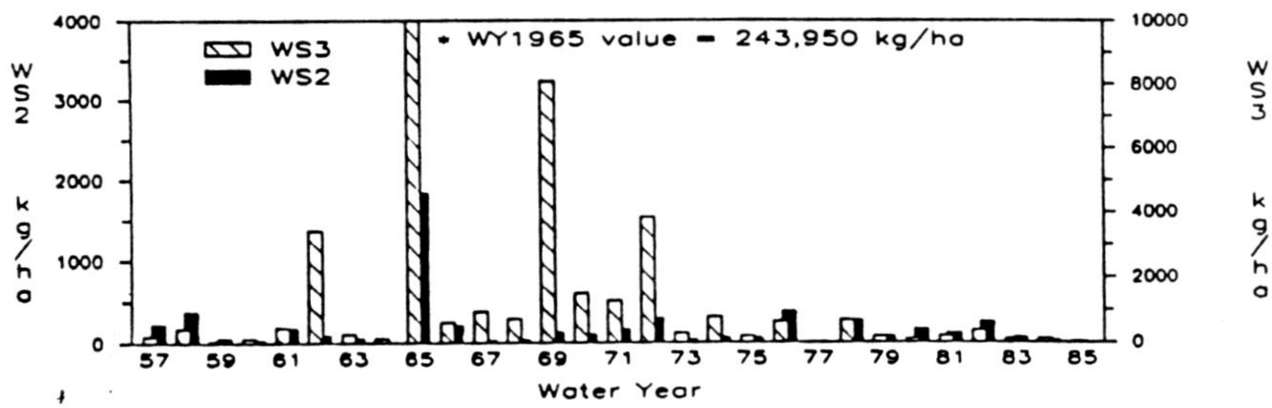
After logging, peak flows in fall and spring increased up to 2 times because soil water storage remained high due to reduced evapotranspiration (Rothacher, 1973). Large peak flows in winter were largely unchanged because (1) soils in logged and unlogged areas are both recharged by this time and respond similarly to precipitation, and (2) the hydrologic properties of soil were not altered to the extent that surface runoff became significant. On other experimental watersheds in western Oregon, where soil disturbance and compaction by roadbuilding and tractor yarding were much greater than on WS1, size of peak flows has been increased (Harr et al., 1975, Harr et al., 1979).

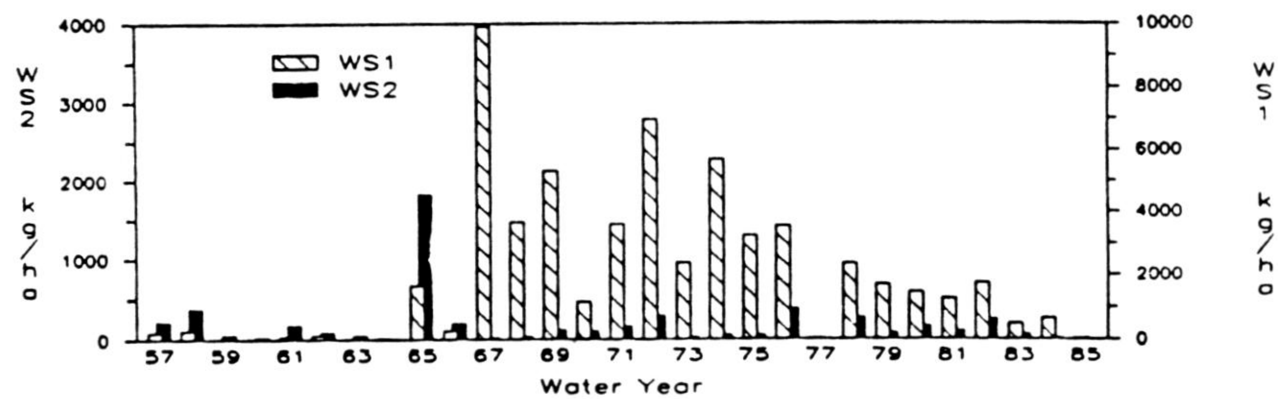
Variation of annual suspended and bedload (material trapped in sediment basin) sediment yields among watersheds has been great. In the first 14 years following cutting and burning WS1 has yielded 12 times as much particulate matter as WS2. Much of this increase has come from accelerated debris avalanche erosion after clearcutting. Seven debris avalanches (>75 m^3 each) moved soil down slope between 1964 and 1972. About 75 percent of the volume of soil moved by debris avalanches came from sites of current or past slump-earthflow activity, emphasizing the importance of interactions between these two types of processes. Surface erosion processes, particularly dry ravel, also increased substantially (Mersereau and Dyrness, 1972), but most sites of accelerated surface erosion have returned to rates more typical of forested areas. Soil which has entered the channel systems after logging has been routed slowly downstream through the numerous large logs and alder (Alnus rubra) and willow (Salix spp.) riparian vegetation. Despite burning and some physical removal of sediment-trapping organic matter from the main channel, much of the soil eroded from slopes after logging is still stored in the channel system.

WS3, on the other hand, experienced very rapid release of sediment. Most debris avalanche activity in the watershed was related to roads, principally fill slope failures (Fredriksen, 1963, 1965, 1970). The masses of fill material entered steep headwater channels and moved rapidly downstream sweeping up alluvium, colluvium, and streamside vegetation along the way. This series of debris torrents in the major December 1964 storm moved about two-thirds of the total particulate matter export from WS3 over the first 17 years after logging and road construction. About 80 percent of export for the period occurred in two days. Total post-logging yield has been about 90 times that of control WS2.

The debris torrent histories of WS1 and WS3 have determined the contrasts in their sediment yield histories. The road fill failures at the heads of long, steep, straight channels initiated debris torrents which flushed the WS3 channel system. No torrents have flushed the WS1 channels because of a variety of factors, including debris avalanche location in the watershed. WS1 debris avalanches have not had sufficient velocity, volume, and straight down-channel trajectory to trigger debris torrents. Annual sediment yield from WS 1 now exceeds yield from WS3 as sediment is slowly released from storage in the lower WS1 main channel and as soil is eroded from an active earthflow in the upper part of the watershed.

Comparative Sediment Yield from Study Watersheds





SITE 4. LOOKOUT CREEK EARTHFLOW

This 900 m long and 150 m wide earthflow is moving south into Lookout Creek at an average rate of about 10 cm/yr (Figure 2, Swanson and Swanston, 1977). Bedrock is a variety of volcaniclastic materials capped by a basalt flow which is the source of blocks forming the talus slope at the headscarp. Except for two small clearcut areas, the earthflow is forested, mainly with 400 to 500 year-old trees in the lower half while most trees on the upper half were established following a wildfire in the mid-1800's.

The earthflow landscape is irregular with scattered steep (>60%) slopes, which probably represent vegetated scarps, and many low relief areas, including poorly drained depressions. Drainage pattern and channel cross-sectional geometry are very irregular. The earthflow can be divided into three active blocks in the lower half of the whole earthflow. Each block is bounded by open, lateral shear cracks and a tension crack system across the head (Figure 2). The upper half of the earthflow does not appear to have been active in the last century or so, based on straight growth of trees in that area.

Earthflow movement is monitored with (1) stake arrays (strain rhombs) across active cracks to measure relative surface movement between blocks, (2) inclinometer tubes for monitoring vertical velocity profiles, (3) crackmeters to record continuously the opening of crack systems, (4) theodolite surveys of points on the earthflow from stable reference points off the earthflow, and (5) analysis of tree rings in scar tissue on live trees being split up the middle because they straddle an active crack (Swanson and Swanston, 1977). Water inputs in rain and snowmelt and groundwater levels are also continuously recorded, so that movement-water input relations can be examined. The purpose of the work is to gain a basic understanding of earthflow behavior so we can better assess impacts of management activities on this erosion process.

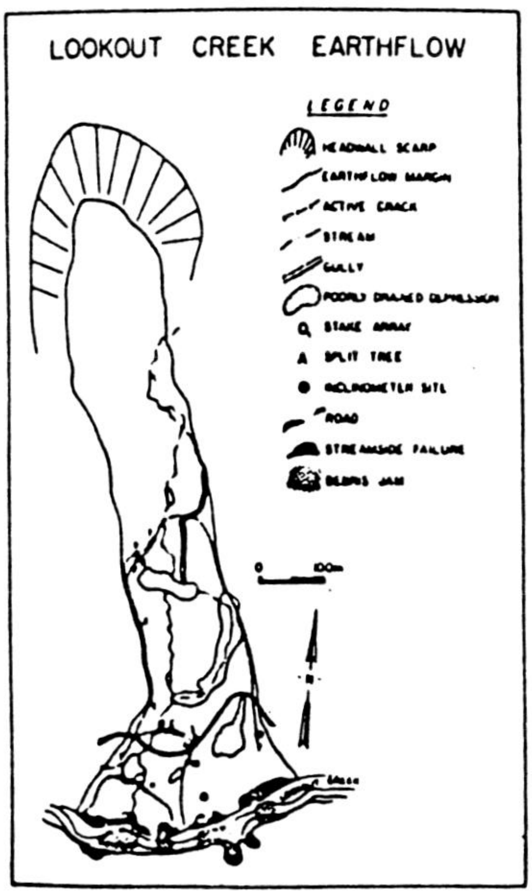


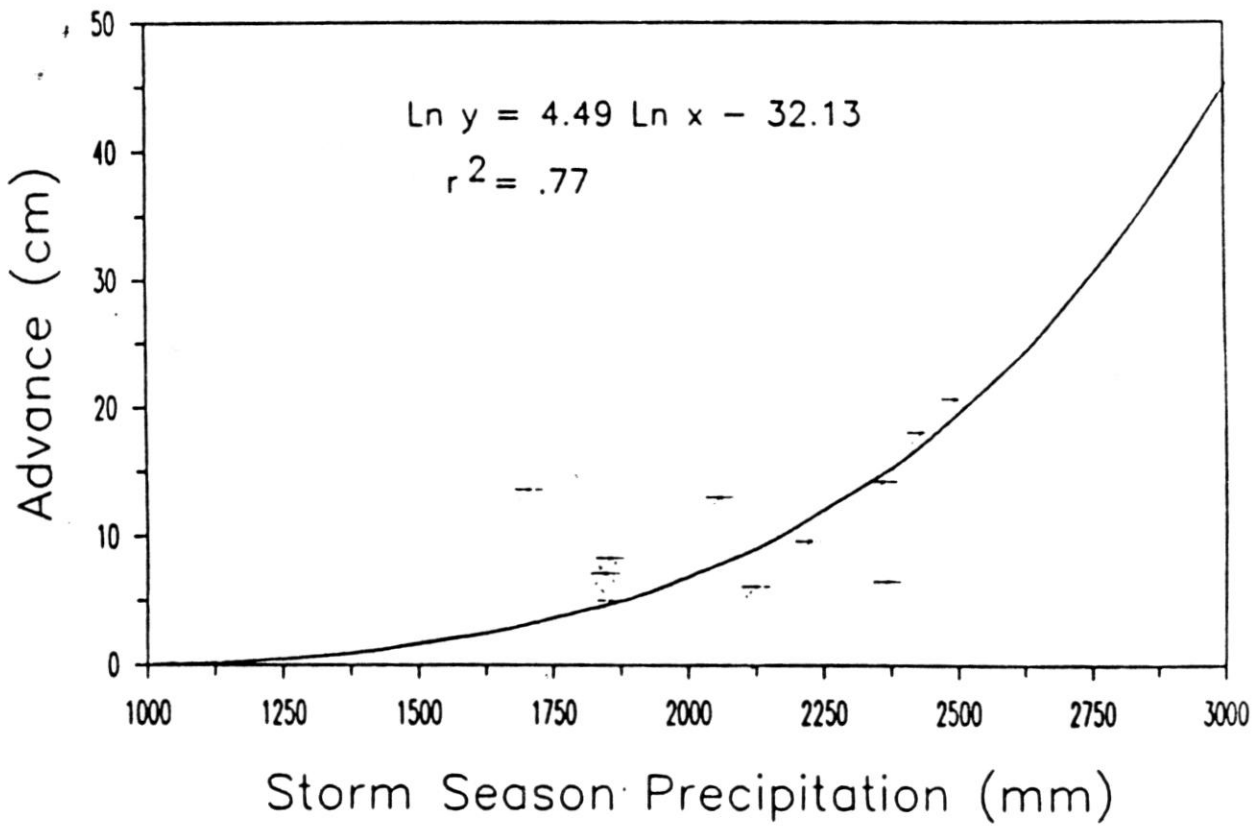
Figure 2. Map of Lookout Creek earthflow. Mapped by C. W. Lienkaemper (from Swanson and Swanston, 1977).

The five year record of annual movement from repeat surveys of stake arrays reveals large year-to-year differences in movement, determined by water inputs during current and previous years (Table 4). Very little movement occurred in the 1976-1977 drought year, and this dry period appears to have also caused low total movement rate in the next year. Movement in 1978-1979 was twice that in 1977-1978, although the more recent period had 20 percent less precipitation.

Earthflow Movement (cm/yr)

Water Year	S/A #2	S/A #3	S/A #6	Precip (mm)*
1974 - 1975	9.6	5.0	no data	2225
1975 - 1976	14.2	8.6	5.9	2361
1976 - 1977	0.2	0.7	0.7	1049
1977 - 1978	6.1	3.9	2.8	2125
1978 - 1979	13.6	9.2	6.0	1706
1979 - 1980	5.0	3.3	2.2	1858
1980 - 1981	8.3	6.2	3.7	1856
1981 - 1982	20.6	10.3	6.2	2496
1982 - 1983	6.5	3.7	2.5	2368
1983 - 1984	18.0	9.6	5.5	2432
1984 - 1985	7.1	4.7	2.6	1847
1985 - 1986	13.0	6.0	3.5	2060

* Precipitation October 1 - June 1



Comparison of crackmeter and precipitation records indicates tight control of movement rate by water availability (Figure 3). Movement at this site does not begin in the fall until nearly 90 cm of rain has fallen. Once the system is primed with water, movement continues at a slow rate until spring except for periods of accelerated movement in response to storm periods of water input in excess of about 12 cm/24 hr.

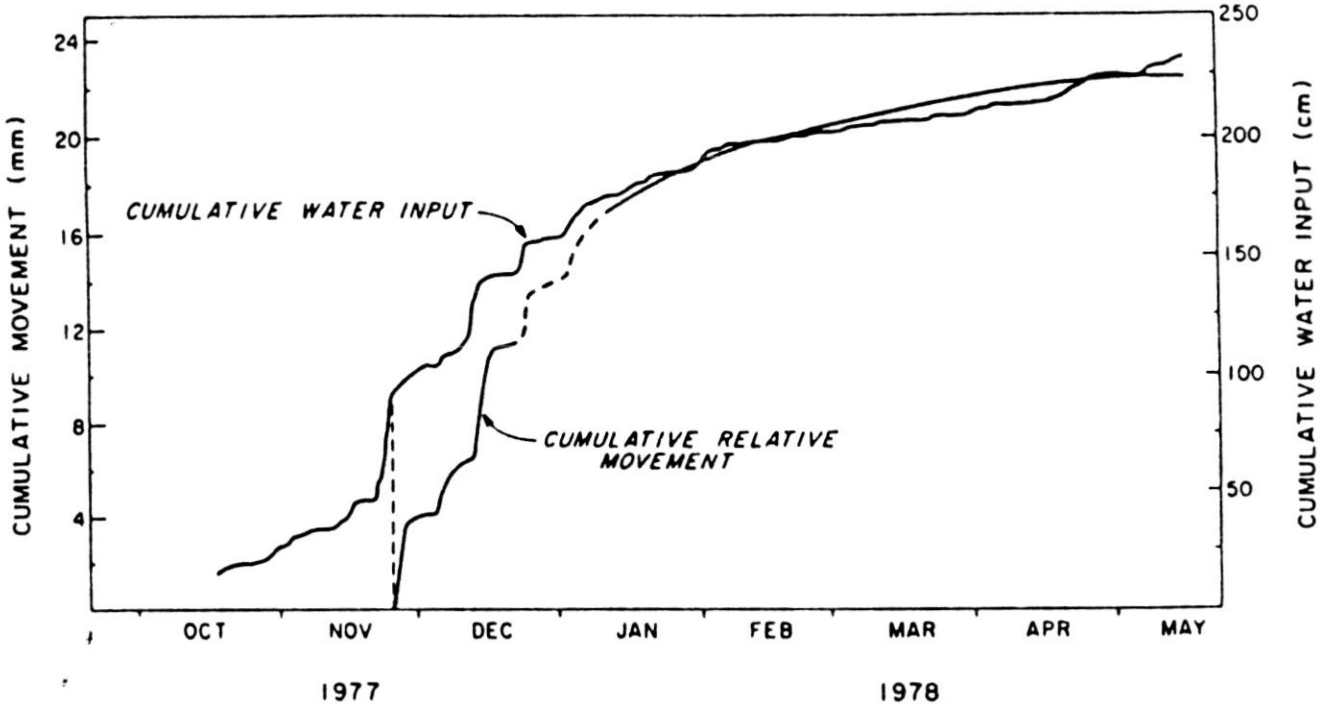
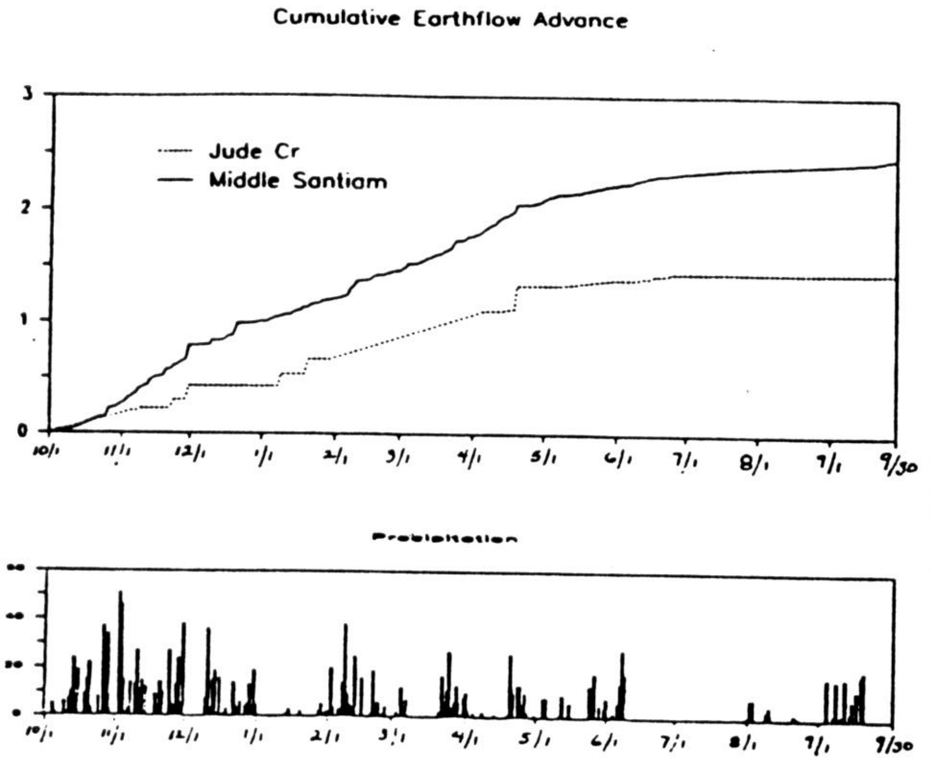
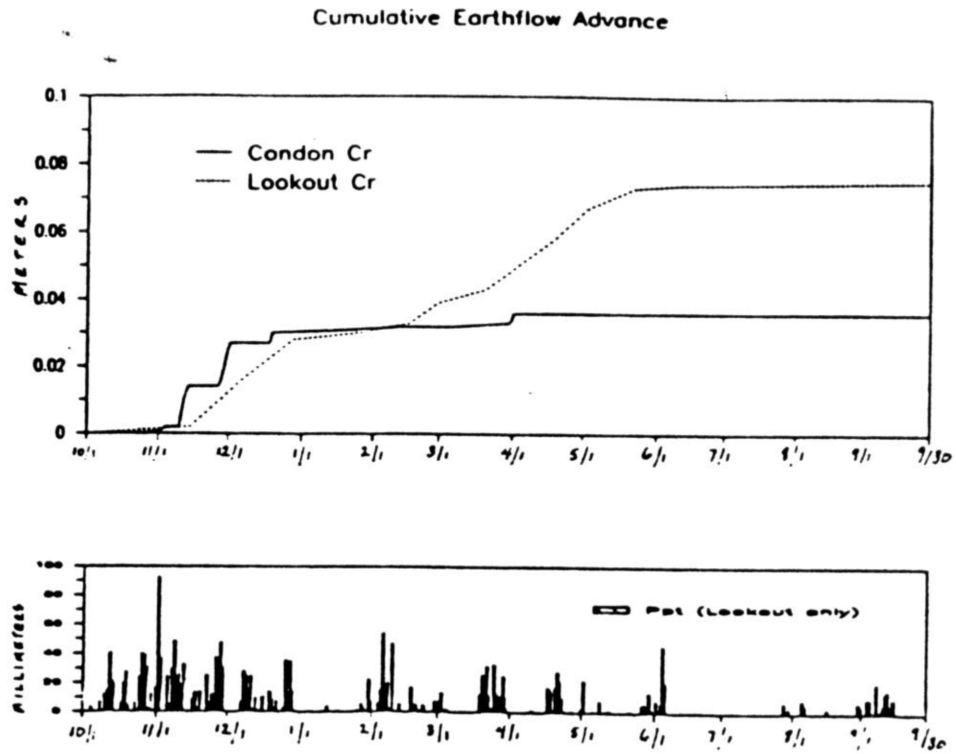


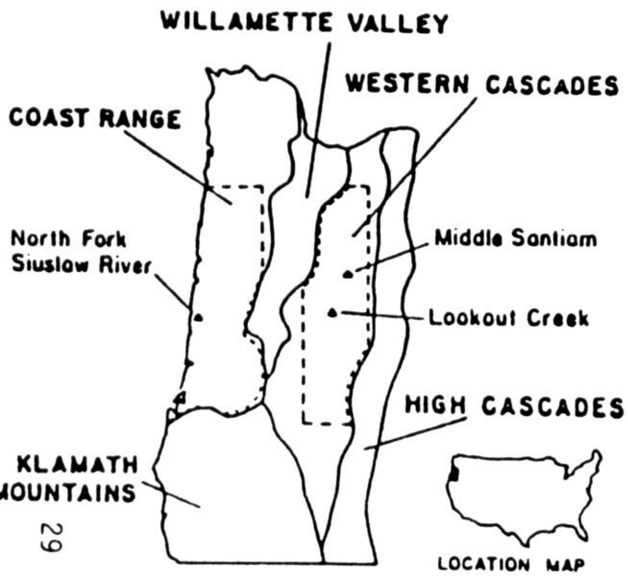
Figure 3. Cumulative water input and relative movement at crackmeter located at site 6 (Fig. 2). Movement curve is dashed for period when only total movement is known.

Sediment delivery to Lookout Creek occurs by bank cutting and streamside slides after long periods of earthflow movement constricting the channel. The last major episode of sediment input to Lookout Creek from this earthflow was during the December 1964 and January 1965 floods.

Earthflow movements can affect the structure and species composition of forest ecosystems. For example, differential movement near stake arrays 7, 8, and 9 (Figure 2) has tipped and split trees, leading to much windthrow, many holes in the canopy, and a multileveled forest with abundant understory vegetation. Close upslope, in areas of no recent earthflow movement, the canopy of Douglas-fir and western hemlock is complete, heavily shading lower levels of the forest and, thereby, greatly limiting understory development.







Comparison of movement at four earthflow study sites for Water Year 1985. Jude Creek and Middle Santiam earthflows are situated in the Middle Santiam River drainage. Condon Creek earthflow is in the North Fork Siuslaw River drainage. The Cascade earthflows are underlain by weathered, altered volcaniclastic bedrock. Spring snowmelt is important in the movement regimes of these features. Coast Range study sites are underlain by sandstones and siltstones. Precipitaion in this region rarely falls as snow.

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Mechanics and Stability of the Lookout Creek Earth Flow

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ABSTRACT

The Lookout Creek earth flow in the western Cascade Mountains of Oregon has moved an average of about 3.5 in. (8.9 cm) annually over the past decade. The currently active slide mass which has been moving for at least the past 80 years, overlies a 40,000-yr-old debris deposit. Monitored since 1975, measurable earth flow movement occurs only during the wet season; piezometric level, which is at or near the ground surface, varies only about 3 ft (0.9 m) between the wet and dry seasons. The base of the earth flow appears to be a shear zone about 10 in. (25 cm) thick located at a depth of 21.5 ft (6.5 m). Although earth flow movement does not correlate directly with piezometric levels, it does correlate with shear-zone pore-water pressures computed with a finite-difference approximation to the Terzaghi theory of one-dimensional consolidation; the finite-difference model uses piezometric pressure measured in the earth flow as a boundary condition. A rise in pore-water pressure in the shear zone of about 85 psf (4.1 kPa), or 1.4 ft (0.4 m) of water, is the calculated threshold value at which the earth flow begins to move. However, because the earth flow has a high drainage capacity, timber harvesting, which affects the ground-water regime, is unlikely to induce a large increase in movement.

SITE 5. REVEGETATING DEBRIS AVALANCHES AND TORRENT SITES

This road backslope failed in 1957, entered the channel below the road, and this material moved as a debris torrent downstream to Lookout Creek. The slide scar was planted with Douglas-fir seedlings many of which survived; but they have stunted growth and a chlorotic condition from growing in the nutrient deficient subsoil. The torrent track is now a lush stand of alder overtopped by a few black cottonwood (*Populus trihcocarpa*).

More than 140 such debris avalanches moving greater than 75 m^3 of soil have occurred from forested, clearcut, and road right-of-way sites since 1950 (Dyrness, 1967, Swanson and Dyrness, 1975). All but two events began in soil derived from volcaniclastic bedrock, indicating the strong control of bedrock and soil types on slope stability. In the debris avalanche-prone part of the Forest, rates of debris avalanche erosion from clearcuts and road right-of-way exceed the forest rate by 2.8 and 31 times respectively, based on rates calculated by dividing soil volume moved by 28 years and by the area in each land status at the end of the record. This estimate of management impact on debris avalanche erosion is similar to results of other studies in the Pacific Northwest (Swanston and Swanson, 1976).

This method of measuring management impacts can result in substantial under- or overestimates. Management impacts may be overestimated because (a) forest rates are used as the natural debris avalanche erosion rate, but the actual natural rate should include periods of accelerated erosion following natural disturbances such as wildfire, (b) in the case of roads, analysis on this time scale assesses impacts of some road construction, site location, and maintenance practices no longer employed, and (c) management impacts are only temporary and there may be a one to two decade period of accelerated erosion followed by a long interval of debris avalanche erosion at rates lower than in older forested areas. If (c) is true, cutting may affect the timing of debris avalanche erosion more than the overall long term rate. On the other hand, management impacts for general National Forest land may be underestimated by Andrews Forest data, because logging and roading have generally been conducted with the highest contemporary standards. Furthermore, intensity of timber harvest activities in the Forest has declined markedly since the mid-1960's. These estimates of impact are also conservative because the calculation method uses area in each land status at the end of the inventory period. This is the time of smallest forested area and largest clearcut and road right-of-way areas. Since we divide total volume of soil moved by debris avalanches for the period by these area terms, the forest debris avalanche erosion rate is overestimated and road and clearcut rates are underestimated.

There is need for assessment of debris avalanche impact on long term timber productivity. This involves determining both landscape area impacted by debris avalanches and the recovery of productivity on these sites. General observations suggest that area affected is less than a few percent of the landscape, even in debris avalanche-prone areas; but recovery rate may be so slow that at least one rotation of timber production may be lost.

Effects of Landslide Erosion on Subsequent Douglas-fir Growth and Stocking Levels in the Western Cascades, Oregon[1]

D. W. R. MILES, F. J. SWANSON, AND C. T. YOUNGBERG[2]

ABSTRACT

Shallow, rapid landslides are common events in steep terrain of the Pacific Northwest. The effect of landslides on timber growth potential of forest land was estimated by examining a 30-yr history of clearcutting and landsliding in the western Oregon Cascades. The height growth of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] and stocking level of all commercial conifer species on naturally regenerated landslides were compared with the height growth and stocking level on nearby, artificially regenerated clearcut units of similar aspect, elevation, ages, and slope position. Average height growth of Douglas-fir trees 5 to 18 years old on the landslides was reduced 62% compared to trees on clearcuts, and the average stocking level was reduced 25% from the clearcut level. One-third of the landslide area was estimated to be nonstockable because of unstable or impenetrable substrate.

Additional Index Words: forest productivity, soil disturbance, stocking potential.

Miles, D. W. R., F. J. Swanson, and C. T. Youngberg. 1984. Effects of landslide erosion on subsequent Douglas-fir growth and stocking levels in the western Cascades, Oregon. Soil Sci. Soc. Am. J. 48:667-671.

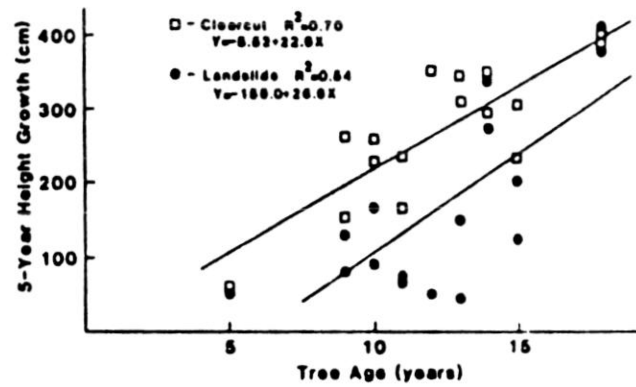

Fig. 2—Relationship between sapling age and height growth for trees on landslides and clearcuts.

Table 1—Sampled landslide-clearcut pairs site, tree growth, and stocking data.

							Landslide			Clearcut		
Landslide age	Site type†	Elevation	Aspect	Slope	Landslide map area	Tree age	5-yr ht. growth	(S)‡	Stocking	5-yr ht. growth	(S)‡	Stocking
yr		m	°	%	m²	yr	cm		%	cm		%
6	RF	850	335	74	105	§	§		29	¶		¶
9	RF	550	000	80	312	§	§		0	¶		¶
10	FO	790	350	100	237	§	§		0	¶		¶
11	RF	670	165	75	193	§	§		0	¶		¶
11	RF	1100	180	52	177	5	53.6	(20.5)	100	60.1	(13.6)	50
11	FO	760	350	173	36	6	33.5	(11.7)	17	¶		¶
11	RF	730	335	67	942	9	132.9	(92.6)	80	262.1	(49.8)	73
11	CC	730	015	70	550	10	97.9	(75.8)	95	225.9	(55.5)	90
11	FO	790	190	70	858	10	123.0	(41.2)	100	¶		¶
12	CC	820	010	79	79	§	§		54	¶		¶
14	RF	750	150	85	318	10	171.6	(54.4)	80	¶		¶
16	FO	670	235	80	145	§	§		14	¶		¶
16	RF	720	010	82	563	10	183.6	(55.2)	100	258.0	(59.7)	100
16	FO	760	100	57	325	11	67.4	(29.0)	88	236.4	(47.3)	77
16	RF	760	170	50	600	12	52.9	(35.5)	100	357.6	(112.4)	55
16	RF	580	130	85	1115	13	42.3	(31.2)	10	311.6	(81.3)	75
17	RC	730	130	40	452	11	75.9	(31.2)	80	164.5	(85.5)	100
17	CC	760	245	78	512	14	279.2	(66.4)	55	298.2	(58.5)	55
17	CC	910	130	50	236	14	338.9	(50.7)	50	348.5	(81.7)	90
18	RC	560	240	50	373	18	383.0	(141.2)	80	407.5	(85.8)	82
19	RF	490	090	70	1065	13	150.1	(70.7)	100	342.0	(55.9)	95
24	CC	690	280	80	1287	15	126.8	(81.2)	45	237.4	(88.9)	100
24	RF	760	020	70	307	18	417.3	(80.7)	80	396.4	(95.0)	100
26	CC	690	105	85	192	15	203.8	(94.6)	70	302.5	(97.1)	92
28	RF	460	110	70	586	9	81.3	(50.5)	30	168.9	(49.4)	100

† RF = roadfill, RC = roadcut, CC = clearcut, FO = forest.
‡ Standard deviation of height growth.
§ Landslide trees too young (less than 5 years old) or not Douglas-fir.
¶ No landslide trees measured, or no clearcuts suitable for comparison.

Vegetation composition on recent landslides in the Cascade Mountains of western Oregon

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Shallow, rapid landslides are common events and significant causes of vegetation disturbance in the Pacific Northwest. Landslides remove surface soil and above- and below-ground biomass from steep slopes and deposit them downslope or in streams. Vegetation cover and frequency were sampled on 25 landslides aged 6–28 years in the Cascade Mountains of western Oregon. Landslides sampled were debris avalanches ranging in surface area from 36 to 1287 m^2, in elevation from 460 to 1100 m, and in slope from 40 to 173%. The landslides originated in undisturbed forests, recently harvested tracts of timber, road cuts, and road fills. Substrates within landslide areas were separated into five types and the vegetation cover was estimated for each: bedrock, 19%; secondary erosion, 25%; primary scar, 51%; secondary deposition, 57%; primary deposition, 71%. Vegetation cover averaged 51% overall and cover ranged from 7 to 88% among landslide sites. No relation between landslide age and vegetation cover was established. *Pseudotsuga menziesii* (Mirb.) Franco was the most common tree species overall and dominated all substrates except bedrock, where no single tree species occurred on more than 20% of the plots. *Rubus ursinus* Cham. & Schlecht. was the most common shrub species on all substrates. *Anaphalis margaritacea* (L.) B & H and *Trientalis latifolia* Hook. were the most common herb species on all substrates except bedrock, where annual *Epilobium* spp. were most common.

TABLE 2. Average cover for major vegetation types on five landslide substrates

Substrate type	Area in type (%)	Cover (%)				
		Total	Tree	Shrub	Herb	Grass
Bedrock	4.5	19	7	4	8	2
Secondary erosion	11.4	25	8	3	17	2
Primary scar	63.8	51	24	13	22	4
Secondary deposition	6.1	57	28	19	18	2
Primary deposition	14.2	78	45	23	26	4

TABLE 1. Environment, site, and vegetation characteristics of landslide plots in western Oregon

Landslide age (years)	Site type*	Slope (%)	Aspect (°)	Landslide area (m^2)	Elevation (m)	Total vegetation cover (%) ($\pm$SD, n = 13–20)
6	RF	74	335	105	850	25.6±20.0
9	RF	80	0	312	550	38.5±21.9
10	FO	100	350	237	790	76.4±24.5
11	FO	173	350	36	760	27.2±32.2
11	FO	70	190	858	790	84.5±16.3
11	CC	70	15	550	730	24.8±31.6
11	RF	52	180	177	1100	35.6±32.5
11	RF	67	335	942	730	47.8±33.3
11	RF	75	165	193	670	9.2±11.0
12	CC	79	10	79	820	38.3±40.2
14	RF	85	150	318	750	82.4±20.2
16	FO	57	100	325	760	66.7±25.8
16	FO	80	235	145	670	57.2±44.6
16	RF	50	170	500	760	65.9±28.1
16	RF	82	10	563	720	77.8±23.2
16	RF	85	130	1115	580	7.1±8.3
17	CC	78	245	512	760	58.2±30.8
17	CC	50	130	236	910	76.9±13.8
17	RC	40	130	452	730	50.0±31.9
18	RC	50	240	373	560	58.0±28.2
19	RF	70	90	1065	490	53.8±31.4
24	CC	80	280	1287	690	11.2±12.8
24	RF	70	20	307	760	86.8±16.6
26	CC	85	105	192	690	69.3±19.6
28	RF	70	110	586	460	42.4±28.9

*RF, road fill; FO, forest; CC, clear-cutting; RC, road cut.

SITE 6. MACK CREEK

The adjacent clearcut and forested reaches of Mack Creek have been sites of intensive stream ecosystem research since the early 1970's, including studies of conditions and roles of large organic debris in streams. Large woody debris derived from the adjacent forest shapes aquatic habitats, provides nutrients, cover, and substrate for aquatic organisms, and regulates movement of sediment, particulate organic matter, and water through the stream system. Consequently, natural or man-imposed changes in debris conditions affect physical and biological functions of streams.

Debris conditions vary with stream size. Concentrations of coarse woody debris (>10 cm diameter) generally decrease downstream where wider channels have greater transport capability and the canopy is open over the stream, so input of large woody debris is lower. Large debris in first- and second-order streams is randomly distributed along streams, and is generally located where it initially fell, because the stream is too small to move it. Intermediate-sized streams, such as this third-order section of Mack Creek, can move some large pieces of debris at flood flows, but not whole down trees. Therefore, these streams have scattered, distinct accumulations, many of them affecting the full channel width. Large rivers can transport all debris that enters them and they deposit this material high on the banks and on upstream ends of islands. This material then affects the stream only at high flow.

We have studied the history of large debris in Mack Creek by dating log input to the stream with tree-ring analysis (Swanson et al., 1976) and by following changes in debris conditions through time. Generally we have observed scattered inputs during wind storms and this material moves and accumulates on the large, stable debris jams during very high flow events. Maps made in 1975 of Mack Creek above the road crossing (Figures 4 and 5) can be compared with the distribution of logs today to get a measure of variability of debris conditions. Much of the change occurred during a high flow event in November 1977. The main accumulations which were keyed on large, down, old growth trees (MA-13 and MA-16) have remained intact with minor modification. Accumulation MA-14 appears to have washed out because the main piece had decayed and partially collapsed under its own weight. It was, therefore, hit directly, broken up, and washed downstream by the high flow. So in streams of this size, debris conditions change as a result of new inputs, redistribution during high flows, and the slow, continual process of wood decomposition.

Monitoring of this site will continue on a long term basis. Changes are observed by annually mapping any new or moved pieces and by repeat surveys of monumented channel cross-sections. Changes in the adjacent forest will be followed by annual checks of a map showing standing and down live and dead trees in a 2-ha area straddling the creek. Debris conditions in streams of other sizes of the same forest type, and some flowing through younger stands, are being monitored at other sites in the area.

Dynamics of large woody debris in streams in old-growth Douglas-fir forests

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Transfer of large woody debris (>10 cm diameter) from old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) forests into five first- to fifth-order stream reaches (drainage areas of 0.1 to 60.5 km^2) has ranged from 2.0 to 8.8 Mg·ha^{-1}·year^{-1} in 7- to 9-year study periods. Amounts of large debris in these streams range from 230 to 750 Mg·ha^{-1}, with generally lower values in larger channels. The addition of woody debris is widely scattered in time and space and comes mainly from single trees rooted away from the streambank. We infer that wind is a major agent for entry of wood into these streams. Downstream movement of debris is strongly related to length of individual pieces; most pieces that moved were shorter than bankfull width.

TABLE 1. Geomorphic characteristics of study areas and year of study initiation

Study site	Initiation of study	Stream order	Elevation (m)	Watershed area (km^2)	Reach length (m)	Sample area (ha)	Stream gradient (%)	Mean bankfull width (m)
Watershed 9	1976	1	500	0.1	170	0.06	37	3.5
Watershed 2	1976	2	550	0.8	146	0.08	26	5.2
Mack Creek	1975	3	785	6.0	332	0.40	13	11.9
Upper Lookout Creek	1975	3	775	11.7	483	0.75	8	15.5
Lower Lookout Creek	1977	5	435	60.5	350	0.84	3	24.0

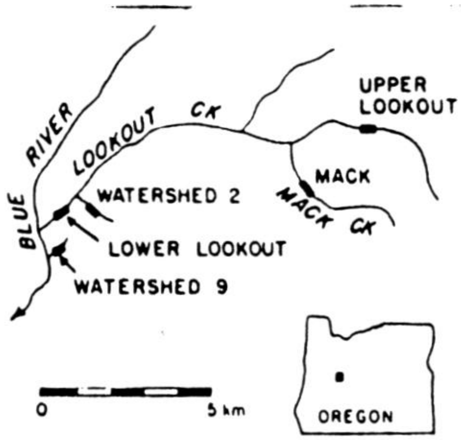


FIG. 1. Woody debris study sites are located in the H. J. Andrews Experimental Forest, Willamette National Forest, Oregon.

TABLE 2. Estimates of the amount and input rates of woody debris for each study site; mass values are based on bulk density = 0.40 g cm^{-3} (see text for discussion)

Study site	Amount of woody debris		Input rate		Turnover time (years)
	Volume (m^3·ha^{-1})	Mass (Mg·ha^{-1})	Volume (m^3·ha^{-1}·year^{-1})	Mass (Mg·ha^{-1}·year^{-1})	
Watershed 9	500	200	14	6.3	36
Watershed 2	750	300	9	4.0	83
Mack Creek	570	228	11	5.0	52
Upper Lookout Creek	340	136	5	2.0	68
Lower Lookout Creek	230	92	20	8.8	12

Table 5. Summary of woody debris delivery and redistribution by study site

Study site	Date of first map	No. of pieces mapped	No. of pieces moved between first map and 1984	No. of pieces added between first map and 1984	No. of added pieces that moved
Watershed 9	1976	80	5	12	0
Watershed 2	1976	87	7	15	0
Mack Creek	1975	106	53	43	18
Upper Lookout Creek	1975	305	40	21	5
Lower Lookout Creek	1977	46	30	12	6

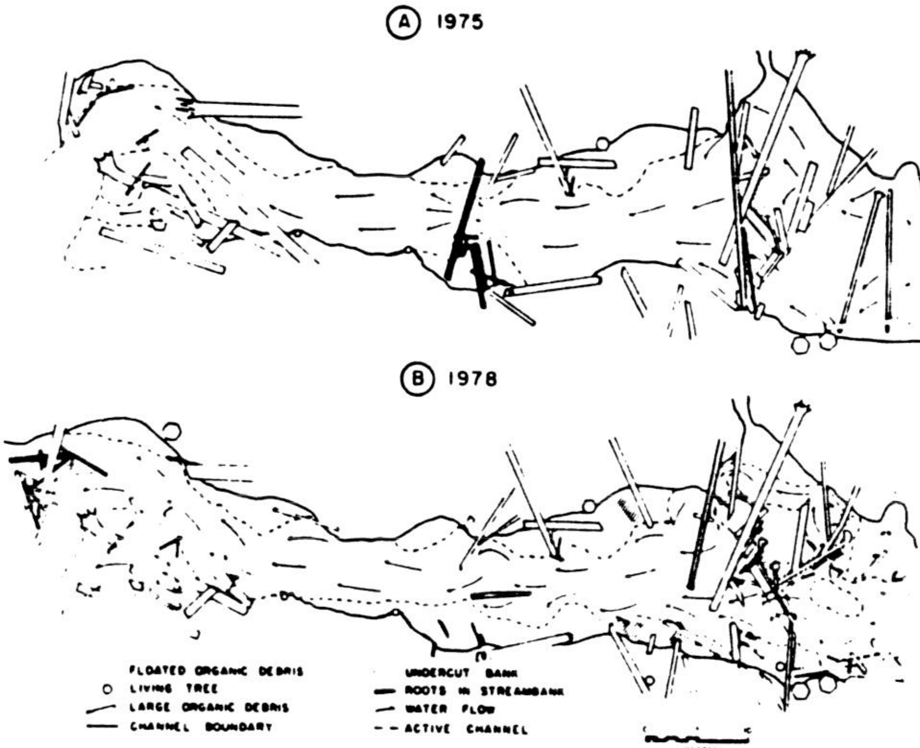


Fig. 2. The November 1977 high flow redistributed a large amount of wood in Mack Creek. For example, most of the material highlighted i black (A) was washed out of the study area, but some material was redeposited at the next bend (black pieces in B). The stippled log in A broke an pivoted downstream.

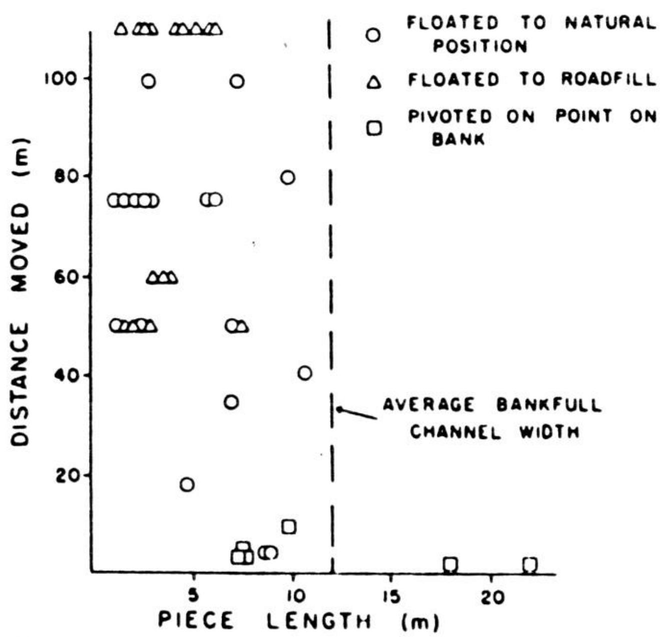
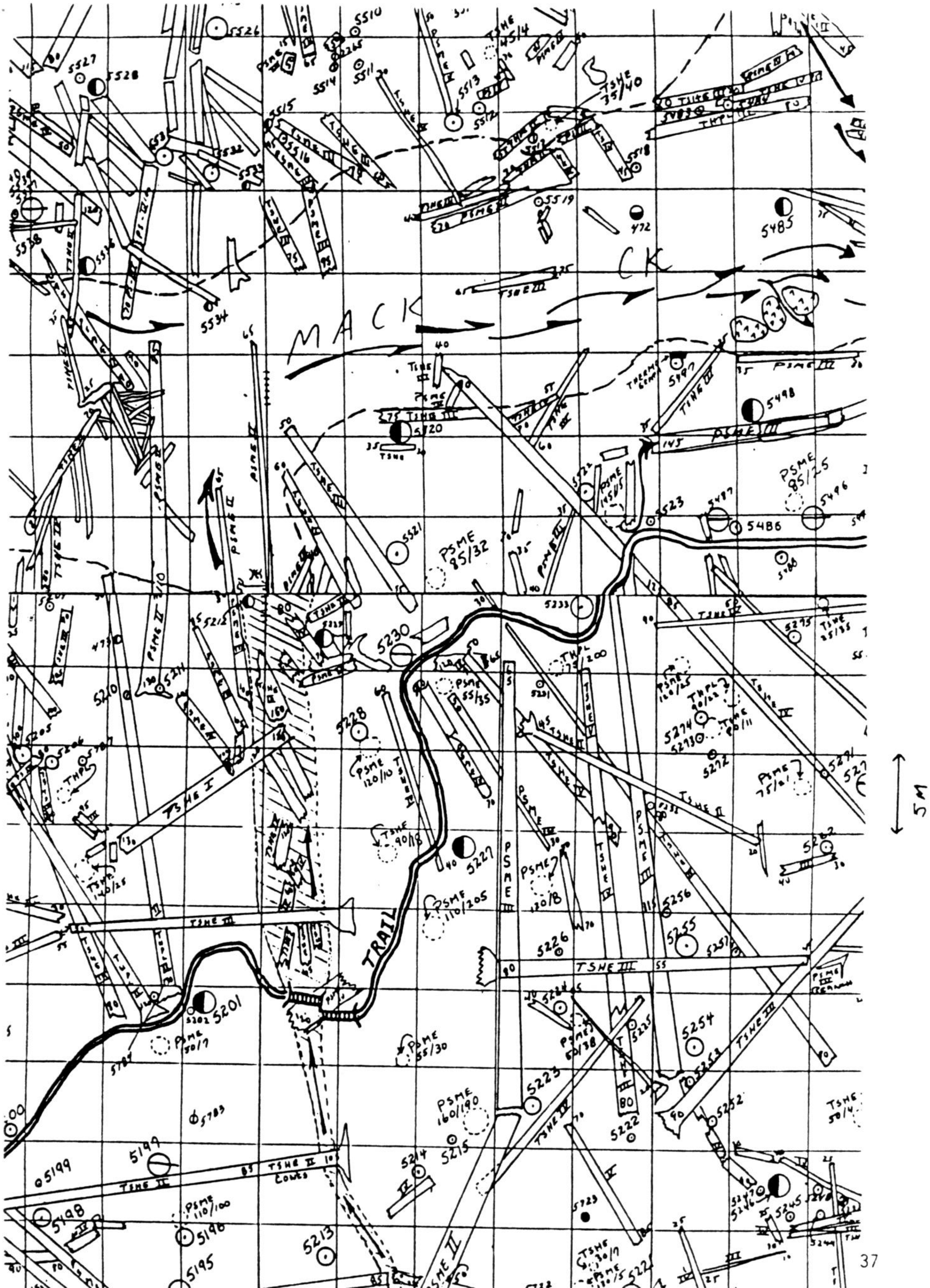


Fig. 3. Unanchored logs that were shorter than bankfull width were


MACK
CK
TRAIL
5M
PSME 85/32
PSME 85/25
PSME 160/190
PSME 55/30
PSME 50/7
PSME 110/205
PSME 120/10
PSME 110/100
THPL 75/200
TSHE 90/18
TSHE 35/40
TSHE III
TSHE II
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SITE 7: CHANNEL AND VALLEY FLOOR MORPHOLOGY OF LOOKOUT CREEK

We are interested in the development and pattern of landforms both within the channel and along the valley floor in high-gradient, boulder-bed mountain streams. These patterns can be viewed across a hierarchy of spatial scales extending from the drainage basin to individual particles (Fig. 1). At this stop, we can view the organization of a 5th-order mountain stream at several of these scales. Lookout Creek, a tributary of Blue River is the master stream for the H.J. Andrews and is typical of streams of this size in the western Cascades. It is one of the primary sites for interdisciplinary studies of riparian zone structure and function among geomorphologists, terrestrial ecologists, and aquatic biologists.

The channel of Lookout Creek is organized into a set of bedform features, termed channel units. These features, which generally measure more than one channel width in length, form a distinctive scale of variation in mountain streams. We have identified five major and three minor unit types; key parameters distinguishing units include bed slope, relative roughness, flow pattern, and the proportion of unit surface area exhibiting supercritical or upper regime flow characteristics (Table 1). In channels having multiple unit types (as opposed to just pools and riffles), the sequence or longitudinal arrangement of channel units is an important property of the system. First-order Markov analysis of channel unit sequences on Lookout Creek and elsewhere (Grant 1986) demonstrates preferred sequence combinations (Fig. 2). We expect that sequence and distribution of channel units will provide a basis for discriminating the morphology of stream reaches in different geomorphic terranes.

In this part of Lookout Creek, the valley floor appears as a set of low surfaces supporting vegetation of widely different ages (Fig. 3). Adjacent to the channel is a low (0.5-1.0 m) surface similar to the active channel shelf described by Osterkamp and Hupp (1984) and colonized by annual herbs and early successional species (e.g., <u>Salix</u>). This surface commonly is inundated during winter high flows. Away from the channel are 1.0-2.0 m high surfaces composed of boulders and large cobbles and supporting dense stands of young (20 year-old) alder (<u>Alnus</u> <u>rubra</u>). These surfaces date from the 1964 storm, a flood with approximately a 100-year return period which eroded valley bottoms, stripped old-growth and younger vegetation from channel-adjacent surfaces and deposited boulders and woody debris. Shade-tolerant Douglas-fir are now becoming established on these surfaces. Bordering the channel in places but generally at some distance from the channel are higher (2-3 m) surfaces supporting old-growth Douglas-fir, western hemlock, and western red cedar.

Current research at this site is investigating the linkages between the stream and the adjacent forest. The proportion of stream perimeter adjacent to surfaces supporting vegetation of different stature and type directly affects input of light, nutritional resources, and organic debris to the stream. We hypothesize that the organization of in-stream biota is correspondingly influenced by the structure of the surrounding forest.

Other valley floor features of interest include secondary channels and alluvial fans from tributary watersheds (Fig. 3). Secondary channels form as the channel re-occupies or abandons old channels during high flow events; changes in channel location are often precipitated by shifting woody debris accumulations. The

Fig. 1: A hierarchical organization for stream networks.

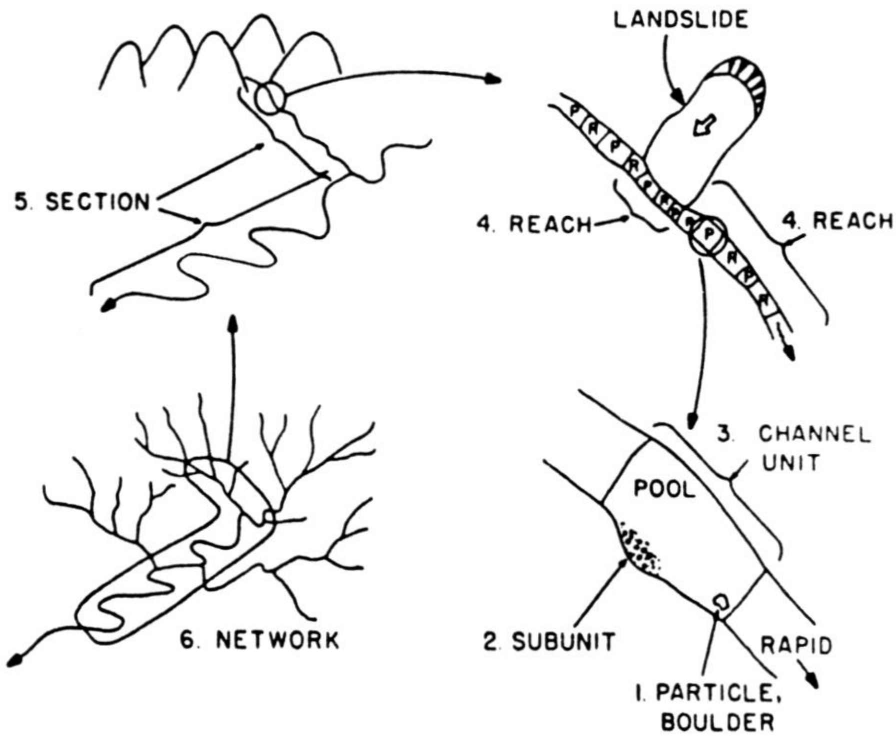


Fig. 2: Preferred two-unit sequences for French Pete Creek based on transition probabilities. Only sequences with transition probabilities greater than 0.02 are shown. Arrows extend from upstream to downstream unit.

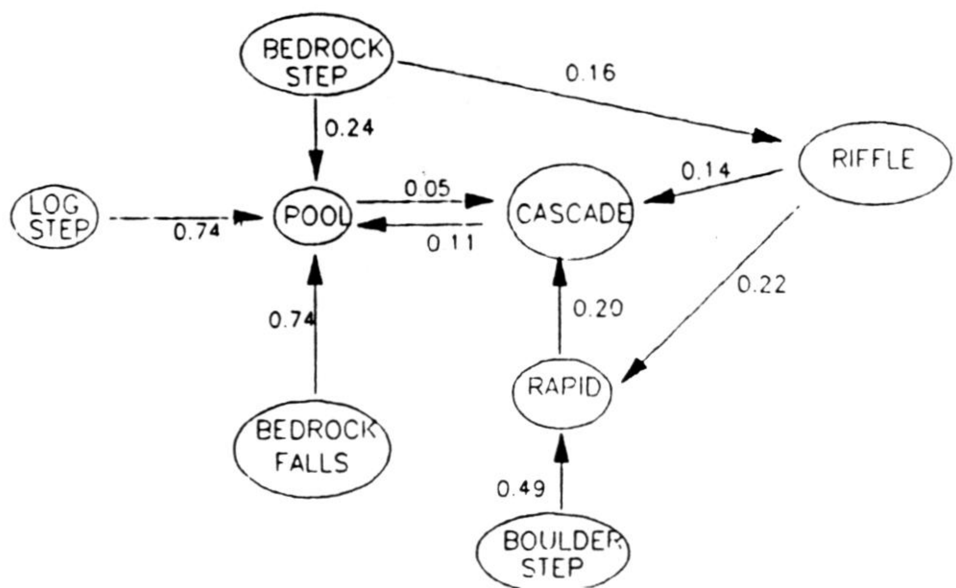
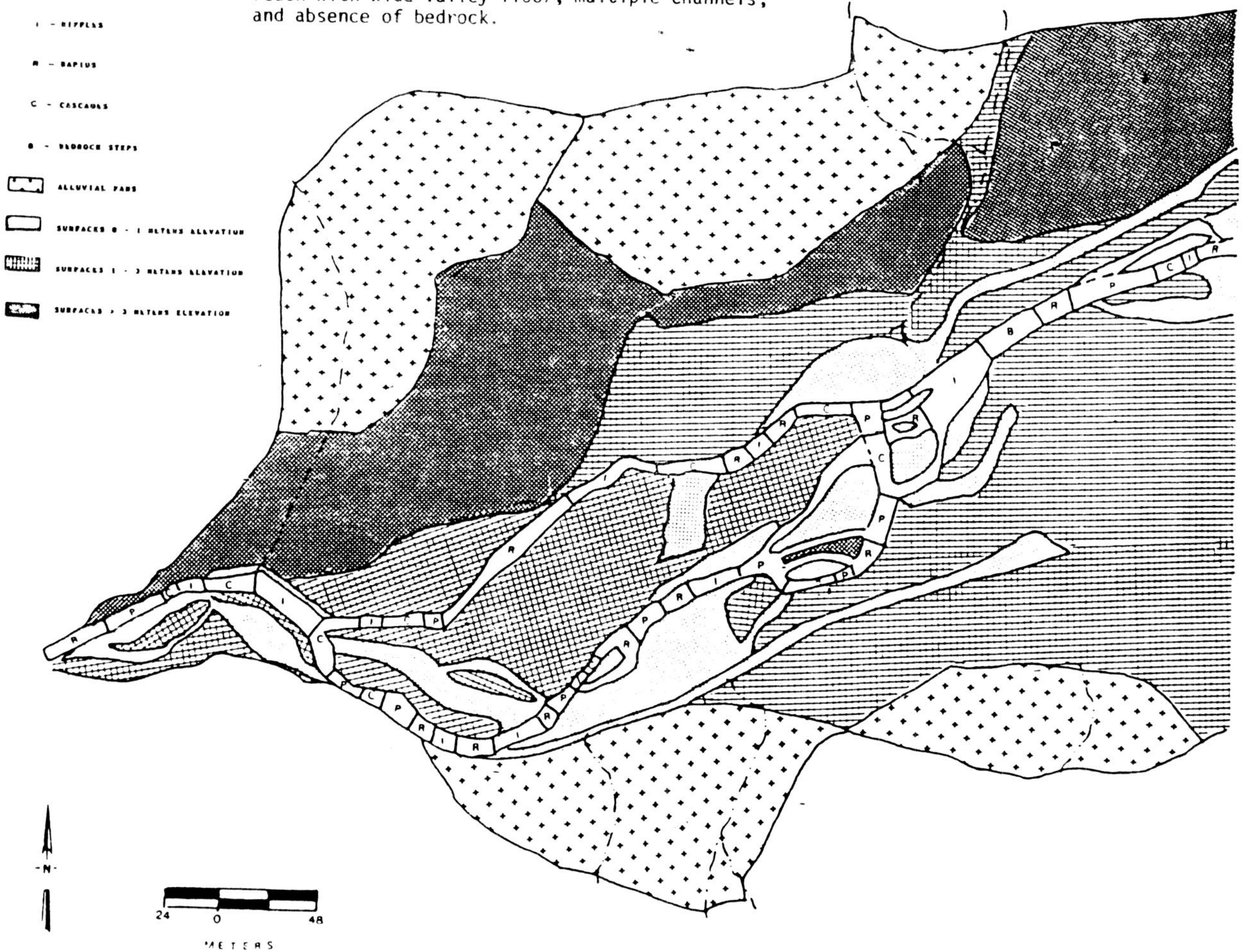


Fig. 3: Channel and valley floor landforms in the vicinity of the concrete bridge site (site 7), Lookout Creek. The section of stream shown here is a typical unconstrained reach with wide valley floor, multiple channels, and absence of bedrock.



size, degree of dissection, and stratigraphy of the fans is related to terrace-floodplain width and drainage area and debris flow potential of tributaries. Fans at the mouths of larger watersheds (about 40 to 200 ha) are deeply dissected by the tributary streams and had stopped growing by Mazama-ash time. Many smaller watersheds, on the other hand, continue to construct small fans in which Mazama ash may be buried up to 4 m deep.

Channel and valley floor features comprise one level of the spatial hierarchy (Fig. 1). At the next broader level, we can view these features as organized into a set of 'reach-types', defined by the type and degree of lateral constraint imposed on the channel by the valley walls. We distinguish reaches as <u>constrained</u> or <u>unconstrained</u> depending on whether the high-water channel occupies greater or less than one-half of the total active (<3 m above the low flow channel) valley floor width (Fig. 4; Table 2). Constrained reaches result from bedrock outcrops in the valley wall, where active or dormant earthflows impinge directly on the channel or where the channel is bordered by resistant banks due to alluvial fans or glacial outwash.

Reaches differ in terms of both channel and valley floor characteristics (Table 2). Constrained reaches tend to have a greater proportion of their length in pools than unconstrained reaches; this may be due to higher frequency of pool-forming elements, such as bedrock outcrops and large boulders in the channel along these reaches (Lisle 1986) (Table 2). Since constrained reaches are as steep or steeper than unconstrained reaches, they also have greater frequencies of steep (rapid and cascade) units (Fig. 5). Unconstrained reaches, such as the one we are located in, have wider zones of herbaceous and non-woody vegetation bordering the channel and greater distances to coniferous vegetation (Table 2), suggesting that detrital and light input to these reaches is substantially different than in constrained reaches. Multiple channels are also characteristic of unconstrained reaches (Fig. 3).

Current research is focusing on both morphogenesis and dynamics of channel and valley floor units as well as quantitative description and comparison of reach-types in different geomorphic settings. We expect that the sequence of reaches along a channel will prove significant both in interpreting the processes leading to reach formation and understanding how biological systems track physical processes and landforms.

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ig. 4: Map of the lower 5.5 km section of Lookout Creek showing each-type designations: A = bedrock-constrained; B = nconstrained; C = earthflow-constrained; D = unconstrained. ote location of wide, unconstrained (reach D), shown in detail n Fig. 3, is just upstream from where a large dormant earthflow omplex constricts the valley floor to less than two channel idths (reach C). Channel and valley floor characteristics of each-types are given in Table 2.

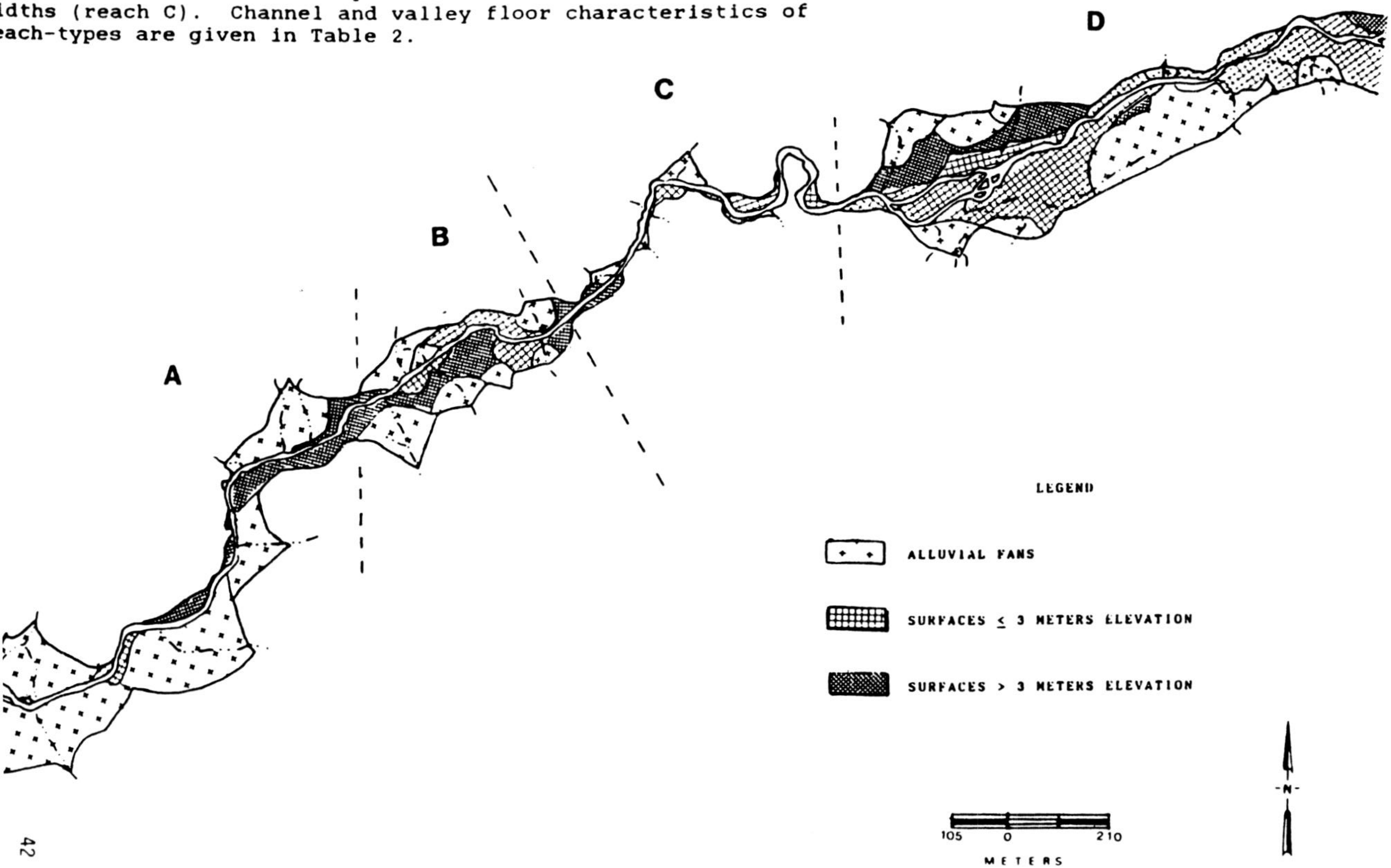

Fig. 5: Longitudinal profile of lower Lookout Creek. Capital letters refer to reach designations mapped in Fig. 4 and described in Table 2. Numbers in parentheses are average reach gradients.

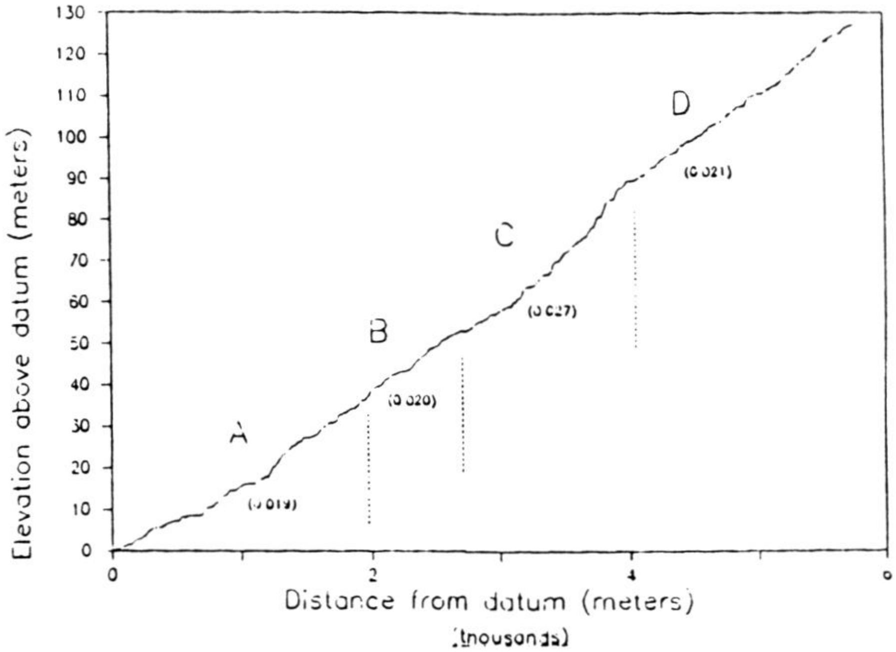

Table 1: Summary of average channel unit characteristics, Lookout Creek

	Length (channel widths)	Slope (%)	Unit slope/ topographic long slope	Unit area in super-critical flow (%)	Relative roughness (D84/R)	Width ratio (a) Lowflow (m/m)	Width ratio (a) Active (m/m)	Flow pattern
Pools	1.1	0.4	0.2	0-5	0.3-0.5	0.9	1.0	Divergent
Riffles	1.4	1.0	0.5	5-15	0.5-1.0	1.0	0.8	Divergent
Rapids	1.6	2.4	1.1	15-40	0.5-1.5	1.2	1.0	Straight
Cascades	1.1	5.2	2.4	40-100	1.0-2.0	1.5	1.3	Convergent
Bedrock falls	1.4	5.6	2.6	40-100	1.0-2.0	1.3	1.0	Convergent
Bedrock steps	0.3	9.2	4.2	90-100	1.0	0.9	0.9	Straight
Boulder steps	0.3	13.6	6.2	90-100	1.0	1.3	1.0	Straight

(a) Width ratio is the ratio of upstream to downstream channel width, defined in terms of either the lowflow channel or the active (unvegetated or highwater) channel.

Table 2: Some Characteristics of Reaches of Lower Lookout Creek Location. Location of Reaches Shwon in Fig. 4.

Reach	Constriction Index[1]	Length (m)	Water surface Slope	% Bedrock Bank	% Bedrock Bed	Boulders (>1.5m) per 100 m	% Channel Length in Pools	Average Width, Non-Forest Veg. (m)	Distance to Conifer (m)
A (bedrock constrained)	1.2	1980	0.019	44	21	3.8	39	3	7
B (unconstrained)	2.8	720	0.020	15	15	6.0	19	5	13
C (earthflow)	1.3	1350	0.027	24	6	11.7	32	4	7
D (unconstrained)	5.6	1720	0.021	2	1	1.5	20	9	40

[1] Width of valley floor <3 m above low flow channel / average channel width.

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