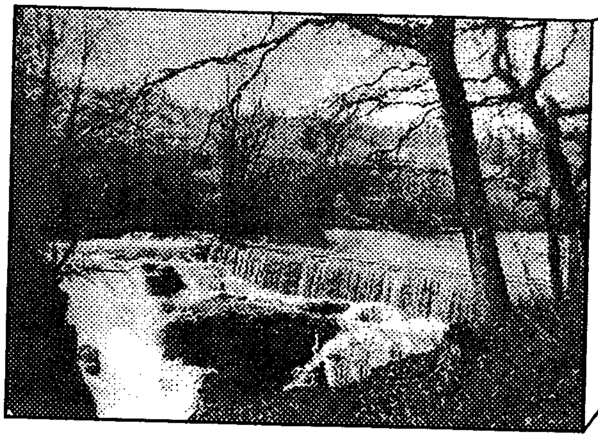
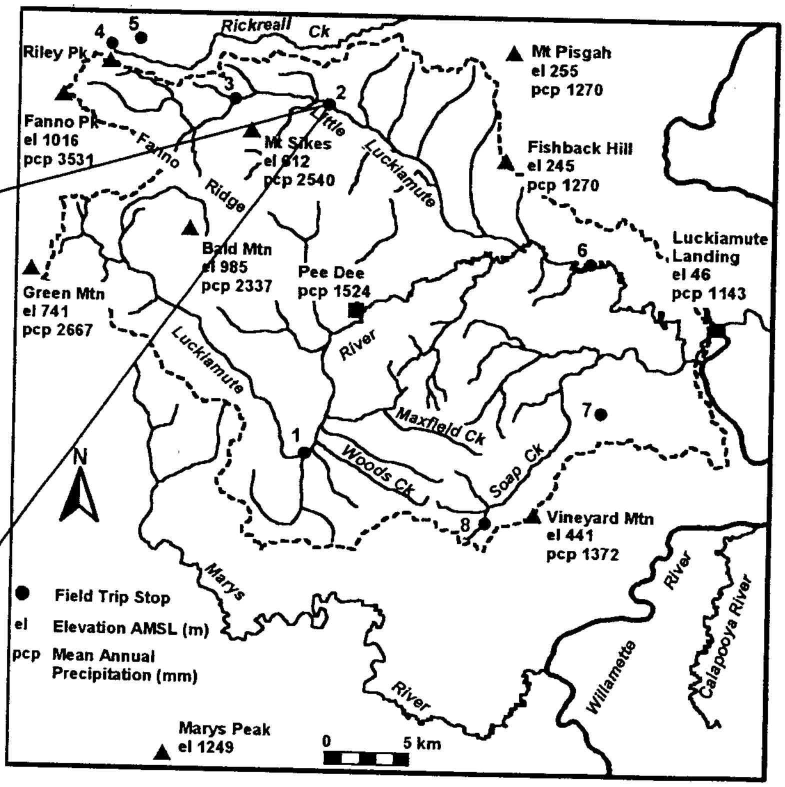
Appended Field Guide to the Luckiamute River Watershed, Upper Willamette Basin

Pre-Meeting Field Trip
May 12, 2004





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Luckiamute River Watershed, Upper Willamette Basin: An Integrated Environmental Study for K–12 Educators

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INTRODUCTION

This field trip examines aspects of environmental science in the Luckiamute River Watershed, upper Willamette Basin, Oregon. A 1-day itinerary is designed for K–12 science educators with an interest in watershed studies and natural science disciplines (earth science, biology, chemistry).

Selected localities, natural features, and respective discussions for this field trip were derived from a 6-week Environmental Science Institute course convened during Summer 2001 at Western Oregon University. The institute course targeted undergraduate science majors, preservice education majors, practicing education professionals, and masters-level education students. The course was designed with four integrated science modules in geomorphology, field botany, paleoclimatology, and environmental chemistry. The geomorphology module focused on landscape analysis, geographic information systems, surficial mapping methodology, and field hydrology. The botany module emphasized characterization of riparian habitats, floristic changes over time, impacts of invasive plant species, and field monitoring methodologies. The paleoclimatology module included derivation of climate variables from modern and ancient flora, and examination of the Tertiary fossil record of the mid-Willamette Valley. The environmental chemistry module examined land use and water quality issues in the Willamette Basin, with a focus on aqueous chemistry, field measurement techniques, and pesticide contamination. Discussion topics of this field trip concentrate on the geomorphology, botany, and environmental chemistry of the Luckiamute Watershed. Selected aspects of the paleoclimatology module are covered in a companion paper in this volume (Myers and others, 2002). As this field trip and guidebook are sponsored by an alliance of geoscience organizations, the content emphasis is accordingly weighted toward a geologic perspective.

The field guide is organized into two principal sections. The first provides a literature review and background information on the regional setting of the Luckiamute River. The second is a detailed road log and stop description, with suggestions for field-based science-education activities.

The road log for this 1-day field trip begins at the north entrance to the CH2M Hill Alumni Center on the campus of Oregon State University, Corvallis. The trip consists of a 100+ mile loop through the Luckiamute Watershed via Philomath Boulevard, Kings Valley Highway (Oregon 223), Falls City Road, Monmouth Road, Helmick Road, Oregon 99W, and Soap Creek Road (Fig. 1). Field trip stops include those that are both scenic and scientific, with an emphasis on integrated environmental studies at the watershed scale.

PHYSIOGRAPHY

The Luckiamute River constitutes a part of the Willamette Basin in west-central Oregon (Fig. 2). This seventh-order watershed (Strahler, 1957) drains eastward from the Coast Range into the Willamette River and occupies a total drainage area of 815 km^2. The Luckiamute Basin is bounded by the Willamette River to the east, the crest of the Coast Range to the west, Green Mountain and Marys River to the south, and the Rickreall Creek Watershed to the north (Fig. 2). Land surface elevations range from 46 m (150 ft) at the confluence with the Willamette

Field Guide to Geologic Processes in Cascadia: Oregon Department of Geology and Mineral Industries Special Paper 36, 2002.

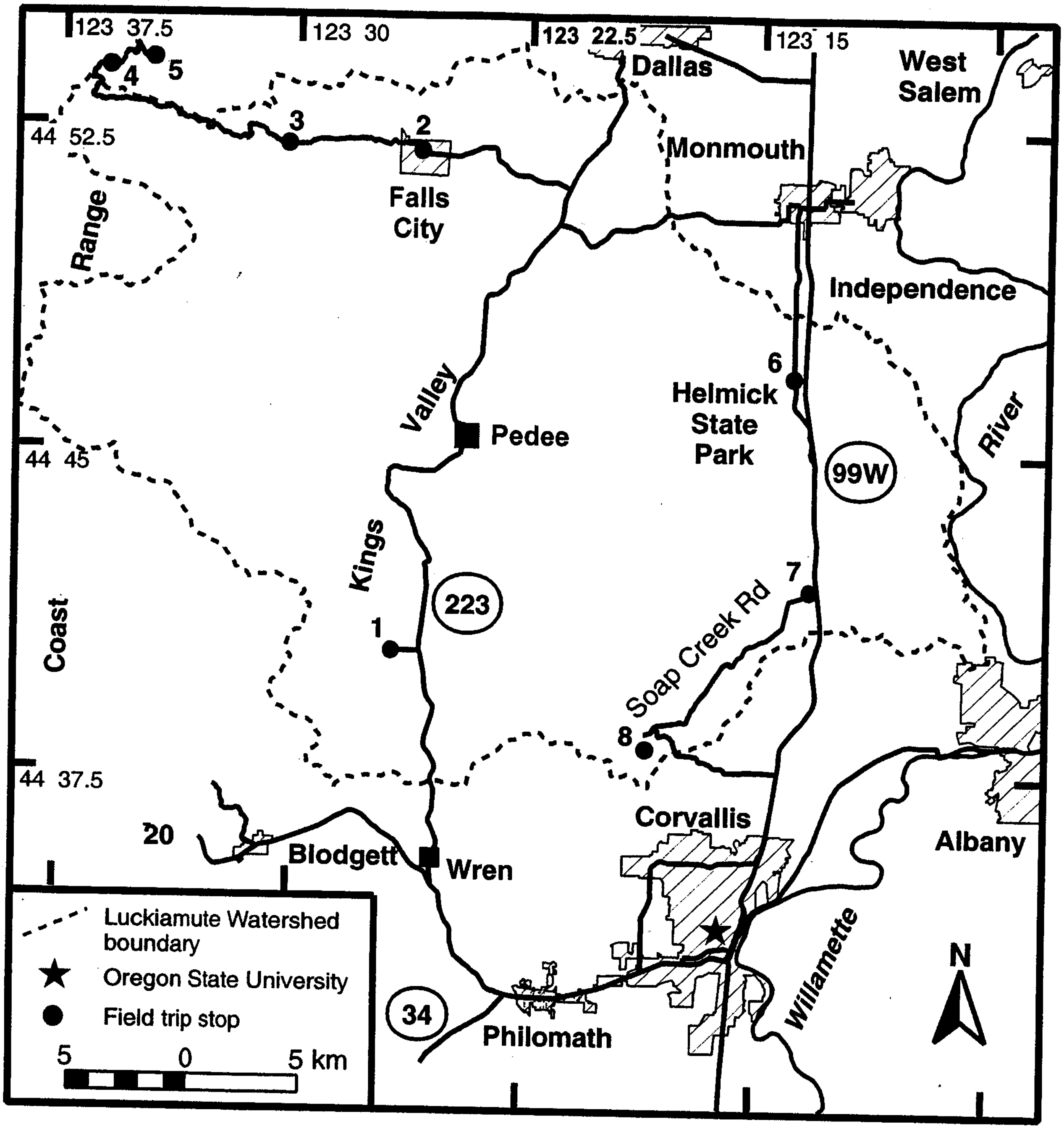

Figure 1. Location map and field trip route for the Luckiamute Watershed.

River to 1016 m (3333 ft) at Fanno Peak. The Luckiamute has an average gradient of 3 m/km, a total stream length of 90.7 km, and an average basin elevation of 277 m (910 ft) (Rhea, 1993; Slack and others, 1993). Fanno Ridge separates the watershed into two tributary subbasins, with the Little Luckiamute to the north and the main stem of the Luckiamute to the south (Kings Valley) (Fig. 2). Lower-order tributaries include Boughey Creek, Waymire Creek, Vincent Creek, Plunkett Creek, Woods Creek, Maxfield Creek, and Soap Creek.

The greater Willamette Valley extends northward 190 km from Eugene to Portland, Oregon. This lowland is up to 60 km wide, separating the Coast Range to the west from the Cascade Range to the east. Valley floor elevations range from 150 m (500 ft) to 3 m (10 ft), with an average gradient of 2 m/km (Slack and others, 1993).

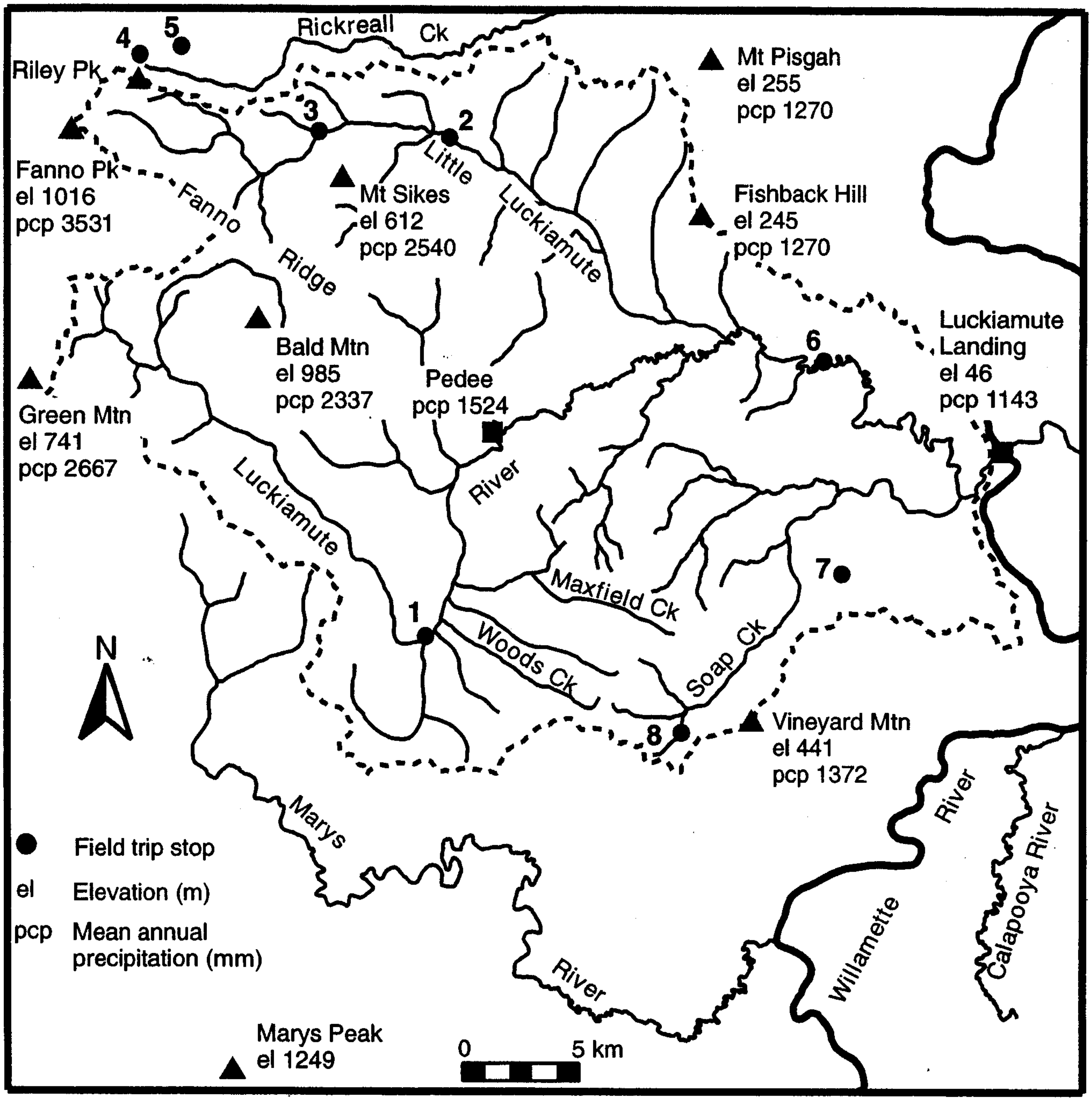

Figure 2. Physiographic map and spot annual precipitation for the Luckiamute Watershed.

TECTONIC SETTING

The Luckiamute Watershed is on a convergent tectonic margin where the Juan de Fuca Plate subducts eastward beneath North America. This subduction zone is associated with a long history of oblique convergence, tectonic accretion, arc volcanism, dextral shear, and clockwise rotation (Wells and others, 1984). Long-term rates of plate convergence average 3.5 to 4.0 cm/yr (Adams, 1984). Paleoseismic studies along coastal Oregon suggest that the region experiences large magnitude, subduction-style earthquakes with a recurrence interval of approximately 300 to 500 years (Darienzo and Peterson, 1990).

The western two-thirds of the Luckiamute River drains the central Oregon Coast Range (Fig. 2). This mountain system began to uplift between 15 and 10 Ma (Snavely and others, 1993) and it continues to be neotectonically active (Adams, 1984). Thus the present-day relief in the Oregon Coast Range is a combination of net uplift due to plate convergence and vertical incision by surface processes (Kelsey and others, 1994).

Historic releveling surveys of western Oregon suggest that the western boundary of the Luckiamute is presently tilting eastward at a rate of approximately 1 x 10^{-8} rad/yr with a crustal shortening of 10^{-7} yr^{-1} (Adams, 1984). Although tilt data suggest that portions of the Luckiamute are neotectonically active, Mitchell and others (1994) reported no evidence for historic uplift in this part of the Coast Range. By comparing topographic relationships in this region to the southern Coast Range and the Olympics, Kelsey and others (1994) hypothesized that the subducting Juan de Fuca slab is likely segmented at the latitude of the Luckiamute.

The Willamette Valley proper represents a forearc basin situated between the Coast Range and the Cascade Volcanic Arc. The northern Coast Range forms a broad, north-plunging anticlinorium, with pre-Miocene strata dipping eastward toward the Willamette Valley (Yeats and others, 1996). The Cascades are associated with a long history of intermediate to mafic volcanism dating from late Eocene (40-35 Ma) to present. Arc volcanism has been narrowing and migrating eastward over time, with the geometry of High Cascade volcanoes controlled by the present-day subduction-zone configuration (Priest, 1990)

BEDROCK GEOLOGY

Yeats and others (1996) and Snavely and Wells (1996) provided comprehensive summaries of the bedrock geology in the Luckiamute region. The bedrock comprises an Eocene to Oligocene sequence of basaltic volcanic rocks, marine sedimentary rocks, and mafic intrusives of varying composition (Fig. 3). In ascending order, lithostratigraphic units include the Siletz River Volcanics (upper Paleocene to middle Eocene; 58-46 Ma), Tyee Formation (middle Eocene; 53-48 Ma), Yamhill Formation (middle and upper Eocene; 48-44 Ma), Spencer Formation (upper Eocene; 44-41 Ma), and undifferentiated mafic intrusions (middle Oligocene; 34-30 Ma). The Siletz River Volcanics are composed primarily of submarine basalt lava flows interbedded with breccia, sandstone, and siltstone. The Tyee Formation is characterized by an arkosic sandstone lithofacies, interpreted as deltaic and submarine fan deposits. The Yamhill Formation comprises interbedded siltstone and shale of marine origin. The Spencer Formation comprises arkosic sandstone, siltstone, and mudstone, interpreted as shallow marine deposits. Given the convergent tectonic setting, strata in the Coast Range portion of the Luckiamute are extensively faulted and fractured.

Bedrock map units are grouped into four lithospatial domains in the Luckiamute, as recognized on the basis of outcrop pattern (Fig. 3). These include the Siletz River Volcanics Domain (south), the Tyee Domain (west-southwest), the Yamhill–Intrusive Domain (north-northwest), and the Spencer–Valley Fill Domain (east). The Siletz River Volcanics Domain constitutes 19% of the watershed and is mainly seafloor basalt. The Tyee Domain (29% of total area) is underlain primarily by the Tyee Formation with local mafic intrusives supporting ridge tops. The Yamhill-Intrusive Domain occupies 23% of the watershed and is characterized by the outcrop of equal parts of the Yamhill Formation and mafic intrusives. The Spencer–Valley Fill Domain (29%) is underlain by a patchwork of Spencer Formation and Quaternary alluvium. Each of these bedrock spatial domains is associated with unique landform assemblages and surficial processes.

SURFICIAL GEOLOGY AND GEOMORPHOLOGY

Geomorphic systems of the Luckiamute Watershed can be divided into a valley-floor regime to the east and a hillslope-colluvial regime to the west (Fig. 4). The style of the surficial process and landform associations are controlled by topographic position, underlying bedrock geology, and resistance to erosion. Hillslope landforms and colluvial processes dominate the Siletz River, Tyee, and Yamhill–Intrusive Domains, whereas fluvial landforms and alluvial processes are characteristic of the Spencer–Valley Fill Domain.

Valley Floor–Fluvial Regime

The lower Luckiamute is characterized by a mix of alluvial stratigraphic units and geomorphic surfaces. Landforms include active channels, floodplains, fill terraces, and strath-pediment surfaces (McDowell, 1991). In addition to these fluvial landforms, the lower Luckiamute is associated with swaths of low-relief colluvial hillslopes supported by the Spencer Formation (Fig. 4). Present-day geomorphic conditions extend back to at least the Pliocene, the time at which the Willamette River eroded through intrabasinal divides, permitting

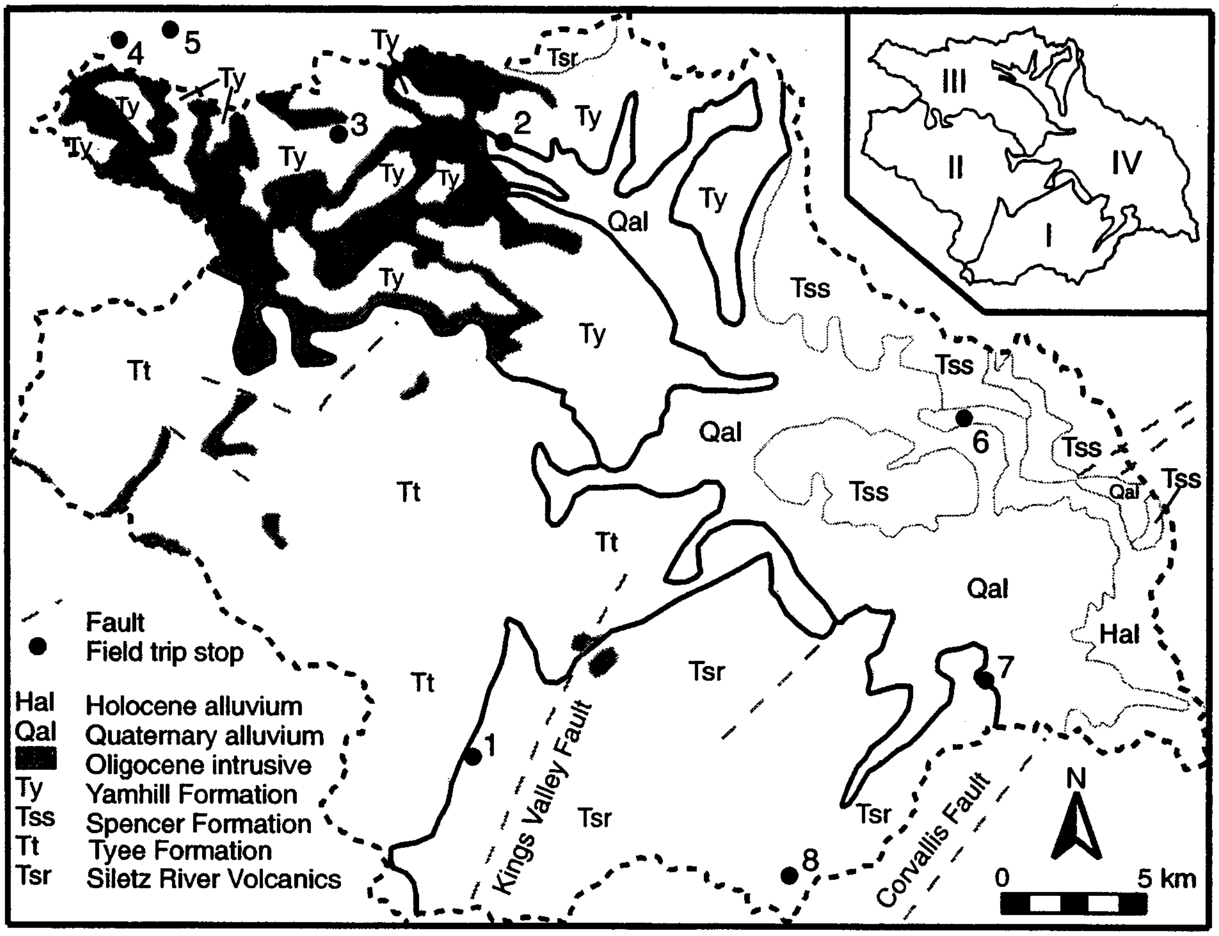

Figure 3. Bedrock geology of the Luckiamute Watershed (after Walker and MacLeod, 1991). Inset map shows grouping of recognized lithospatial domains: I = Siletz River Domain, II = Tyee Domain, III = Yamhill–Tertiary Intrusive Domain, IV = Spencer–Valley Fill Domain.

open drainage to the Columbia River (McDowell, 1991). Pleistocene through Holocene terrace development records a complex history of base level fluctuation, internal erosion-deposition cycles, and glacial-outburst floods (Missoula Floods) from the Columbia River system.

Maximum thickness of Pliocene to Holocene sedimentary fill in the mid-Willamette Valley is up to 150 m (Yeats and others, 1996). Balster and Parsons (1966) mapped terrace and floodplain surfaces in this region on the basis of topography and soil development. The active channel of the lower Luckiamute is incised 8 to 9 m below the floodplain, with higher level terrace surfaces at 12 to 15 m above the mean annual stage (Reckendorf, 1993). The higher-level terrace surfaces are covered with rhythmically-bedded, silty slack-water deposits of the Willamette Formation (Missoula Flood deposits, 13.5-12 ka). These late Pleistocene surfaces are inset with lower terrace and floodplain deposits that are predominantly Holocene in age (post-Missoula Flood, <12 ka) (Fig. 4; O'Connor and others, 2001).

Hillslope–Colluvial Regime

Parsons (1978) presented a geomorphic overview of the Coast Range portion of the Luckiamute. Small-scale intrusions and volcanic rocks support ridge tops and provide the resisting media for steep terrain. On average, hillslope gradients range from 25 to 30% with maxima up to 90%. Local relief is on the order of 300 to 500 m. Hillslope processes dominate this part of the Luckiamute Watershed, including slide, debris flow, creep, tree throw, and faunal turbation. Fluvial transport and erosion

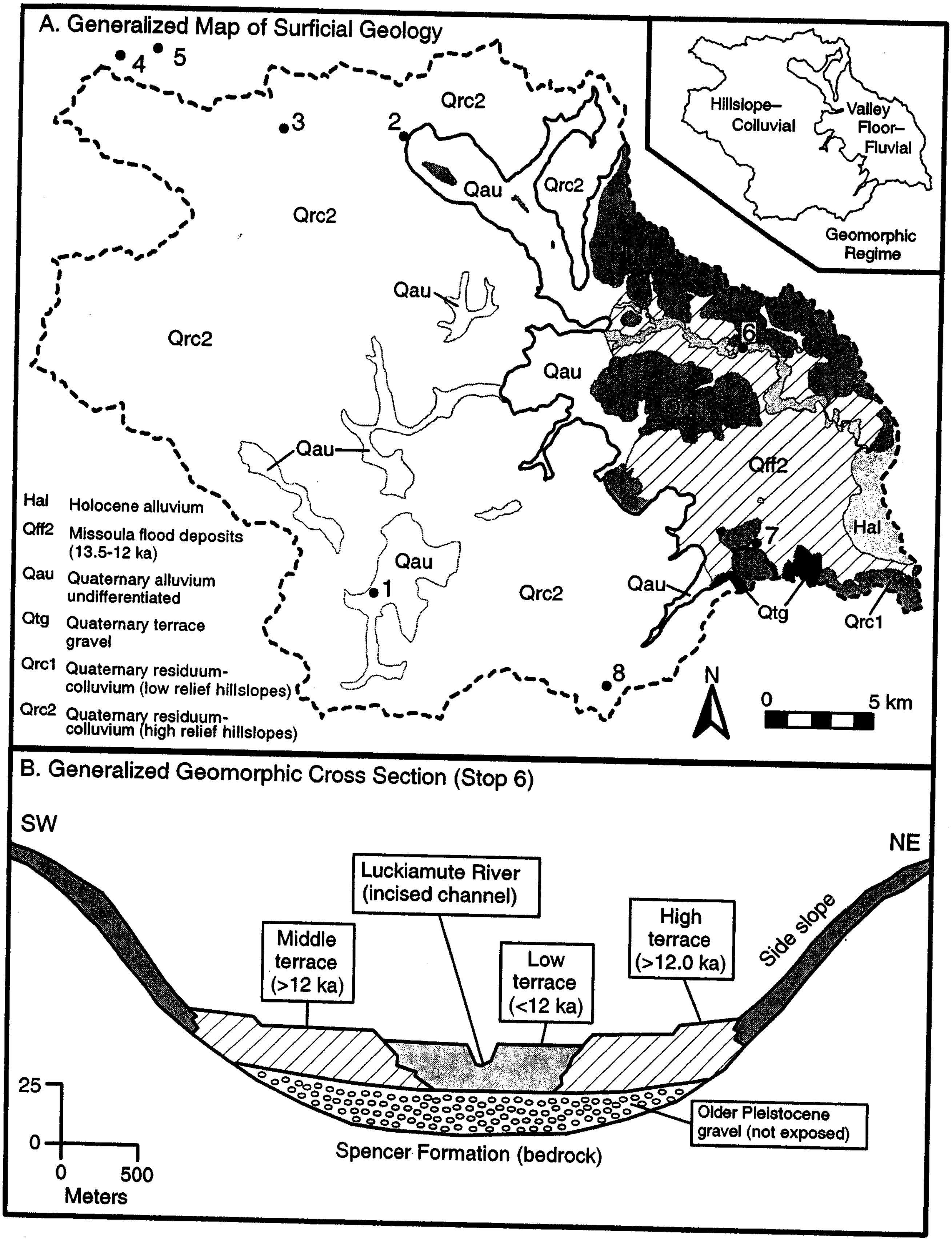

Figure 4. Surficial geology and geomorphology of the Luckiamute River Basin. Surficial map units are modified from O'Connor and others (2001), after Taylor and others (1996). Cross section shown in Frame B represents generalized landform elements at Helmick State Park (Stop 6).

occur in narrow, low-order tributary valleys. Upland landforms include ridge tops, side slopes, hollows, landslide scars, and dissected pediments. Narrow valley bottoms are geomorphically active, with channels, floodplains, low terraces, and small-scale debris fans (Balster and Parsons, 1968).

The Oregon Coast Range is noted for hazards associated with landslides, flooding, and debris flow activity (Gresswell and others, 1979; Robinson and others, 1999). The Oregon Department of Forestry (2000) has recently released a set of debris flow hazard maps for parts of the Luckiamute Watershed. These maps were derived from slope analysis of 30-meter digital-elevation models. Preliminary evaluation of the these hazard maps indicates that hillslopes underlain by the Tyee Formation are the most prone to debris flow (Table 1). The data suggest that bedrock lithology exerts a strong control on the style of hillslope process, soil development, and related landforms in the upland portion of the Luckiamute.

Table 1. Debris flow hazard potential ranked by lithospatial domain, Luckiamute Watershed (data derived from Robinson and others, 1999)

Lithospatial domain	Domain area (km^2)	Percent of domain area in hazard zone	Hazard rank
Tyee	241	38.1	1
Yamhill–Tertiary intrusives	193	24.6	2
Siletz River	151	30.2	3
Spencer–Valley Fill	229	0.7	4

Soil Associations

Geographic Information Systems (GIS) analyses of county soil surveys (Knezevich, 1975, 1982) yield distribution data for soil series, orders, and subgroups in the Luckiamute Basin. Inceptisols, Ultisols, and Mollisols are the most abundant soil orders in the watershed, representing 38%, 31%, and 24% of the total area, respectively. Inceptisols are typically composed of up to 50% lithic clasts and are associated with active hillslopes (>45% gradient). More deeply weathered Ultisols are common on metastable, lower-gradient hillslopes and pediment surfaces (Parsons, 1978). Representative subgroups include Haplohumults (31%), Xerochrepts (14%), Haplumbrepts (14%), Argixerolls (8%), and Haplaquolls (8%). Colluvial soil associations in the Coast Range portion include: (1) Jory, Peavine, Bellpine, Apt, and Honegrove (Haplohumults); and (2) Price, Ritner, Klickitat, Valsetz, Luckiamute, and Cruiser (Haplumbrepts and Cryochrepts). Down basin, alluvial soil associations include: (1) Woodburn, Coburg, Willamette, Malabon (Argixerolls); (2) Veneta, Willakenzie (Haploxeralfs); and (3) Waldo, Wapato (Haplaquolls). The spatial distribution of soil assemblages is ultimately controlled by geomorphic process. As such, Reckendorf (1973, 1993) emphasized their use as a primary criteria for floodplain mapping in the mid-Willamette Valley.

CLIMATOLOGY AND HYDROLOGY

Taylor and Hannan (1999) summarized historic climate data for western Oregon. The Luckiamute straddles Oregon Climate Zones 1 (Coastal Area) and 2 (Willamette Valley), with westerly Pacific marine air serving as the primary moisture source. Precipitation patterns are strongly seasonal with 75% of the annual total falling from October to March. Hydrometeorologic events are driven primarily by cyclonic and frontal storm systems. Rain-on-snow events are common at higher elevations.

Annual precipitation varies greatly from west to east across the Luckiamute Watershed, as governed by westerly airflow and a lee-side rain-shadow effect in the Coast Range. Annual precipitation in the watershed ranges from 3600 mm along the northwestern boundary to 1140 mm in the center of the Willamette Valley, a west-to-east precipitation gradient of 95 mm/km (Fig. 2).

The U.S. Geological Survey maintains a gauging station on the Luckiamute River at Helmick State Park (USGS Suver Station 14190500; Stop 6 on Fig. 1 and 2). The station is 18 km upstream from the basin outlet, with 650 km^2 of drainage area positioned above the monitoring point (approximately 80% of the total). Analysis of the stream-flow record reveals that flooding and high discharges directly correspond to seasonal precipitation patterns. During the winter season, average discharge is on the order of 50 m^3/s, whereas summer months are typified by less than 3 m³/s. The two peak discharges of record were observed at 700 and 620 m³/s during December 1964 and February 1996, respectively. The 100-yr flood event at the Suver Station is marked by a discharge of 760 m³/s (Waichler and others, 1997).

Waichler and others (1997) derived a rainfall-runoff model for the Luckiamute Watershed. They estimated an average annual precipitation of 1894 mm for the entire watershed, with a total input volume of 1.23×10^9 m³. A water budget analysis indicates that 61% of the total annual rainfall is accounted for as runoff, whereas 39% is consumed in the form of evapotranspiration and groundwater flow.

VEGETATION

The Coast Range portion of the Luckiamute Watershed lies in the *Tsuga heterophylla* Zone of Franklin and Dyrness (1988). Dominant forest species include *Pseudotsuga menziesii* (Douglas fir), *Tsuga heterophylla* (western hemlock), and *Thuja plicata* (western red cedar), with a lesser occurrence of *Abies grandis* (grand fir). These species formed part of the classic old-growth timber stands that were logged extensively in the Pacific Northwest during the early 1900s. Disturbed valley zones are characterized by *Alnus rubra* (red alder) and *Rubus spp* (blackberry). *Acer macrophyllum* (big leaf maple) is a common late succession species in valley bottoms and hollows. Balds with meadow grasses and mosses occur locally along higher elevation ridge tops. Lower reaches of the Luckiamute Watershed lie in agricultural crop and pasture land, with local patches of mixed *Quercus garryana* (Oregon white oak) and urban mosaic species.

LAND USE AND ENVIRONMENTAL SETTING

Since European settlement, the predominant economic activities in the Willamette Valley have centered on agriculture in the lowlands and timber harvesting in upland forests. Over the past several decades, industrialization and rapid population growth have resulted in significant impact to the habitat and environmental quality of the region. Given that greater than 75% of all water use in the Willamette Basin is derived from surface sources, land-use and river quality issues are at the forefront of environmental planning in western Oregon.

Private timber companies own a large part of the upper Luckiamute, and 67% of the watershed is classified as forest. In contrast, the eastern valley section comprises a mix of agricultural lands (15% of total), native vegetation (3%), and urban development (1%) (Urich and Wentz, 1999). Primary commodities in the agricultural zones include grass seed, wheat, hay, oats, and mixed crops (clover, sweet corn, mint, alfalfa, filberts) (Wentz and others, 1998). As such, agricultural pesticides and fertilizers are the primary anthropogenic agents that can potentially impact surface and groundwater quality in the Luckiamute Basin.

Wentz and others (1998) presented a water-quality summary for the Willamette Basin, including smaller tributary systems such as the Luckiamute. The greatest potential for water-quality degradation in the lower Luckiamute is from fertilizer-related nitrates and pesticides (herbicides, insecticides, and fungicides). Documented nitrate impacts include nutrient loading, excessive aquatic plant growth, and eutrophication. Nitrate concentrations fluctuate according to seasonal rainfall-runoff patterns with annual maxima common during winter months. Pesticides are also routinely detected at significant concentration levels (3-14 ppb) in the Willamette and related tributaries. Commonly detected pesticides include atrazine, simazine, metochlor, deethylatrazine, diuron, and diazinon. Only atrazine and deethylatrazine are associated with forest-management practices in mountainous subbasins outside of the agricultural zones. Pesticide transport is either through direct advection in a dissolved state or via adsorption to fine-grained suspended sediments.

ROAD LOG AND STOP DESCRIPTIONS

Miles	(approximate)
0.0	Depart Oregon State University's CH2M Hill Alumni Center toward the south and then right (west) onto Western Avenue.
0.5	Turn left (south) onto 35th Street.
0.6	Turn right (west) onto Philomath Boulevard (Highway 34/20), toward Philomath.
2.9	Note low-relief hillslopes of the Eocene Spencer Formation to the south (left) of Philomath Boulevard.
3.2	Crossing buried part of the Corvallis Fault, continue west on Highway 34/20 through Philomath, note Marys Peak in distance.

En Route to Stop 1

The drive west from Corvallis on Highway 34/20 provides spectacular views of the central Oregon Coast Range and Marys Peak. The field trip route in this area follows the Marys River drainage, an east-flowing fluvial system that serves as a principal water source for the city of Corvallis. Examples of late Quaternary floodplain and terrace surfaces are evident along the Marys River Valley in the vicinity of Philomath (Fig. 1 and 2).

At mileage point 3.2, Philomath Boulevard crosses the Corvallis Fault, a major thrust and strike-slip system that was active during the early Tertiary. This fault zone trends northeast, dips approximately 10° NW, and is associated with 11 to 13 km of crustal shortening (Yeats and others, 1996). The net result is the westward juxtaposition of the older lower Eocene Siletz River Volcanics next to younger Tertiary sedimentary strata (to the east). Snavely and others (1993) extended the Corvallis Fault offshore to the southwest, where it intersects a north-trending right-lateral strike-slip fracture referred to as the Fulmar Fault. Their offshore mapping suggests that the Corvallis Fault is a major geologic feature associated with convergent-margin tectonics.

Marys Peak is the highest point (1249 m) in the Oregon Coast Range and is supported by erosionally-resistant intrusive rocks of the Marys Peak Sill. Up to 390 m of Oligocene (29.9 Ma) gabbroic rocks intrude sandstone of the middle Eocene Tyee Formation (Yeats and others, 1996). The entire stratigraphic sequence is in turn cut by the Kings Valley Fault, a high-angle reverse fault with relatively limited throw (Walker and Macleod, 1991). High-elevation ridge tops of Marys Peak are associated with unique plant communities composed of mosses and grasses (Franklin and Dyrness, 1988).

5.7	Bear right (west) onto US 20, follow signs toward Newport.
9.7	Turn right (north) onto Kings Valley Highway (Oregon 223).
12.7	Kings Valley Highway crosses into the Luckiamute Watershed.
14.5	Kings Valley Highway bends from northeast to northwest at Plunkett Creek. The highway crosses the approximate position of the Kings Valley Fault at this point (Fig. 1 and 3).
16.0	Turn left (west) onto Luckiamute Road.
16.7	Proceed 0.7 mi on Luckiamute Road to **Stop 1**, bridge crossing Luckiamute River.

Stop 1. Kings Valley (Hoskins)

The main stem of the Luckiamute River forms the principal physiographic feature of Kings Valley. The Hoskins stop is just west of the Kings Valley Fault, which lies near the boundary between the Tyee and Siletz River Domains (Fig. 3).

Systematic geomorphic mapping forms the foundation upon which integrated watershed studies are constructed (Taylor, 1999). Kings Valley and the Coast Range at this stop provide a framework for discussion of a surficial mapping protocol in unglaciated, mountainous landscapes. Taylor and others (1996) devised a four-fold geomorphic mapping scheme in which units are delineated on the basis of age, origin (process), landform, and material (texture) (Table 2). The technique emphasizes the link between landforms and processes in landscapes dominated by hillslopes, mass wasting, and fluvial erosion. Hillslopes are characterized by colluvial diamicton (matrix supported gravel) with landforms subdivided into ridges, side slopes, hollows, and noses. Gravel-dominated valley bottoms are characterized by channel processes and debris flow activity. Valley-bottom landforms are subdivided into channels, floodplains, terraces, fans, and aprons. The four-fold nature of the mapping protocol lends itself particularly well to the layered approach of geographic information systems (GIS). Field trip participants are provided an opportunity to apply the systematic map protocol to the upper Luckiamute River drainage.

16.7	Return east to Kings Valley Highway
17.4	Turn left (north) onto Kings Valley Highway (Oregon 223) Enter town of Pedee, continue north on Kings Valley Highway.
33.5	Turn left (west) onto Falls City Road.
37.8	Enter Falls City.
37.9	Turn right onto Black Rock Road.
38.0	Stop 2, Falls at Falls City (pull out on left side of road).

Stop 2. Falls at Falls City

Falls City lies at the domain boundary between the Spencer–Valley Fill Domain to the east, and the Yamhill-Intrusive Domain to the west (Fig. 3). The city is set along the Little Luckiamute River and has traditionally served as an access point for timber operations. Field Stop 2 is at the falls of the Little Luckiamute River, just west of town center (Fig. 2).

Table 2. Four-fold surficial-map protocol for unglaciated mountainous landscapes (after Taylor and others, 1996).

1. Age of surficial material
- H = Holocene (<10,000 years old)
- W = Wisconsin (89 to 10 ka)
- I = Illinoian
- P = Pleistocene undifferentiated
- EP = early Pleistocene
- MPl= middle Pleistocene
- LP = late Pleistocene
- Q = Quaternary undifferentiated
- CZ = Cenozoic undifferentiated

2. Origin of surficial process
- A. Hillslope
  - r = residuum (in situ regolith)
  - c = colluvium (mass wasting)
  - ds = debris slide
  - rf = rock fall or topple
- B. Valley bottom
  - a = stream alluvium (normal flow)
  - hcf = hyperconcentrated flow
  - df = debris flow
  - sw = slackwater deposition
- C. Lacustrine
  - l = lacustrine deposit, undiff.
  - lb = lake-bottom deposit
  - ld = lacustrine deltaic
- D. Other
  - g = glaciofluvial, undifferentiated
  - go = glacial outwash
  - e = eolian
  - cr = cryoturbation
  - x = anthropogenic disturbance
  - f = artificial fill
  - rk = bedrock

3. Landform Units
- A. Hillslope
  - n = nose
  - sl = side slope
  - h = hollow
  - veneer = <2 m of regolith
  - blanket = >2 m of regolith
  - bf = boulder field
  - bs = boulder stream
  - pg = patterned ground
  - tls = talus
- B. Valley bottom
  - ch = channel
  - fp = floodplain (recurrence interval = ≤ 2-3 yr)
  - t = terrace (t1, t2 ...tn; height above river)
  - f = fan
  - f-t = fan terrace (f1, f2 ...fn; height above river)
  - a = apron (footslope deposit)
  - lo = lobe
  - lv = levee
  - ox = oxbow, abandoned channel
- C. Other
  - ft = flow track (debris flow)
  - hm = hummocky topography
  - rb = rock block-slide deposit
  - x = excavated, fill, disturbed ground
  - d = delta

4. Material (composition and texture)
- b = boulders (>256 mm clast supported)
- c = cobbles (64-256 mm clast supported)
- p = pebbles (4-64 mm clast supported)
- g = gravel (>2 mm clast supported)
- sg = mixed sand and gravel
- s = sand (0.05-2.0 mm)
- st = silt (0.002-0.05 mm)
- cy = clay (<0.002 mm)
- l = loam (mix of sand, silt, clay)
- d = diamicton undifferentiated
- bbd = very bouldery diamicton
- bd = bouldery diamicton
- cd = cobbly diamicton
- pd = pebbly diamicton
- ds = sandy matrix diamicton
- dt = silty matrix diamicton
- dy = clayey-matrix diamicton
- rk = bedrock (modify by lithology)
- rs = rotten stone, saprolite
- tr = travertine
- tu = tufa
- ma = marl
- og = organic-rich sediment
- w = water
- u = unkown

Figure 5. Falls City knickpoint along the Little Luckiamute River (Stop 2).

The falls represent a knickpoint or hydraulic step in the longitudinal profile of the Little Luckiamute. Total knickpoint relief is approximately 6 m (Fig. 5). Knickpoint zones along rivers represent significant perturbations in the hydraulic system, intimately related to base-level changes and lithologic discontinuities in the channel substrate (Wohl, 2000). The falls at Falls City are formed on resistant sedimentary lithofacies of the Yamhill Formation. North- to northeast-trending fractures are evident in bedrock pavement along the active channel and provide a strong control on knickpoint development. The Falls City knickpoint is eroding headward with time by processes of block plucking and wall-rock undercutting. Gravel tools generated by knickpoint erosion are in turn available for downstream channel abrasion. The presence of bedrock-lined channels and the relative absence of gravel alluvium suggest that the Little Luckiamute at this position is under capacity with respect to sediment load, that is, the total available stream power exceeds sediment load thresholds (Montgomery and others, 1996). This field stop provides access to readily observable river features that demonstrate concepts of landscape erosion and geomorphic work.

38.0	Continue west on Black Rock Road.
38.2	Bear left onto the gravel portion of Black Rock Road.
41.8	**Stop 3**, Black Rock (pull out where bridge crosses Little Luckiamute River).

Stop 3. Black Rock (Little Luckiamute)

Invasive plant species are problematic for both native and agricultural plant communities as they can compete for resources and displace competitors. Local extirpation of native plant species has obvious impacts on wildlife and natural habitats. Competition between plant species is a part of any habitat, but introduction of nonnative species disrupts relationships evolved among native plants and their communities within those specific habitats.

Table 3. Occurrence of common invasive plant species at selected field trip localities in the Luckiamute Watershed (BR = Black Rock—Stop 3; HSP = Helmick State Park—Stop 6; SSp = Sulphur Springs—Stop 8).

Species	Origin	Occurrence		
		BR	HSP	SSp
Capsella bursa-pastoris (shepherdspurse)	Europe	X	X	X
Cichorium intybus (cichory)	Medi-terranean		X	X
Cirsium arvense (Canada thistle)	Eurasia		X	X
Cirsium vulgare (bull thistle)	Eurasia		X	X
Conium maculatum (poison hemlock)	Europe		X	X
Cytisus scoparius (Scotch broom)	Europe	X		X
Daucus carota (wild carrot)	Europe		X	X
Digitalis purpurea (foxglove)	Europe	X		X
Dipsacus fullonum (common teasel)	Europe	X	X	X
Hedera helix (English ivy)	Eurasia Africa	X		
Hypericum perforatum (common St Johnswort)	Europe		X	X
Lamium purpureum (purple deadnettle)	Europe	X	X	X
Leucanthemum vulgare (oxeye daisy)	Europe			X
Rubus armeniacus (Himalayan blackberry)	Armenia	X	X	X
Rumex acetosella (red sorrel)	Europe	X	X	X
Senecio jacobaea (tansy ragwort)	Europe	X	X	
Solanum dulcamara (bittersweet nightshade)	Europe		X	X
Tanacetum vulgare (common tansy)	Europe		X	X
Taraxacum officinale (dandelion)	Europe	X	X	X
Verbascum thapsus (common mullein)	Eurasia	X	X	X

Botanical survey techniques are critical for documenting the occurrence of invasive plant species and assessing their relative impact on the ecosystem. Three broad categories of survey methodologies include systematic (taxonomic), monitoring (as distinct from ecological), and ecological (Stiling, 1998). Common nonnative, invasive plant species at select Luckiamute field localities, including Black Rock, are listed in Table 3. Field trip participants are provided an opportunity to explore plant identification methods, botanical survey techniques, and their potential application in a classroom setting.

41.8 Continue west on Black Rock Road
42.3 Bear right at Y intersection, note quarry on right.
43.4 Proceeding on Black Rock Road. Please note that logging roads in this vicinity are narrow and steep, with limited sight distance and active log transport. Use extreme caution when driving this part of the route; citizens-band radio communication is recommended.

En Route to Stop 4

The field trip route west of Black Rock winds along hillslopes of the Coast Range that are intensively managed for forest production. This area is owned by private timber companies and is actively logged by clear-cut methodologies. Logging activities have a profound influence on vegetative plant communities and geomorphic processes. The route through this area follows the Luckiamute drainage divide and provides views of Laurel Mountain to the north of the watershed (Fig. 1 and 2).

Laurel Mountain forms a part of the crest of the Coast Range, with a maximum altitude of 1094 m (3589 ft). Average annual rainfall at the crest exceeds 3800 mm/yr (Taylor and Hannan, 1999). The southeast-facing hillslope of Laurel Mountain was subject to extensive slope failure and debris flow activity in response to a high-intensity, long-duration storm event in February of 1996 (Robinson and others, 1999). Extensive debris slide scars are evident as breaks in the forest canopy below the peak of Laurel Mountain to the north (right) of Black Rock Road. Debris slides were initiated on steep hillslopes (up to 90% gradient) underlain by rocks of the Yamhill-Intrusive Domain. Ten discrete slide zones produced a net landslide erosion rate of 42 m^3/ha over an area of 8.0 km^2,

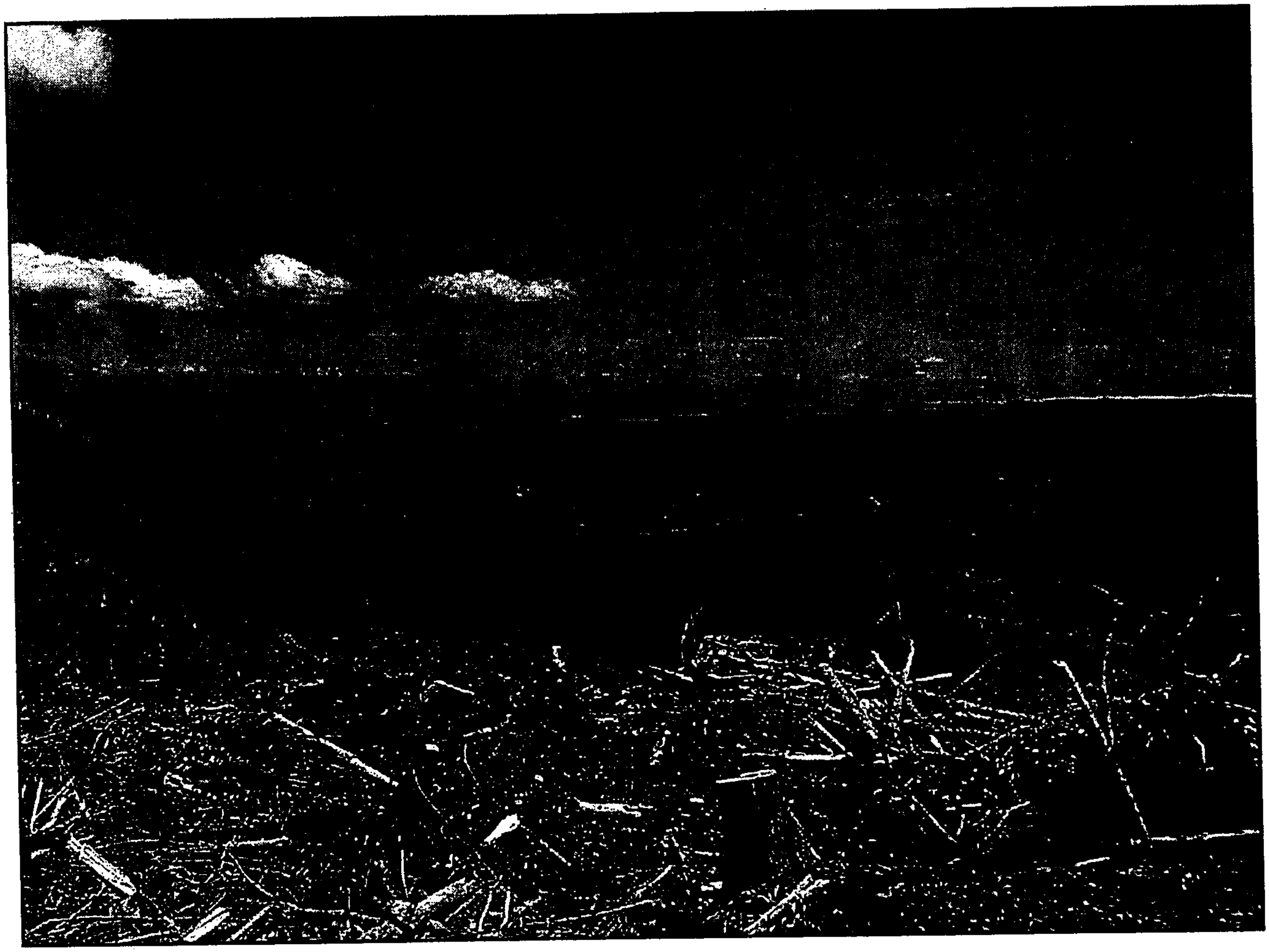

Figure 6. Overview of Coast Range watersheds and mid-Willamette Valley (view to east from Stop 5).

one of the highest that was documented during the 1996 storm event (Robinson and others, 1999).

44.7 Three-way intersection, continue straight on center road, following contour.
45.7 Three-way intersection, continue straight on center road, following contour.
46.8 Bear left at Y intersection.
47.5 Continue straight at T intersection.
47.8 Continue straight at T intersection.
48.7 Bear right (north) at Y intersection, note **S-Line** tree marking. The road crosses over the Luckiamute drainage divide at this point, with Riley Peak directly to the east. **Stop 4,** road aggregate quarry.

Stop 4. Road Aggregate Quarry

Stop 4 is at a road aggregate quarry set in the Yamhill–Intrusive Domain (Fig. 1 and 3). The quarry provides an excellent exposure of Oligocene gabbro intruding Eocene Yamhill sedimentary strata. The rock assemblages are extensively fractured and typify the bedrock supporting this part of the Coast Range.

Oligocene igneous intrusives form erosionally resistant outcrops that tend to support ridge tops and steep hillslopes. Soil in this part of the Coast Range constitutes part of the Valsetz-Yellowstone complex, characterized by Inceptisols developed in gravelly diamicton (Knezevich, 1982). Quarry-wall exposures illustrate the high degree of rock weathering that is common in the Coast Range. Examples of spheroidal weathering are readily evident. Chemical weathering acts on preconditioned joint blocks to create rounded, boulder-like forms. Clay alteration of feldspars results in volume expansion, differential rock stress, and spalling of joint planes (Easterbrook, 1999). The net result is to produce spherically weathered forms. Regolith deposits produced by spheroidal weathering can be misinterpreted as rounded gravel alluvium associated with river transport and represent a potential source of error in interpreting the origin of a geomorphic surface.

49.5	Continue north-northeast on S-Line.
50.4	Note road-maintenance shed on right.
50.6	Turn right (east) onto unnamed logging road; continue past Silver Falls area.
51.1	**Stop 5,** Coast Range drainage divide, overview of Willamette Valley.

Stop 5. Coast Range Drainage Divide

Although just north of the Luckiamute drainage divide, this stop provides a vantage point to view the crest of the Coast Range and mid-Willamette Valley (Fig. 6). Extensive logging and clear-cut forest practices are evident at this stop.

Numerous studies have linked the increased occurrence of landslides and debris flows in the Coast Range to logging and related road construction (Swanson and others, 1977; Ice, 1985; Sidle and others, 1985). Forest practices commonly lead to physical and biological alterations of hillslopes that may contribute to exceedence of landslide thresholds during the winter rain season. Logging-related parameters contributing to slope failure include decreased root strength, decreased evapotranspiration and increased pore pressure, alteration of snow melt patterns, oversteepening of slopes along road cuts, and hydraulic blowouts related to culverts (Robinson and others, 1999).

Stop 5 also provides an opportunity to discuss residuum as a surficial deposit. Residuum is a form of regolith that results from in-place weathering of bedrock with negligible components of downslope transport (Taylor, 1999). Gravel clasts in the regolith at this stop exhibit weathering rinds indicative of in-place chemical alteration, limited transport, and surface stability. Mills and Allison (1995) used clast weathering rinds as a relative dating tool for surficial deposits and as a method to interpret transport processes in colluvium-dominated landscapes. Similar approaches are applicable in the Coast Range.

51.1	Return to Falls City along previous route.
64.3	Falls City town center.
68.7	Turn right (south) onto Kings Valley Highway (Oregon 223).

En Route to Stop 6

The route from this point to Stop 6 is through the Spencer–Valley Fill Domain (Figure 3). The topography of this area is characterized by relatively flat floodplains and terraces punctuated by low-relief, rolling hills supported by the Spencer Formation (Fig. 4). Land use along this part of the route is dominated by agricultural production and local wood-lot management. Fertilizer and pesticide use are primary environmental factors that impact water quality in this part of the watershed. In addition, crop-management practices have profoundly influenced the occurrence and distribution of invasive plant species in the ecosystem.

Crop mapping in the upper Willamette Basin is very useful in estimating mass loading of pesticides and fertilizer compounds in the watershed (Anderson and others, 1997). Grass seed production in the region consumes the most land area and is the agricultural activity associated with highest rates of pesticide application. Atrazine, metochlor, and diuron are herbicides that are most commonly used and detected in water quality samples (Anderson and others, 1997). The drive between Stop 5 and Stop 6 provides an opportunity to view land-use practices in the mid-Willamette Valley and discuss associated environmental impacts.

The Polk County Flora Project at Western Oregon University is a long-term environmental assessment and monitoring program that focuses on native and invasive plant species in the regional ecosystem. The flora project provides a collaborative framework for faculty, students, and the local K-12 education community to conduct botanical surveys using geographic information systems (GIS), global positioning systems (GPS), and internet technologies. Field trip participants are provided an overview of the Polk County Flora Project with demonstrations of related activities.

69.6	Turn left (east) onto Monmouth Road, and follow signs toward Monmouth.
76.6	Enter city of Monmouth, turn right (east) onto Main Street.
76.9	Turn right (south) onto Knox Street (Helmick Road), continue south on paved highway.

81.7 **Stop 6,** Helmick State Park.

Stop 6. Helmick State Park

Helmick State Park lies along the lower Luckiamute River and is representative of the mid-Willamette Valley geomorphic setting (Fig. 4). Hillslopes to the north are underlain by sandstone lithofacies of the Spencer Formation. A flight of low- to mid-level fluvial terraces is readily observable as topographic breaks in agricultural fields directly south of the park entrance. These surfaces were mapped as Qtl (low terrace), Qtlm (low to middle terrace), and Qth (high terrace) by Bela (1981). The Luckiamute River is incised 8 to 9 meters below Qtl, the alluvial surface upon which the Helmick State Park facility is constructed. Suspended-sediment transport dominates this lower part of the Luckiamute, in marked contrast to the gravel-dominated reaches observed upstream at Stops 1 and 3.

The U.S. Geological Survey maintains the Suver stream gauging station at this stop (USGS Station 14190500). Historic river discharge and stage data form the basis for floodplain management in the Willamette Valley. The Suver station record extends back to 1941, for a total of 60 years of continuous river discharge monitoring. Kochel and Baker (1988) discussed the statistical limitations associated with relatively short duration gauge records, and promoted the use of paleohydrology as a method to extend such records back in time. Paleohydrology involves a series of geomorphic and quantitative techniques that are used to reconstruct prehistoric river conditions (for example, peak discharge and maximum flood stage) from preserved flood deposits. Slackwater deposits are typically composed of fine-grained suspended sediment that is deposited under low-flow velocities during overbank flood events. Slackwater sediment is preserved in sheltered low-energy areas along valley bottoms and provides a record of maximum flood stage. High-water levels can then be incorporated into slope-area equations to determine flood discharge. Field trip participants are afforded an opportunity to inspect the gauging station, examine historical discharge data, and reconstruct stages of past flood events.

The stop at Helmick State Park also provides an opportunity to examine the interaction between anthropogenic disturbance, geomorphic process, and distribution of invasive plant species. Agricultural lands and flood-disturbed zones along the mid-Willamette Valley have historically served as corridors facilitating the spread of invasive plant species throughout the region. The riparian zone and abandoned railroad grade directly north of the state park offer exceptional opportunities for identification of the species listed in Table 3, and for down-basin comparison to those observed at the Black Rock locality (Stop 3).

81.7 Continue south on Helmick Road.
83.8 Intersection of Helmick Road with Oregon 99W, continue south on 99W.
87.4 Turn right (west) onto Coffin Butte Road.
87.5 **Stop 7,** Coffin Butte Landfill.

Stop 7. Coffin Butte Landfill

Coffin Butte Landfill is an Environmental Protection Agency (EPA) Subtitle D refuse disposal facility that is operated by Valley Landfills Inc., of Corvallis. The landfill occupies approximately 700 acres of the former Camp Adair Army Training Facility. Active disposal cells are located at the head of an unnamed tributary to the Luckiamute, in a topographic saddle between Poison Oak Hill and Coffin Butte (Fig. 1 and 2). The unnamed tributary and associated wetlands drain eastward toward the E.E. Wilson National Wildlife Refuge. Hillslopes to the north and south of the facility are underlain by fractured and faulted oceanic basalt of the Siletz River Volcanics (Fig. 3). Basaltic lithofacies are overlain by 10 to 20m of Pleistocene terrace gravel (Fig. 4).

Coffin Butte is the second largest landfill in Oregon with disposal rates ranging from 1200 to 1700 tons per day (Valley Landfills, personal communication). The refuse-disposal cells are designed as a series of stacked, interlocking subunits with a multiple-layer synthetic liner system. Environmental controls in the liner system include impermeable membranes, leachate recovery and leak detection, secondary containment, and methane extraction. A multilevel groundwater monitoring system is employed for leak detection, water quality compliance, and prevention of offsite contaminant migration. In addition, the Coffin Butte facility is equipped with an on-site waste water treatment plant and methane-based electrical generator (Valley Landfills, unpublished document). Field trip participants are presented an overview of landfill design technology, leachate chemistry, and water quality monitoring systems.

87.5 Continue west on Coffin Butte Road.
88.3 Turn left (south) onto Soap Creek Road.

Table 4. Field chemistry of Sulphur Springs and upper Soap Creek at Stop 8. Explanation of units: µS = microSiemens, SU = Standard pH units, mV = millivolt, ppm = parts per million.

Field parameter	Sulphur Springs	Soap Creek
Conductivity (µS/cm)	371	104
pH (SU)	6.7	7.3
Eh (mV)	-287	137
O_2(ppm)	1.2	10.0
CO_2(ppm)	15.0	4.0
Sulfide (ppm)	1.0	0.2
Total hardness (ppm)	280	90

89.0 Cross intersection with Tampico Road, continue straight (south) on Soap Creek Road.
92.6 Note historic Soap Creek School on left (east).
93.9 Turn right onto Sulphur Springs Road, continue straight on gravel portion.
94.1 **Stop 8,** Sulphur Springs (Baker Creek). Note footbridge and pullout on left.

Stop 8. Sulphur Springs (Baker Creek)

Stop 8 includes visits to two sites. The first is to the Sulphur Springs discharge point along the upper reaches of Soap Creek, and the second is to a mesoscale landslide site along Baker Creek (Fig. 1 and 2).

Sulphur Springs is a low-discharge spring located on the north bank of Soap Creek, directly upstream from the confluence with Baker Creek. Sulphur Springs was a popular recreation area in the late 1800s and early 1900s. Today the site constitutes part of the Oregon State University Research Forest facility. The spring emanates from a veneer of valley-bottom alluvium, overlying hydrothermally altered basalt of the Siletz River Volcanics (Fig. 3). The Siletz River Volcanics are highly fractured and associated with significant zeolitization. Zeolites are a group of hydrous-silicate minerals that commonly occur as secondary deposits in association with low-grade alteration. Water chemistry of Sulphur Springs was compared to that of Soap Creek using a basic set of field parameters, the results of which are shown in Table 4.

Field data suggest that water emanating from Sulphur Springs is strongly reducing and oxygen deficient compared to that of Soap Creek. Stagnant water surrounding the spring also displays active bubble release and gas discharge. The working hypothesis is that the gas discharge is generated by anaerobic bacteria in the form of hydrogen sulfide (H_2S) and methane (CH_4). The sulfur is likely derived from groundwater leaching of disseminated pyrite in the altered Siletz River Volcanics. Sulfate (SO_4^{-2}) is in turn converted to sulfide (S^{-2}) by bacteria under reducing conditions, with subsequent release of hydrogen sulfide (H_2S) gas. The methane (CH_4) forms from bacterial decay of organic matter in near-surface, oxygen-deficient water at the Sulphur Springs site. Field trip participants will be afforded an opportunity to directly measure a suite of field parameters, examine additional laboratory data, and formulate reactions that address the influence of bedrock geology on the geochemistry of surface water in the Luckiamute drainage.

The Baker Creek Landslide is 0.5 km south of the confluence between Baker Creek and Soap Creek (Fig. 2). The trail starts at the wooden footbridge and follows an abandoned forest road that was used for logging-related activities at McDonald Forest. The landslide scar disrupts the trail and is readily evident.

The landslide initiated on the fill-slope portion of the forest road and lies at the base of a zero- to first-order tributary draining from the adjacent hillslope to the east. The fresh nature of the scar (Fig. 7), sparse vegetative cover, and presence of invasive plant species (Table 3) suggest that the slope failed during a winter rainfall event within the past several years. Geometric analysis of the landslide scar yields a total transport volume of 750 to 800 m^3, the bulk of which is preserved as hummocky topography along the floodplain of Baker Creek. A complex motion of slide and flow is indicated by the presence of intact road base partially mixed with other debris. The landslide mass has in turn constricted the valley bottom, providing optimal conditions for beaver dam construction, ponding, and significant alteration of the hydrologic regime (Fig. 7).

Swanson and others (1990) emphasized the importance of ecologic links between geomorphic process, landforms, biotic systems, and forest-management practices in mountainous watersheds of the Pacific Northwest. Landslides represent a vegetative-disturbance regime that effect soil substrate conditions, nutrient availability, canopy shading (solar influx), riparian hydrology, and fish habitats.

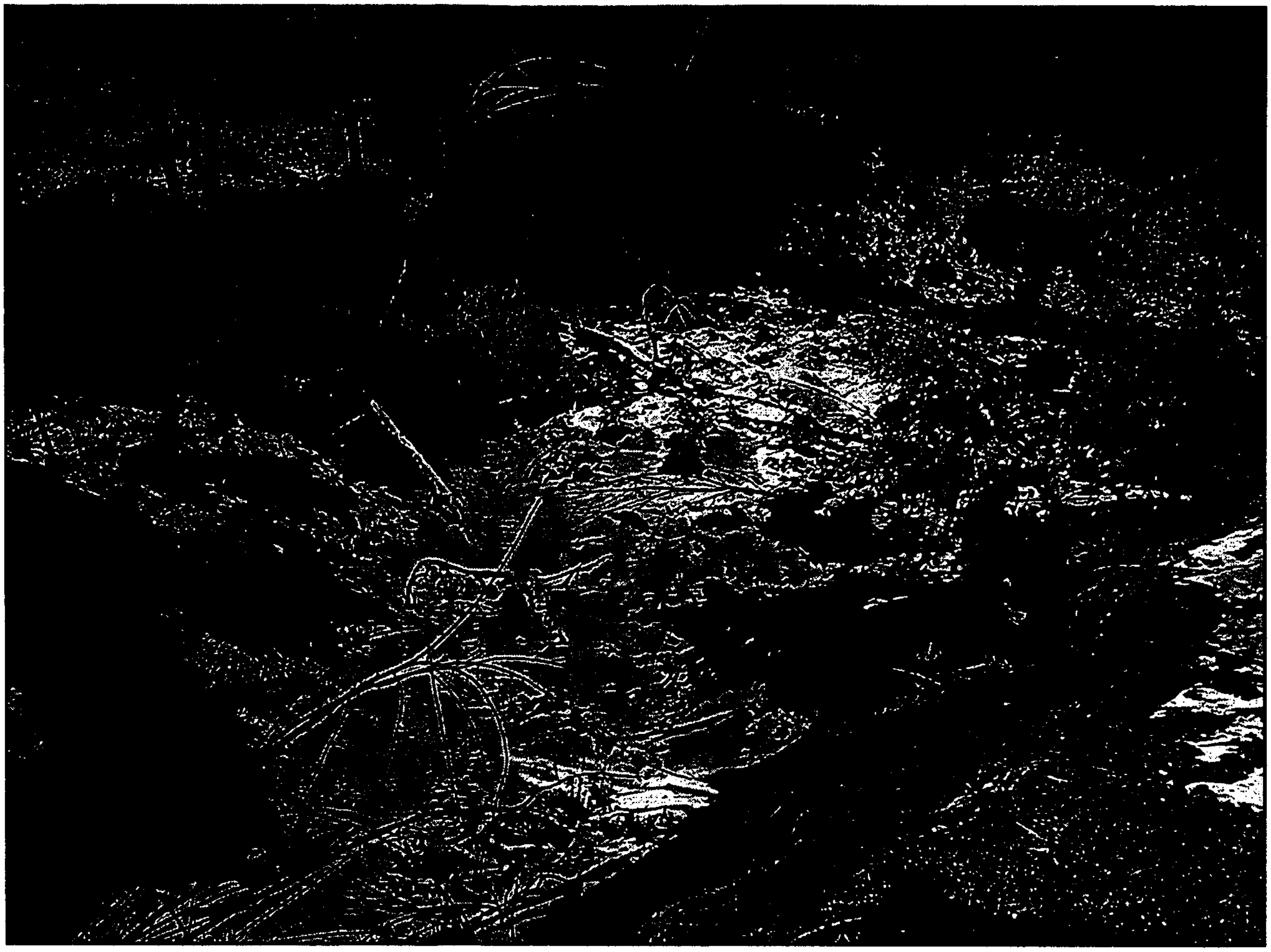

Figure 7. Fresh landslide scar and deposits at Stop 8 along Baker Creek. Note constriction of valley bottom and beaver-dam ponding of drainage. View is from slide scar looking down gradient at snow-covered colluvial deposits.

Opening of the forest canopy by geomorphic disturbance results in extensive development of understory vegetation and multilayered forests (Swanson, 1980). A disturbed regolith provides germination sites for a wide variety of shade-intolerant native and nonnative species (Pabst and Spies, 1998). Flood disturbance of bottom land results in similar vegetative response along floodplain and channel zones (Hupp, 1988). An anthropogenic overprint is added to the system in the form of forest road construction which dramatically alters hillslope hydrology and increases the frequency of slope failure (Montgomery, 1994; Wemple and others, 2000).

The Baker Creek Landslide site provides an excellent mesoscale example of complex process-response between geomorphic and biotic system variables. The following is a summary of system interactions. The forest road was constructed by cut-and-fill methods along the lower segment of a hillslope adjacent to Baker Creek. A culvert was installed at the landslide site to divert water from the low-order hollow to the east. Surface and subsurface water accumulated at the culvert during a high-magnitude rainfall event. Increased pore pressure and the saturated weight of the road fill resulted in slope failure and mass transport to the valley bottom. Constriction of the floodplain provided optimal conditions for subsequent beaver-dam construction and alteration of the riparian hydrology. Beaver ponds dramatically decreased average daily discharge of Baker Creek, altering sedimentation patterns, channel geometry, and displacing the riparian habitat under saturated soil conditions (after Gurnell, 1998). Opening of the forest canopy resulted in the demise of shade-intolerant understory vegetation and incursion of nonnative plant species. The patchwork of geomorphically disturbed hillslopes and valley bottoms in the Oregon Coast Range acts as a conduit for the dispersal of invasive species. The Baker Creek Landslide site represents one of thousands of similar localities in western Oregon and provides a model for the complex interaction between multiple physical and biological factors.

94.1	Return east on Sulphur Springs road.
94.3	Continue straight at turn-off to Soap Creek Road, toward top of ridge.
95.5	Lewisburg Saddle (Oregon State University, MacDonald Experimental Forest).
97.0	Turn left (east) onto Lewisburg Avenue.
98.1	Turn right (south) onto Oregon 99W, follow signs to Corvallis.
101.5	Return to OSU CH2M Hill Alumni Center.

CONCLUSION

The Luckiamute Watershed provides a platform from which to study integrated environmental systems in western Oregon. Active tectonics, extreme precipitation patterns, dynamic geomorphic systems, and intensive land use result in complex interactions between physical and biological components. The field stops and discussions provided in this guide represent a starting point from which science educators can incorporate integrated natural science curricula into their respective classrooms. The pursuit of such endeavors will be necessary to prepare scientifically literate citizens to make informed decisions about complex environmental-resource issues in the 21st Century and beyond.

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Field Trip Introduction

- People
    - Trip Leader Introduction
    - Participant Introduction

- Organizations
    - Western Oregon University – Environmental Science Institute
    - Luckiamute Watershed Council

- Background
    - Luckiamute Watershed – Focus of 2001 WOU Summer Institute Course
        - Undergraduate Science Majors
        - Pre-service Science Education Majors
        - Practicing Science Education Professionals
    - Integrated Content Modules
        - Geomorphology / Hydrology
        - Field Botany
        - Paleoclimatology / Earth History
        - Environmental Chemistry
    - Goal of the Environmental Science Institute at WOU
        - Platform for Interdisciplinary Science
        - Framework for Summer Courses and Research
        - Community Outreach
    - Acknowledgments
        - National Science Foundation – OCEPT Project
        - WOU Division of Extended Programs

- Overview of Field Trip Itinerary (refer to Fig. 1, p. 3)

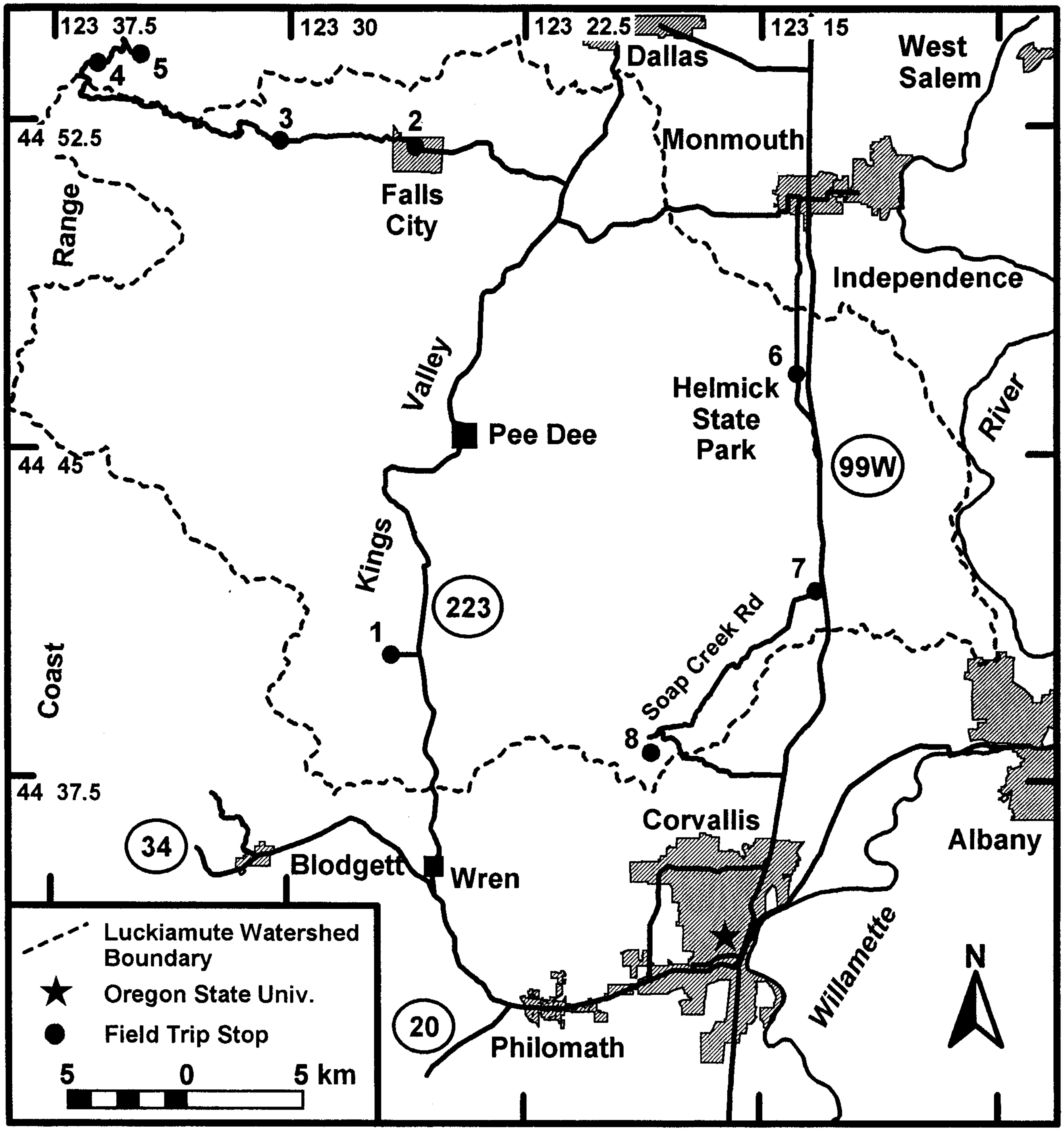


Figure 1. Location map and field trip route for the Luckiamute watershed.

Physiographic Setting of the Luckiamute Watershed

- Boundaries
  - Crest of Coast Range to West (headlands)
  - Willamette River to East

- Drainage Area = 815 km^2

  - Largest Fifth-Field Watershed in central and northern Coast Range

  - Primary Tributaries
    - Little Luckiamute – northern watershed
    - Luckiamute – southern watershed

  - Secondary Tributaries
    - Soap Creek, Maxfield Creek, Woods Creek, Teal Ck

- Elevation Range:
  - Min: 46 m (150 ft) at Willamette
  - Max: 1016 m (3333 ft) at Fanno Peak
  - Avg. Basin Elevation: 277 m (910 ft)

- Basin Morphometry
  - Average Stream Gradient: 3 m /km
  - Total Stream Length: 90.7 km

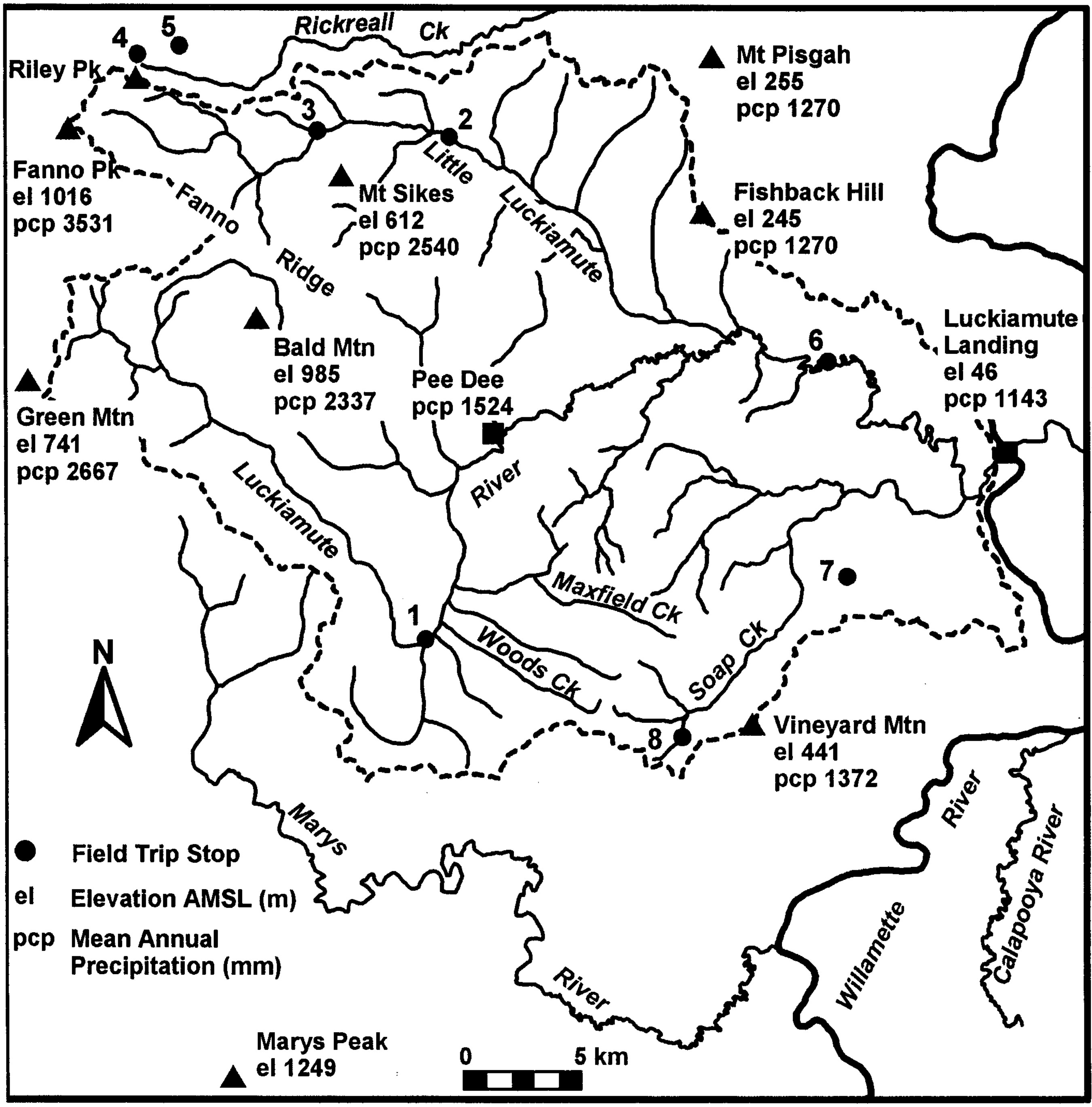
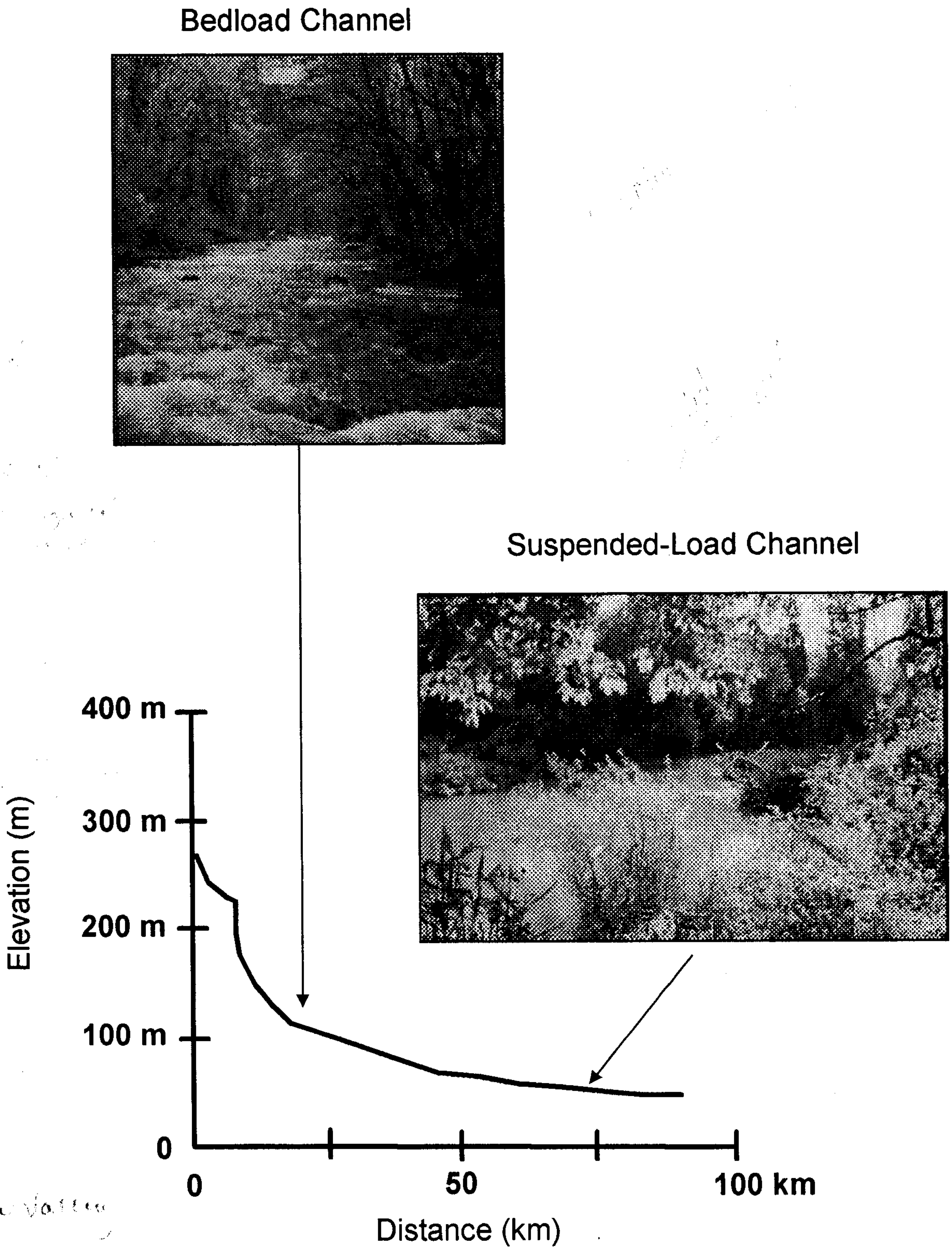


Figure 2. Physiographic map and spot annual precipitation for the Luckiamute Watershed.



Willamette Valley

Longitudinal profile along the Luckiamute River (from Rhea, 1993). Photos from Waichler and others (1997).

Tectonic Setting of the Luckiamute Watershed

- Convergent Tectonic Margin
  - Subduction of Juan de Fuca Plate Beneath North America
    - Convergent Rates: 3.5-4.0 cm/yr
  - Style of Tectonism
    - Oblique Convergence
    - Tectonic accretion
    - Clockwise Rotation
- Coast Range Orogenesis
  - Accreted Marine Volcanic and Sedimentary Rocks
  - Active Uplift Between 15-10 Ma to Present
  - Neotectonics
    - General Uplift and Eastward Tilting
- Tectonic Influence on Luckiamute
  - Luckiamute drains the eastward tilted flanks of the Coast Range (Rhea, 1993)
  - Luckiamute Watershed located at segment boundary of Juan de Fuca Subduction zone

[illegible] at base [illegible]

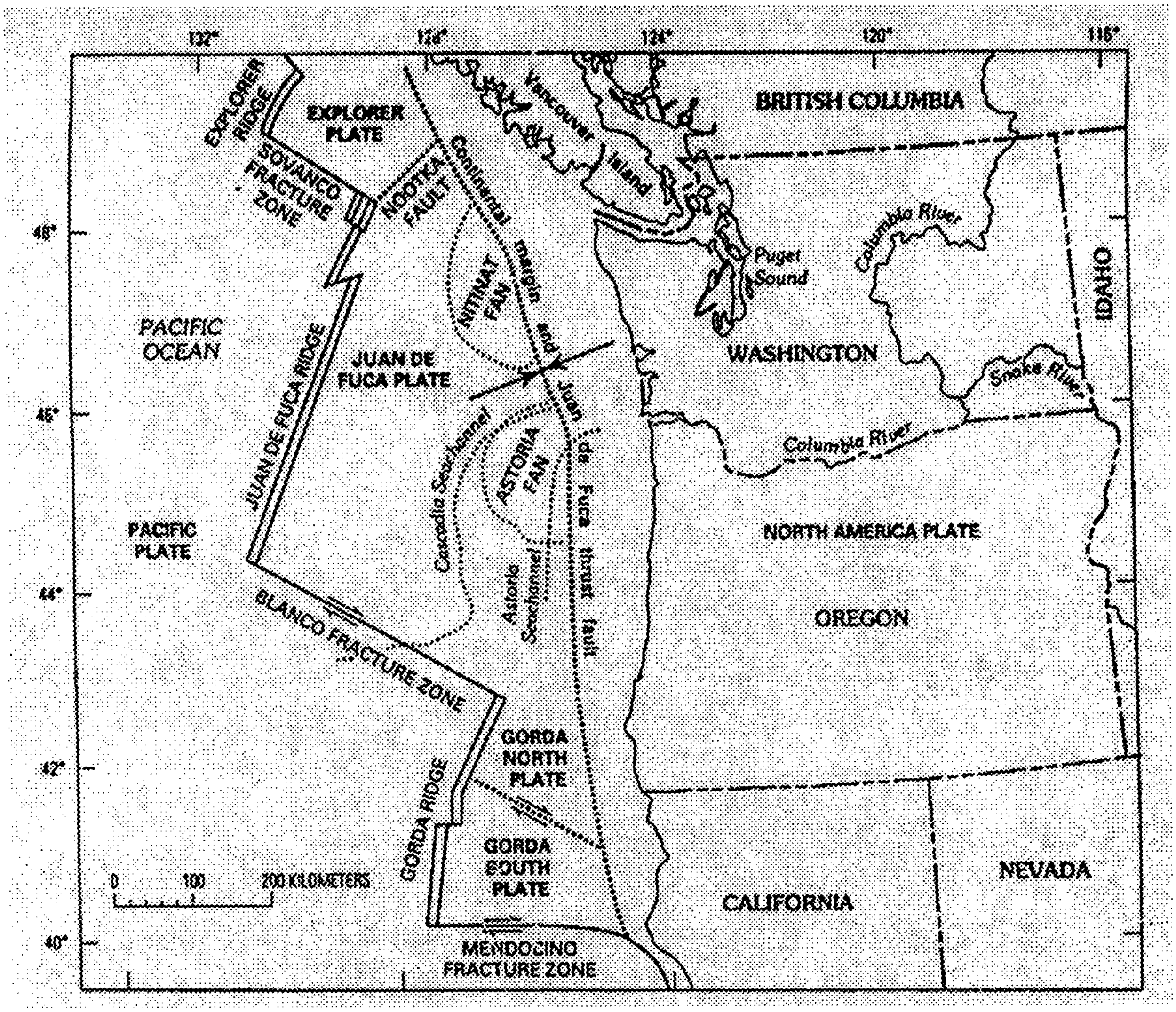
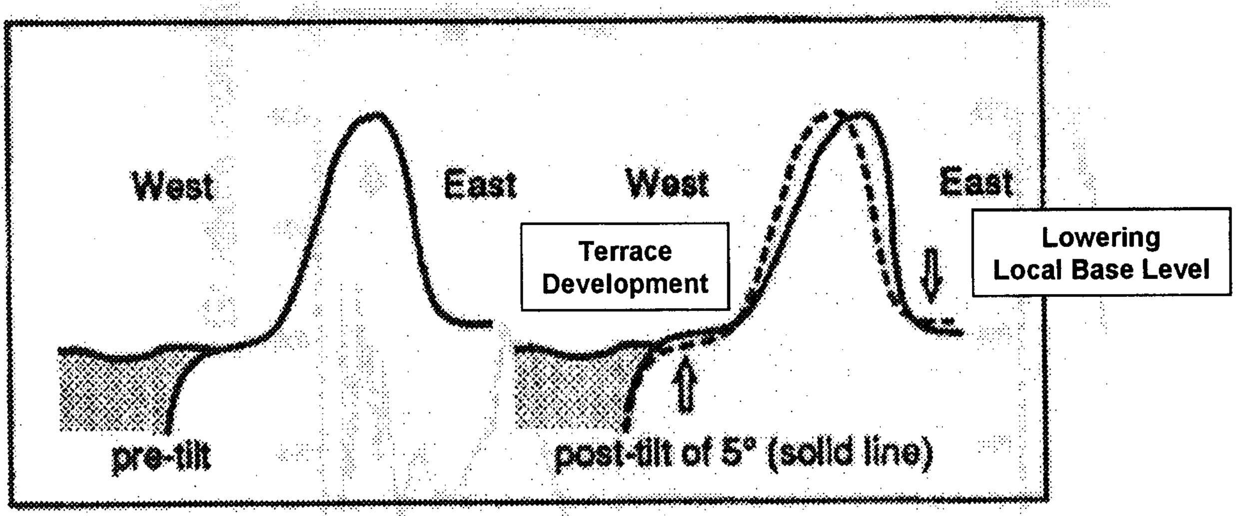
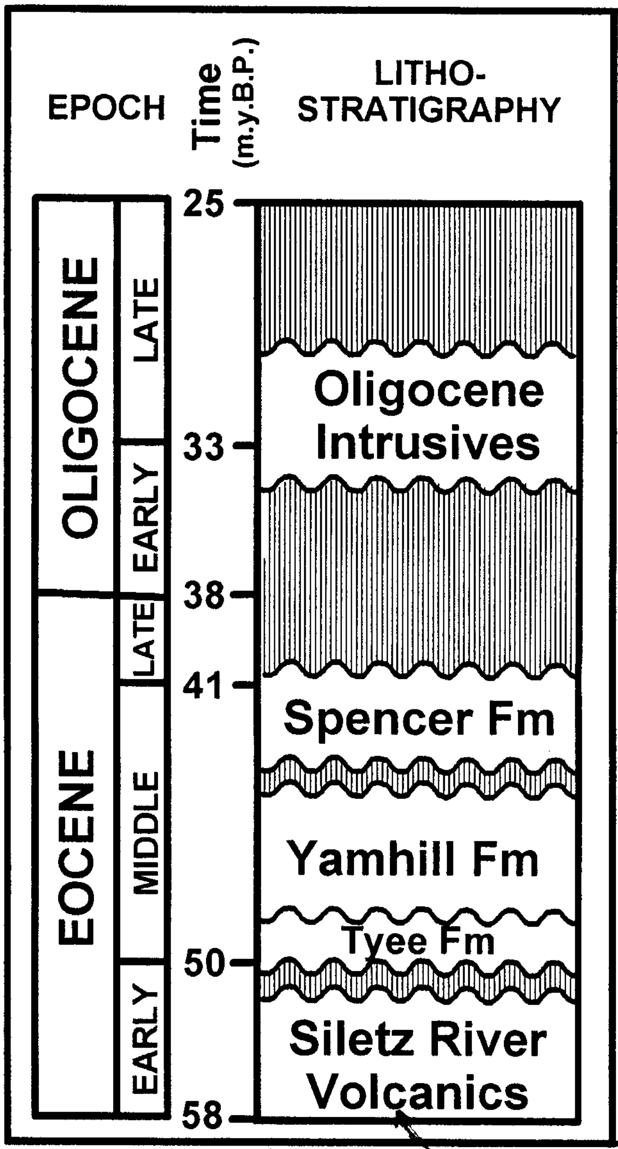


Plate tectonic configuration of the Pacific Northwest.



Cartoon showing effects of Coast Range tilting on watershed gradient (from Rhea, 1993)

Bedrock Geology of the Luckiamute Watershed



Qal – Quaternary Alluvium

Ti – Oligocene Mafic Intrusives: Sheets, sills, and dikes of massive gabbro.

Tss – Spencer Formation: Thick- to thin-bedded marine tuffaceous sandstone, siltstone, and mudstone.

Ty – Yamhill Formation: Massive to thinly bedded marine silstone and sandtone interbeds. Locally includes interlayered basalt lava flows.

Tt – Tyee Formation: Rhythmically bedded, medium-grained feldspathic sandstone and carbonaceous siltstone. Interpreted as deposits of submarine turbidity currents and fans.

Tsr – Siletz River Volcanics: Aphanitic to porphyritic, vesicular pillow flows, tuff breccia, and lava flows. Local interbeds of basaltic siltstone and sandstone. Prevasively zeolitized and veined with calcite. Marine origin interpreted as accreted oceanic crust and seamounts.

Spencer rolling hills

steep Hills b/c [illegible]

w/ both @ same elevation
-marine fan H [illegible]
uplift [illegible]

Flat-floor plain [illegible] - Maulla[illegible] - [illegible]
[illegible]

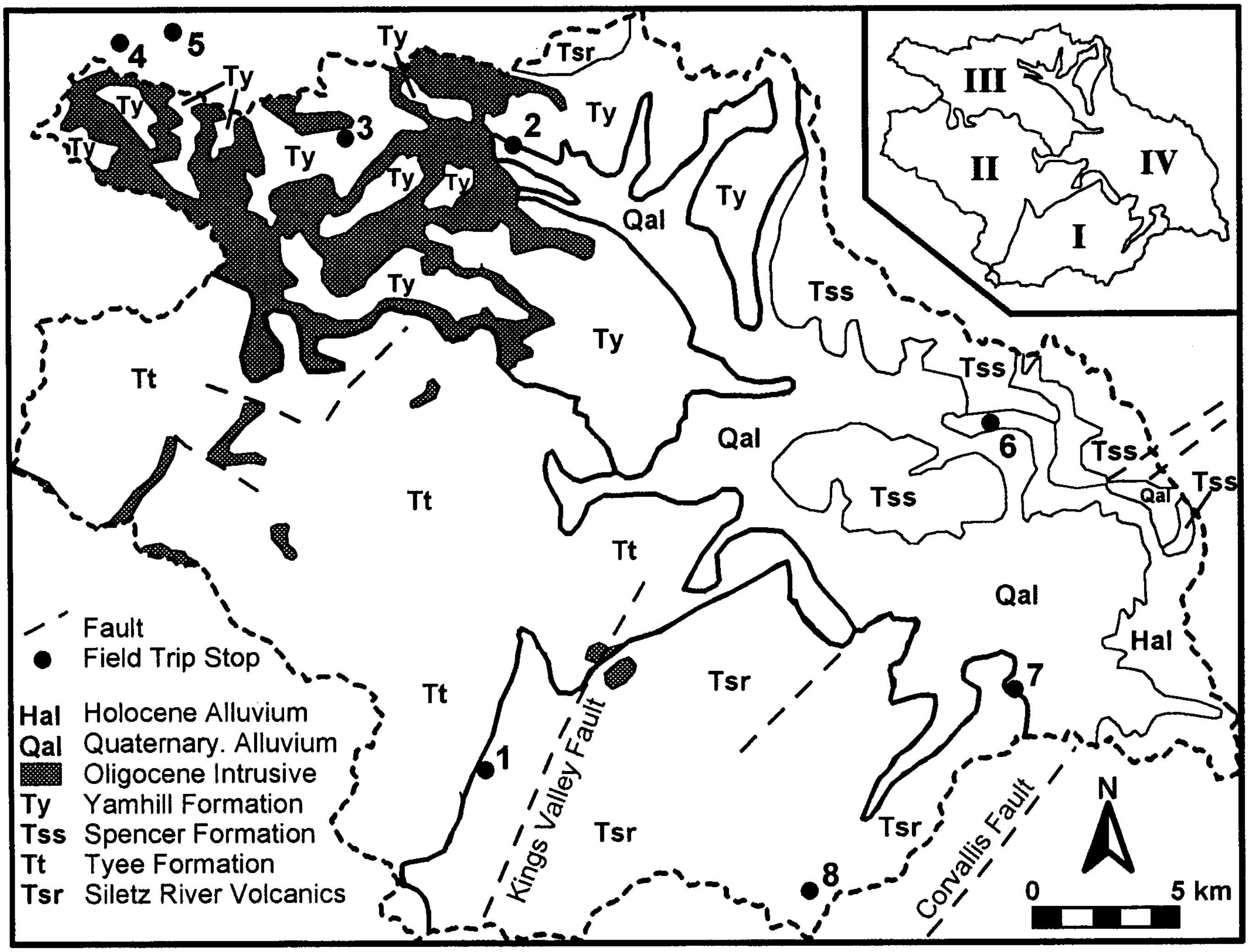
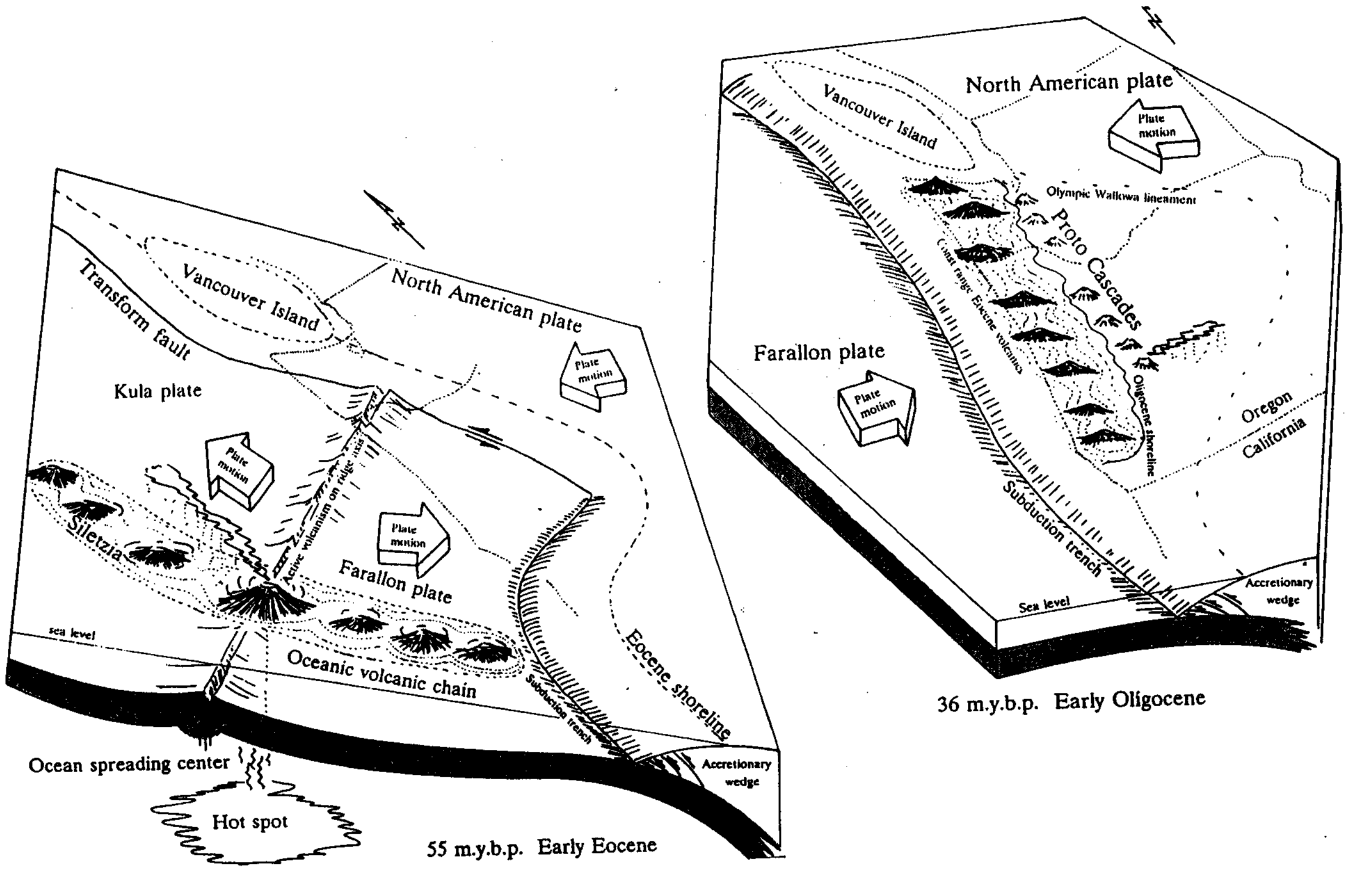


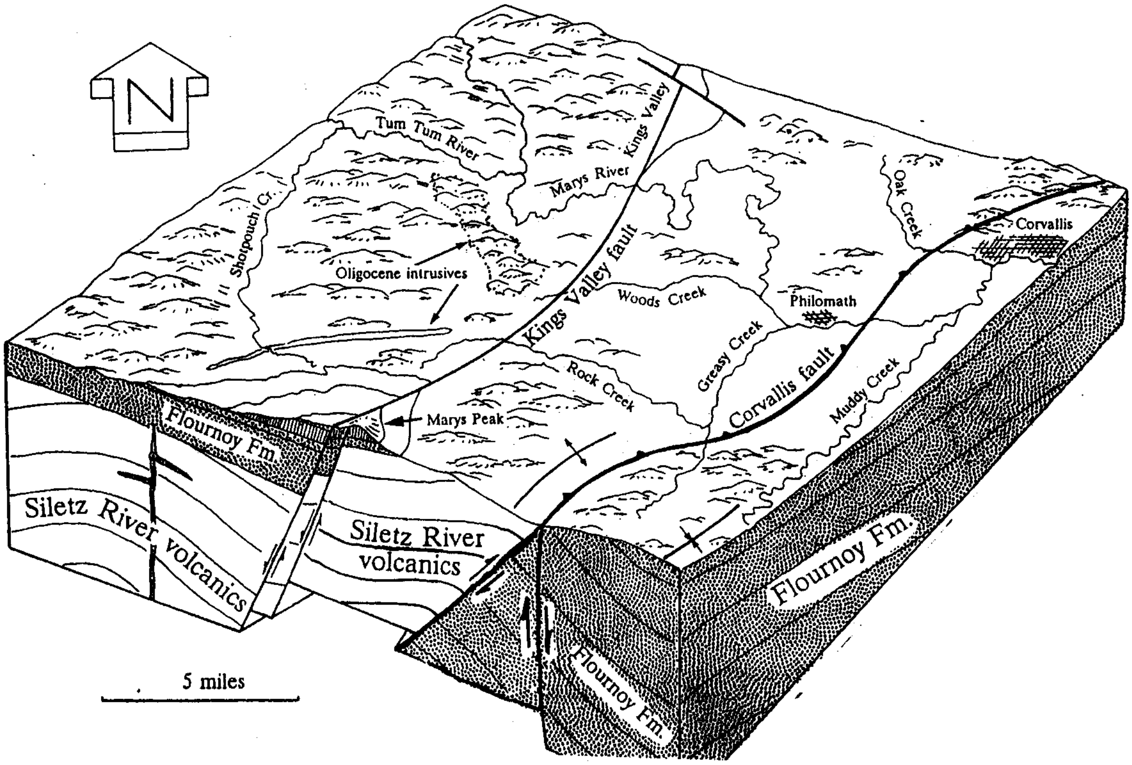
Figure 3. Bedrock geology of the Luckiamute Watershed (after Walker and MacLeod, 1991). Inset map shows grouping of recognized lithospatial domains: I = Siletz River Domain, II = Tyee Domain, III = Yamihill-Ti (Tertiary Intrusive) Domain, IV = Spencer-Valley Fill Domain.



55 m.y.b.p. Early Eocene

36 m.y.b.p. Early Oligocene

Accretionary tectonic model for Siletz River Volcanics (from Orr and Orr, 1999)



Schematic of Corvallis and Kings Valley Faults (from Orr and Orr 1999)

Geomorphology of the Luckiamute Watershed

Valley Floor-Fluvial Regime
- Landforms
  - Channel
  - Floodplain
  - Terrace
  - Small-scale Fans
  - Strath-pediment surfaces
  - Low-relief colluvial hillslopes (Spencer Fm)
- Deposits
  - Alluvial Fill (sorted sand and gravel)
  - Debris Flow Deposits (diamicton)
  - Slackwater Silts and Clay
- Processes
  - Channel Transport
  - Overbank Sedimentation

- Hillslope-Colluvial Regime
  - Landforms
    - Ridge tops
    - Hillslopes-Sideslopes
    - Hollows
    - Pediment Surfaces
  - Deposits
    - Colluvium (gravel diamicton)
    - Residuum (gravel diamicton)
  - Processes
    - Collvial Creep
    - Debris Slide / Flow
    - Tree-throw / Bioturbation

American Geophysical Union Fall 2002 Meeting, San Francisco, California
H21C-0842 Fluvial Geomorphology Session

Bedrock Control on Slope Gradients in the Luckiamute Watershed, Central Coast Range, Oregon: Implications for Sediment Transport and Storage

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Monmouth, Oregon 97360, email: taylors@wou.edu

1. ABSTRACT

The Luckiamute River watershed drains 815 km² along the east flank of the Coast Range in west-central Oregon. Active mountain building and extreme precipitation patterns result in a dynamic geomorphic system characterized by seasonal flooding and slope failure. Style of surficial process and landform associations are controlled by topographic position, underlying bedrock geology, and resistance to erosion.

Bedrock map units are grouped into four lithospatial domains, these include the Siletz River Volcanics Domain (south), the Tyee Domain (west-southwest), the Yamhill-Intrusive Domain (north-northwest), and the Valley Fill-Spencer Domain (east). The Siletz River Domain comprises 19% of the watershed and is mainly seafloor basalt. The Tyee Domain (29% of total area) is underlain by arkosic sandstone lithofacies with local mafic intrusives. The Yamhill-Intrusive Domain occupies 23% of the watershed and is characterized by outcrop of marine siltstone and mafic intrusives. The Valley Fill-Spencer Domain (29%) is underlain by a patchwork of marine sandstones and Quaternary alluvium. Hillslope landforms and colluvial processes dominate the Siletz River, Tyee, and Yamhill domains, whereas fluvial landforms and alluvial processes are characteristic of the Valley Fill Domain.

GIS-based analyses of USGS 10-meter DEMs elucidate associations between lithospatial domains and slope gradients. Average gradients for the Valley Fill, Siletz, Yamhill, and Tyee domains are 3.2 (n = 2290702 10-m cells), 12.7 (n = 1510287 10-m cells), 11.9 (n = 1926899 10-m cells), and 14.5 (n = 2409140 10-m cells) degrees, respectively. The Tyee Domain is associated with significantly steeper slopes on average compared to the other three domains. In addition, greater than 14% of the Tyee Domain area has slopes greater than 25 degrees, compared to less than 1% for the Valley Fill Domain, and less than 8% for the Siletz and Yamhill domains. Results of the slope analyses are consistent with debris-flow hazard models released by the Oregon Department of Forestry, suggesting that hillslopes in the Tyee Domain are most prone to slope failure (percent of domain area in hazard zone: Tyee = 38.1, Siletz = 30.2, Yamhill = 24.6, and Valley Fill = 0.7). Morphometric analysis of low-order valley widths at 500 m increments shows that drainage across the Tyee Domain covers a much wider swath of valley floor (average valley width = 274 m) compared to a similar-sized drainage area in the Yamhill Domain (average valley width = 109 m). These data suggest that bedrock lithology exerts a strong control on hillslope morphology, style of hillslope process, and valley erosion dynamics in headwater portions of the Luckiamute.

The interplay between hillslope transport mechanisms, delivery rates, and channel hydraulics control the volume of sediment exported or stored within a mountainous watershed. The comparatively steep, debris-flow-prone slopes and wide valley bottoms in the Tyee Domain indicate a potential for hillslope transport rates to be greater than the ability of the channel system to export sediment. Analytical results presented herein provide a preliminary dataset upon which to build a field-based sediment-storage budget for the Luckiamute watershed. The working hypothesis is that the Tyee Domain has a significantly greater volume of valley-bottom sediment in storage compared to the other upland domains (Siletz, Yamhill). The model implies that spatial variation of bedrock lithology is a primary factor controlling slope gradients, hillslope delivery rates, and the resulting sediment-transport efficiency of the channel system.

2. INTRODUCTION

Study of the production, transport, and storage of surficial sediment in drainage basins is essential for understanding their evolution and geomorphic behavior. Fluvial regimes are intimately related to hillslope sediment delivery and storage systems (Dietrich and Dunne, 1978). The central Coast Range of Oregon represents an unglaciated, humid-mountainous landscape. Active mountain building and extreme precipitation patterns result in a dynamic geomorphic system characterized by seasonal flooding, slope failure, and debris flow activity (Benda, 1990). As such, forested drainage basins export sediment by colluvial and alluvial processes in high-gradient channel systems. Understanding the controls for routing and storage of sediments in this region are a critical component of habitat management plans (Swanson and others, 1990; Gregory and others, 1989; FEMAT, 1993).

This study involves GIS-based analyses of bedrock distribution and slope gradients in the Luckiamute Watershed of Polk and Benton counties, Oregon (Figure 1). Bedrock and slope gradient data are examined in tandem with valley-bottom widths to make inferences regarding controls on sediment-transport efficiency and valley-erosion dynamics in the central Coast Range. A conceptual model is derived relating sediment storage to hillslope delivery mechanisms and stream-power distribution.

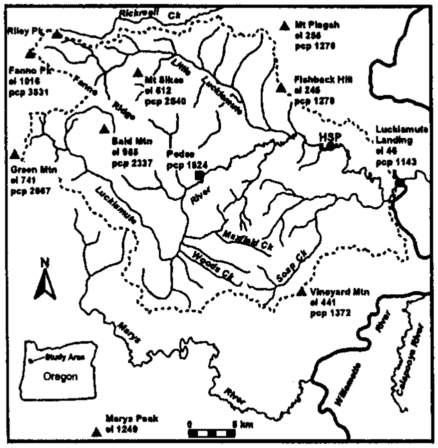

Figure 1. Physiographic map and spot annual precipitation for the Luckiamute Watershed. Abbreviations include el = spot elevation (m), pcp = average annual precipitation (mm), HSP = Helmick State Park (USGS Suver Station 14190500).

3. GENERAL SETTING

3.A. Physiography

The Luckiamute River comprises a portion of the Willamette Basin in west-central Oregon (Figure 1). This seventh-order watershed (Strahler, 1957) drains eastward from the Coast Range into the Willamette River and occupies a total drainage area of 815 km². The Luckiamute Basin is bounded by the Willamette River to the east, the crest of the Coast Range to the west, Green Mountain and Marys River to the south, and the Rickreall Creek Watershed to the north (Figure 1). Fanno Ridge separates the watershed into two tributary subbasins, with the Little Luckiamute to the north and the main stem of the Luckiamute proper to the south (Kings Valley) (Figure 1). Land surface elevations range from 46 m (150 ft) at the confluence with the Willamette River to 1016 m (3333 ft) at Fanno Peak. The Luckiamute has an average gradient of 3 m/km, a total stream length of 95 km, and an average basin elevation of 277 m (910 ft) (Figure 2; Rhea, 1993; Slack and others, 1993).

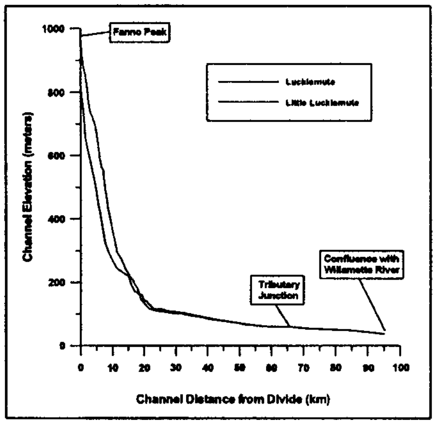

Figure 2. Longitudinal profile and channel gradients of the Luckiamute and Little Luckiamute tributaries.

3.B. Climatology and Hydrology

Taylor and Hannan (1999) summarized historic climate data for western Oregon. The Luckiamute straddles Oregon Climate Zones 1 (Coastal Area) and 2 (Willamette Valley), with westerly Pacific marine air serving as the primary moisture source. Precipitation patterns are strongly seasonal with 75% of the annual total occurring from October to March. Hydrometeorologic events are driven primarily by cyclonic and frontal storm systems. Rain-on-snow events are common at higher elevations.

Annual precipitation varies greatly from west to east across the Luckiamute Watershed, as governed by westerly airflow and a lee-side rain-shadow effect in the Coast Range. Annual precipitation in the watershed ranges from 3600 mm along the northwestern boundary to 1140 mm in the center of the Willamette Valley, a west-to-east precipitation gradient of 95 mm/km (Figure 1).

The U.S. Geological Survey maintains a gauging station on the Luckiamute River at Helmick State Park (USGS Suver Station 14190500; Figure 1). The station is 18 km upstream from the basin outlet, with 650 km² of drainage area positioned above the monitoring point (approximately 80% of total). Analysis of stream-flow record reveals that flooding and high discharges directly correspond to seasonal precipitation patterns. During the winter season, average discharge is on the order of 50 m³/sec, whereas summer months are typified by less than 3 m³/sec. The two peak discharges of record were observed at 700 and 620 m³/sec during December 1964 and February 1996, respectively. The 100-yr flood event at the Suver Station is marked by a discharge of 760 m³/sec (Waichler and others, 1997).

Waichler and others (1997) derived a rainfall-runoff model for the Luckiamute Watershed. They estimated an average annual precipitation of 1894 mm for the entire watershed, with a total input volume of 1.23 x 10⁹ m³. A water budget analysis indicates that 61% of the total annual rainfall is accounted for as runoff, whereas 39% is consumed in the form of evapotranspiration and groundwater flow.

3.C. Vegetation

The Coast Range portion of the Luckiamute watershed lies in the *Tsuga heterophylla* Zone of Franklin and Dyrness (1988). Dominant forest species include *Pseudotsuga menziesii* (Douglas fir), *Tsuga heterophylla* (western hemlock), and *Thuja plicata* (western red cedar), with a lesser occurrence of *Abies grandis* (grand fir). These species formed part of the classic old-growth timber stands that were logged extensively in the Pacific Northwest during the early 1900s. Disturbed valley zones are characterized by *Alnus rubra* (red alder) and *Rubus spp* (blackberry). *Acer macrophyllum* (big leaf maple) is a common late succession species in valley bottoms and hollows. Balds with meadow grasses and mosses occur locally along higher elevation ridge tops. Lower reaches of the Luckiamute Watershed lie in agricultural crop and pasture land, with local patches of mixed *Quercus garryana* (Oregon white oak) and urban mosaic species.

3.D. Tectonic Setting

The Luckiamute Watershed is situated on a convergent tectonic margin with the Juan de Fuca Plate subducting eastward beneath North America. This subduction zone is associated with a long history of oblique convergence, tectonic accretion, arc volcanism, dextral shear, and clockwise rotation (Wells and others, 1984). Long-term rates of plate convergence average 3.5 to 4.0 cm/yr (Adams 1984).

The western two-thirds of the Luckiamute River drains the central Oregon Coast Range (Figure 3). This mountain system began to uplift between 15 and 10 Ma (Snavely and others, 1993) and continues to be neotectonically active (Adams, 1984). Thus present-day relief in the Oregon Coast Range is a combination of net uplift due to plate convergence and vertical incision by surface processes (Kelsey and others, 1994).

Historic releveling surveys of western Oregon suggest that the western boundary of the Luckiamute is presently tilting eastward at a rate of approximately 1 x 10^{-8} rad/yr with crustal shortening of 10^{-7} yr^{-1} (Adams, 1984). Although tilt data suggest that portions of the Luckiamute are neotectonically active, Mitchell and others (1994) reported no evidence for historic uplift in this part of the Coast Range. By comparing topographic relationships in this region to the southern Coast Range and Olympics, Kelsey and others (1994) hypothesized that the subducting Juan de Fuca slab is likely segmented at the latitude of the Luckiamute.

4. BEDROCK GEOLOGY

Yeats and others (1996) and Snavely and Wells (1996) provided comprehensive summaries of the bedrock geology in the Luckiamute region. Bedrock is comprised of an Eocene to Oligocene sequence of basaltic volcanic rocks, marine sedimentary rocks, and mafic intrusives of varying composition (Figure 3). In ascending order, lithostratigraphic units include the Siletz River Volcanics (upper Paleocene to middle Eocene; 58-46 Ma), Tyee Formation (middle Eocene; 53-48 Ma), Yamhill Formation (middle and upper Eocene; 46-44 Ma), Spencer Formation (upper Eocene; 44-41 Ma), and undifferentiated mafic intrusions (middle Oligocene; 34-30 Ma). The Siletz River Volcanics are composed primarily of submarine basalt lava flows interbedded with breccia, sandstone, and siltstone. The Tyee Formation is characterized by arkosic sandstone lithofacies, interpreted as deltaic and submarine fan deposits. The Yamhill Formation is comprised of interbedded siltstone and shale of marine origin. The Spencer Formation is comprised of arkosic sandstone, siltstone, and mudstone, interpreted as shallow marine deposits. Given the convergent tectonic setting, strata in the Coast Range portion of the Luckiamute are extensively faulted and fractured.

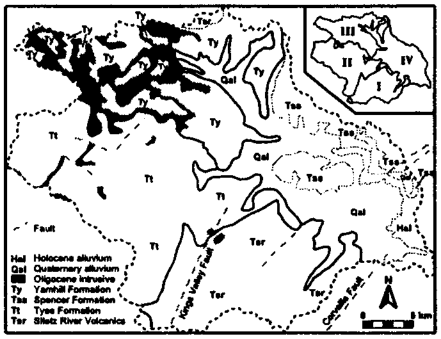

Figure 3. Bedrock geology of the Luckiamute Watershed (after Walker and MacLeod, 1991). Inset map shows grouping of recognized lithospatial domains: I = Siletz River Domain, II = Tyee Domain, III = Yamhill-Ti (Tertiary Intrusive) Domain, IV = Spencer-Valley Fill Domain. See text for discussion.

For this study, bedrock map units are grouped into four lithospatial domains in the Luckiamute, as recognized on the basis of outcrop pattern (Figure 3). These include the Siletz River Volcanics Domain (south), the Tyee Domain (west-southwest), the Yamhill-Intrusive Domain (north-northwest), and the Spencer-Valley Fill Domain (east). The Siletz River Volcanics Domain comprises 19% of the watershed and is mainly seafloor basalt. The Tyee Domain (29% of total area) is underlain primarily by Tyee Formation with local mafic intrusives supporting ridge tops. The Yamhill-Intrusive Domain occupies 23% of the watershed and is characterized by outcrop of equal portions of the Yamhill Formation and mafic intrusives. The Spencer-Valley Fill Domain (29%) is underlain by a patchwork of Spencer Formation and Quaternary alluvium. Each of these bedrock spatial domains is associated with unique landform assemblages and surficial processes.

5. SURFICIAL GEOLOGY AND GEOMORPHOLOGY

Geomorphic systems of the Luckiamute Watershed can be divided into a valley-floor regime to the east and a hillslope-colluvial regime to the west (Figure 4). Style of surficial process and landform associations are controlled by topographic position, underlying bedrock geology, and resistance to erosion. Hillslope landforms and colluvial processes dominate the Siletz River, Tyee, and Yamhill-Intrusive domains, whereas fluvial landforms and alluvial processes are characteristic of the Spencer-Valley Fill Domain.

5.A. Valley floor-fluvial regime

The lower Luckiamute is characterized by a mix of alluvial stratigraphic units and geomorphic surfaces. Landforms include active channels, floodplains, fill terraces, and strath-pediment surfaces (McDowell, 1991). In addition to these fluvial landforms, the lower Luckiamute is also associated with swaths of low-relief colluvial hillslopes supported by the Spencer Formation (Figure 4). Present-day geomorphic conditions

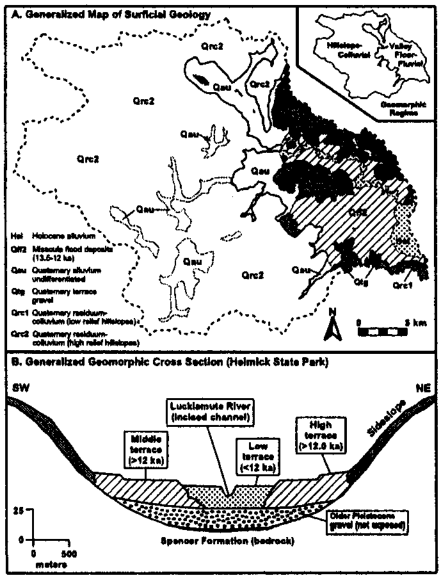

Figure 4. Surficial geology and geomorphology of the Luckiamute River Basin. Surficial map units are modified from O'Connor and others (2001), after Taylor and others (1996). Cross section shown in frame B represents generalized landform elements at Helmick State Park (Location "HSP" on Figure 1).

extend back to at least the Pliocene, the time at which the Willamette River eroded through intrabasinal divides, permitting open drainage to the Columbia River (McDowell, 1991). Pleistocene through Holocene terrace development records a complex history of base level fluctuation, internal erosion-deposition cycles, and glacial-outburst floods (Missoula Floods) from the Columbia River system.

Maximum thickness of Pliocene-to-Holocene sedimentary fill in the mid-Willamette Valley is up to 150 m (Yeats and others, 1996). Balster and Parsons (1968) mapped terrace and floodplain surfaces in this region on the basis of topography and soil development. The active channel of the lower Luckiamute is incised 8 to 9 m below the floodplain, with higher level terrace surfaces at 12 to 15 m above mean annual stage (Reckendorf, 1993). The higher-level terrace surfaces are covered with rhythmically-bedded, silty slack-water deposits of the Willamette Formation (Missoula Flood deposits; 13.5-12 ka). These late Pleistocene surfaces are inset with lower terrace and floodplain deposits that are predominantly Holocene in age (post-Missoula Flood; <12 ka) (Figure 4; O'Connor and others, 2001).

5.B. Hillslope-colluvial regime

Parsons (1978) presented a geomorphic overview of the Coast Range portion of the Luckiamute. Small-scale intrusions and volcanic rocks support ridge tops and provide the resisting media for steep terrain. On average, hillslope gradients range from 25 to 30% with maxima up to 90%. Local relief is on the order of 300 to 500 m. This portion of the Luckiamute Watershed is dominated by colluvial hillslope processes including slide, debris flow, creep, tree throw, and faunal turbation. Fluvial transport and erosion occur in narrow, low-order tributary valleys. Upland landforms include ridge tops, side slopes, hollows, landslide scars, and dissected pediments. Narrow valley bottoms are geomorphically active with channels, floodplains, low terraces, and small-scale debris fans (Balster and Parsons, 1968).

6. SLOPE GRADIENT ANALYSIS

The central Oregon Coast Range is noted for hazards associated with landslides, flooding, and debris flow activity (Gresswell and others, 1979; Robinson and others, 1999). With gravity as a driving force, slope gradients and regolith properties govern the spatial distribution of mass wasting phenomena in mountainous watersheds. Bedrock lithology, in turn, is a primary factor controlling hillslope morphology and significantly affects the style, caliber, and volume of sediment transported by drainage basins (e.g. Hack, 1957; Bull, 1991; Kelson and Wells, 1989). As such, slope gradient analysis was conducted on the Luckiamute Watershed to delineate associations between bedrock type (i.e. bedrock domain), hillslope morphology, and potential for slope failure.

6.A. Methodology

USGS 10-m digital elevation models (DEM) were analyzed using a bundle of Geographic Information Systems software including ArcView 3.3, Idrisi 32, and Surfer 7.0. 7.5-minute DEMs were concatenated and clipped according to the lithospatial domains identified in the Luckiamute Basin (Valley Fill-Spencer, Siletz, Yamhill-Intrusive, and Tyee domains; Figure 3). Slope gradients were calculated for the elevation grid at 10-m node spacing. Slope and elevation grid statistics were derived for each lithospatial domain using Idrisi32 statistical algorithms.

6.B. Results and Discussion

Tables 1 and 2 present summaries of elevation and slope data for the Luckiamute Watershed. The Tyee and Yamhill domains underlie the upper reaches of the Luckiamute and Little Luckiamute tributaries, respectively (Figures 1 and 3). Topographic relief in these domains exceeds 900 m, with valley-bottom elevations on the order of 65 m.

Cumulative frequency plots of slope data illustrate the association between gradient and bedrock domain type (Figure 5). The Tyee Domain is associated with significantly steeper slopes on average compared to the other three domains. Average gradients for the Valley Fill, Siletz, Yamhill, and Tyee domains are 3.2 (n = 2290702 10-m cells), 12.7 (n = 1510287 10-m cells), 11.9 (n = 1926899 10-m cells), and 14.5 (n = 2409140 10-m cells) degrees, respectively. Systematic t-tests of domain means (α = 0.01) document that the Tyee is associated with significantly steeper slopes on average compared to the other three domains. In addition, greater than 14% of the Tyee Domain area has slopes greater than 25 degrees, compared to less than 1% for the Valley Fill Domain, and less than 8% for the Siletz and Yamhill domains.

Results of the slope analyses are consistent with debris-flow hazard models released by the Oregon Department of Forestry (ODF, 2000). Areal analysis of the ODF dataset show that hillslopes in the Tyee Domain are most prone to slope failure and debris flow hazard (Figure 6). Robinson and others (1999) conducted a *posteriori* analyses of landslide activity associated with the February 1996 storm event in western Oregon. Based on reconnaissance surveys and GIS analysis, they concluded that hillslopes ranging from 26 to 39 degrees are associated with moderate to high hazard for shallow rapid landslides. In addition, Robinson and others (1999) identified the Tyee Formation as being particularly prone to slope-failure in the Coast Range. These data suggest that bedrock lithology exerts a strong control on the style of hillslope process, regolith development, and related landforms in the upland portion of the Luckiamute.

Table 1. Summary of Elevation Parameters for the Lucklamute Watershed.

Lithospatial Domain	Domain Area (km²)	Max Elev (m)	Min Elev. (m)	Relief (m)
Valley Fill-Spencer	229.4	244.8	47.0	197.8
Siletz	151.2	637.8	67.1	570.7
Yamhill-Intrusive	193.0	1009.5	66.5	943.0
Tyee	241.2	976.2	68.9	907.3

Table 2. Summary of Slope Parameters for the Lucklamute Watershed.

	Valley Fill-Spencer	Siletz	Yamhill-Intrusive	Tyee
Max Slope	56.8°	61.9°	59.0°	62.0°
Avg Slope	3.2°	12.7°	11.9°	14.5°
Std Dev	3.98°	7.90°	7.97°	9.18°
Variance	15.84°	62.49°	63.51°	84.25°
90th Percentile	9°	24°	24°	28°
% Cells >20°	0.7	18.3	15.4	25.9
% Cells >25°	0.2	7.7	7.9	14.3
Total No. 10-m Cells	2290702	1510287	1926899	2409140

7. VALLEY MORPHOLOGY

Valley-width morphology plays an important role in governing the capacity of mountainous watersheds to export sediment (Taylor, 1998). Miller (1994) observed that narrow valleys promote a high proportion of hydraulic shear stress per unit width, resulting in lateral erosion and sediment transport. Accordingly, wider valleys result in lower unit stream power, promoting sediment storage in floodplains and terraces (Magilligan, 1994). Thus understanding the relationship between valley morphology and gradient in channel systems is necessary for the derivation of sediment transport models.

Valley widths for the Luckiamute and Little Luckiamute tributaries were derived from topographic analysis of USGS 7.5-minute DRGs. Valley widths were determined according to contour patterns at 500-m increments in a down-stream direction from the drainage divide. Only the lower-order reaches of the watershed were examined, with transect extents constrained to the limits of the Tyee and Yamhill lithospatial domains (Figure 7A). Analytical results are graphically illustrated in Figure 7B.

Valley widths for the Luckiamute tributary in the Tyee Domain average 274 m with a standard deviation of 231.5 (n = 67). Comparatively, valley reaches are significantly narrower for the Little Lucklamute (Yamhill Domain) with an average of 109 m (standard deviation = 73.2 , n = 43). Although the plot in Figure 7B illustrates variable expansion and constriction of valleys in both the Luckiamute and Little Lukiamute, data show that on average, drainage across the Tyee Domain covers a much wider swath of valley floor compared to a similar-sized area in the Yamhill Domain. This analysis suggests that bedrock lithology exerts a strong control on valley erosion dynamics in headwater portions of the Luckiamute.

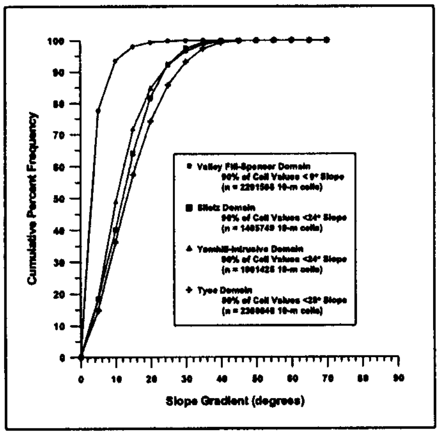

Figure 5. Cumulative percent frequency of slope gradient for the Luckiamute Basin. Data are organized according to lithospatial domain. Systematic t-test analyses (α = 0.01) document that slopes in the Tyee Domain are significantly steeper than those of the other three.

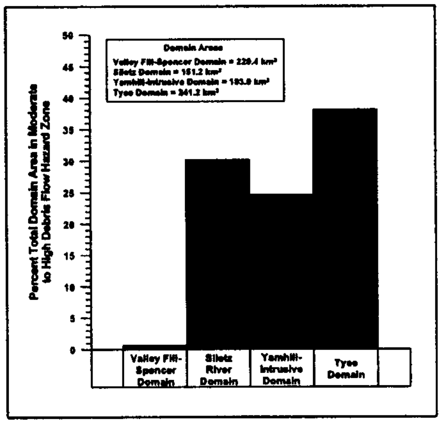

Figure 6. Histogram showing percent of Luckiamute lithospatial domains in the moderate to high debris-flow hazard zones as classified by the Oregon Department of Forestry (ODF, 2000).

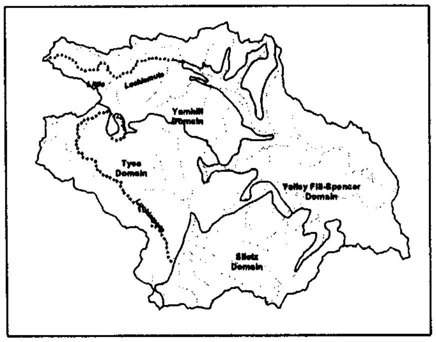

Figure 7A. Map showing sampling distribution (500-m increments) for Luckiamute and Little Luckiamute valley-width data plotted on Figure 7B.

8. CONCEPTUAL SEDIMENT-STORAGE MODEL

Sediment routing and storage models for mountain watersheds provide a valuable technique for assessing the impacts of complex variables on fluvial systems (Schumm, 1977; Dietrich and Dunne, 1978; Bull, 1991). Quantification of sediment flux and storage in valley-bottom compartments is most important as it reflects the ability of watersheds to export sediment. Although sediment yield and storage data are presently not available for the Luckiamute study area, GIS-based analysis of slope gradients and valley-width morphology provide a preliminary tool for assessing sediment-transport efficiency (after Taylor, 1999).

Zero-order hollows serve as principal routing components in mountain watersheds (Dietrich and Dunne, 1978) and form an important facet of Coast Range landscapes (Montgomery and Others, 1998). Local topographic convergence directs colluvium into hollows, with transport rates proportional to degree of convergence (Reneau and others, 1990). Hollows accumulate hillslope regolith via diffusive mass-wasting processes such as creep, tree throw, and bioturbation. The sediment mass is subsequently delivered to higher-order tributaries by a spectrum of hydraulic processes ranging from streamflow to hyperconcentrated flow to debris flow. Once in the primary fluvial system, turbulent channel flow exports sediment out of the watershed as dissolved, suspended, and traction load. Each of these processes routes sediment into and out of storage, depending on energy level of the system. Storage of sediment in drainage basins favors conditions where sediment supply exceeds transport capacity.

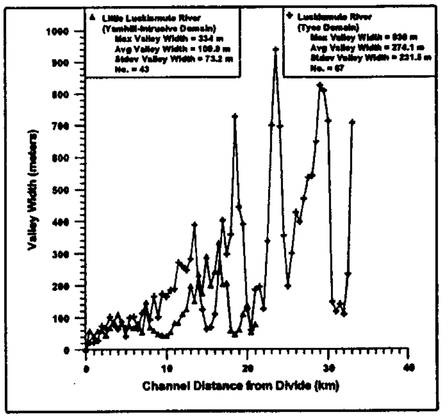

Figure 7B. Plot of valley width (m) vs. channel distance from drainage divide (km) for the Luckiamute and Little Luckiamute tributaries, Tyee and Yamhill lithospatial domains, respectively.

Analytical results presented herein provide a preliminary dataset upon which to build a field-based sediment-storage budget for the Luckiamute watershed. The working hypothesis is that the Tyee Domain has a significantly greater volume of valley-bottom sediment in storage compared to the other upland domains (Siletz, Yamhill). The comparatively steep, debris-flow-prone slopes and wide valley bottoms in the Tyee Domain indicate a potential for hillslope transport rates to be greater than the ability of the channel system to export sediment. The model suggests a net deficit of unit stream power in the Tyee Domain as hillslopes route high volumes of sediment to valley bottoms at magnitudes greater than the channel transport capacity. As slope gradients and valley-width morphology varies according to lithospatial domain in the Luckiamute, the model implies that spatial variation of bedrock lithology is a primary factor controlling slope gradients, hillslope delivery rates, and the resulting sediment-transport efficiency of the channel system.

9. SUMMARY AND CONCLUSION

The Luckiamute Watershed in the central Coast Range of Oregon represents a dynamic geomorphic system characterized by seasonal flooding and slope failure. Style of surficial process and landform associations are controlled by underlying bedrock geology. The Luckiamute is divided into four lithospatial domains including the Siletz River (seafloor basalts), the Tyee (arkosic sandstone), the Yamhill-intrusive (marine siltstone and gabbro), and the Valley Fill-Spencer (Quaternary alluvium and Tertiary marine sandstone). GIS-based analyses of USGS 10-m DEMs elucidate associations between lithology and slope gradients. The Tyee Domain is associated with significantly steeper slopes, wider valley bottoms, and higher occurrence of slope failure compared to the other three domains. The comparatively steep, debris-flow-prone slopes and wide valley bottoms in the Tyee Domain indicate a potential for hillslope transport rates to be greater than the ability of the channel system to export sediment. The model suggests a net deficit of unit stream power along the lower-order portions of the Luckiamute tributary. Analytical results presented herein provide a preliminary dataset upon which to build a field-based sediment storage budget for the Luckiamute Watershed. To this end, work in the near future will involve detailed geomorphic mapping and estimates of sediment storage volumes in valley-bottom compartments.

10. ACKNOWLEDGMENTS

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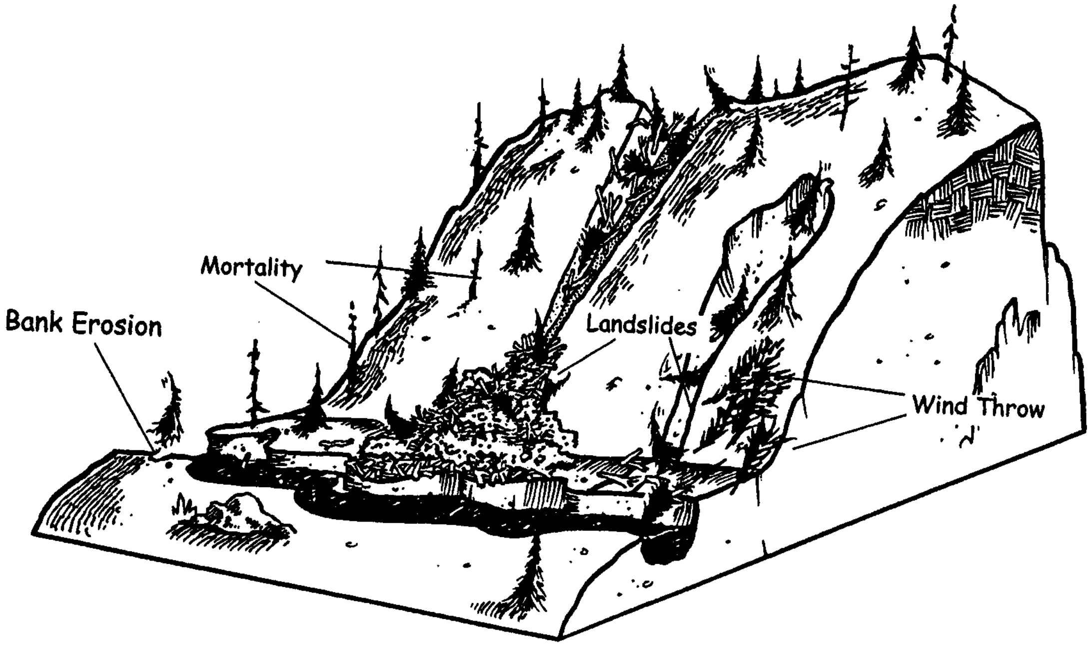
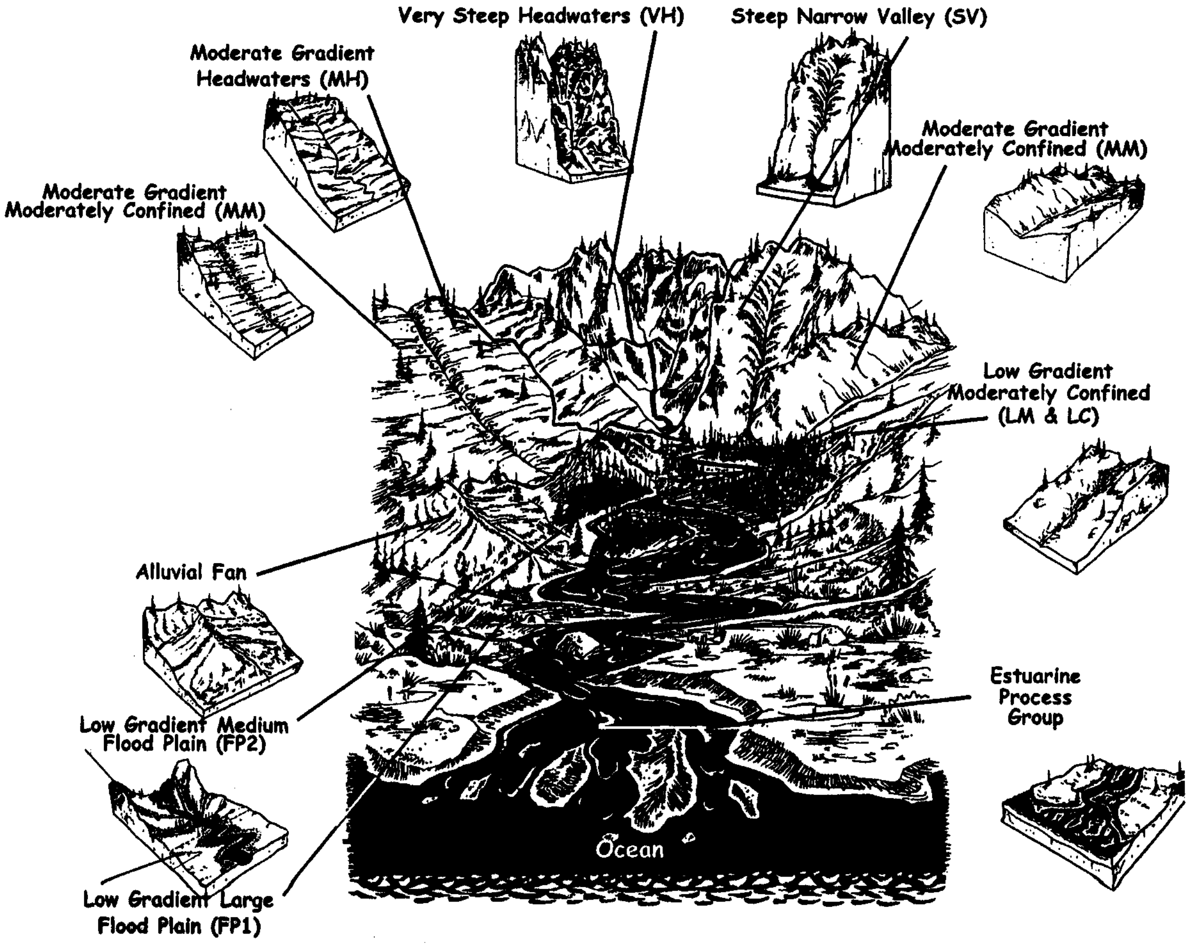


Geomorphic configuration of mountainous watersheds in the Coast Range.



Typical distribution of CHTs in a mountainous watershed.

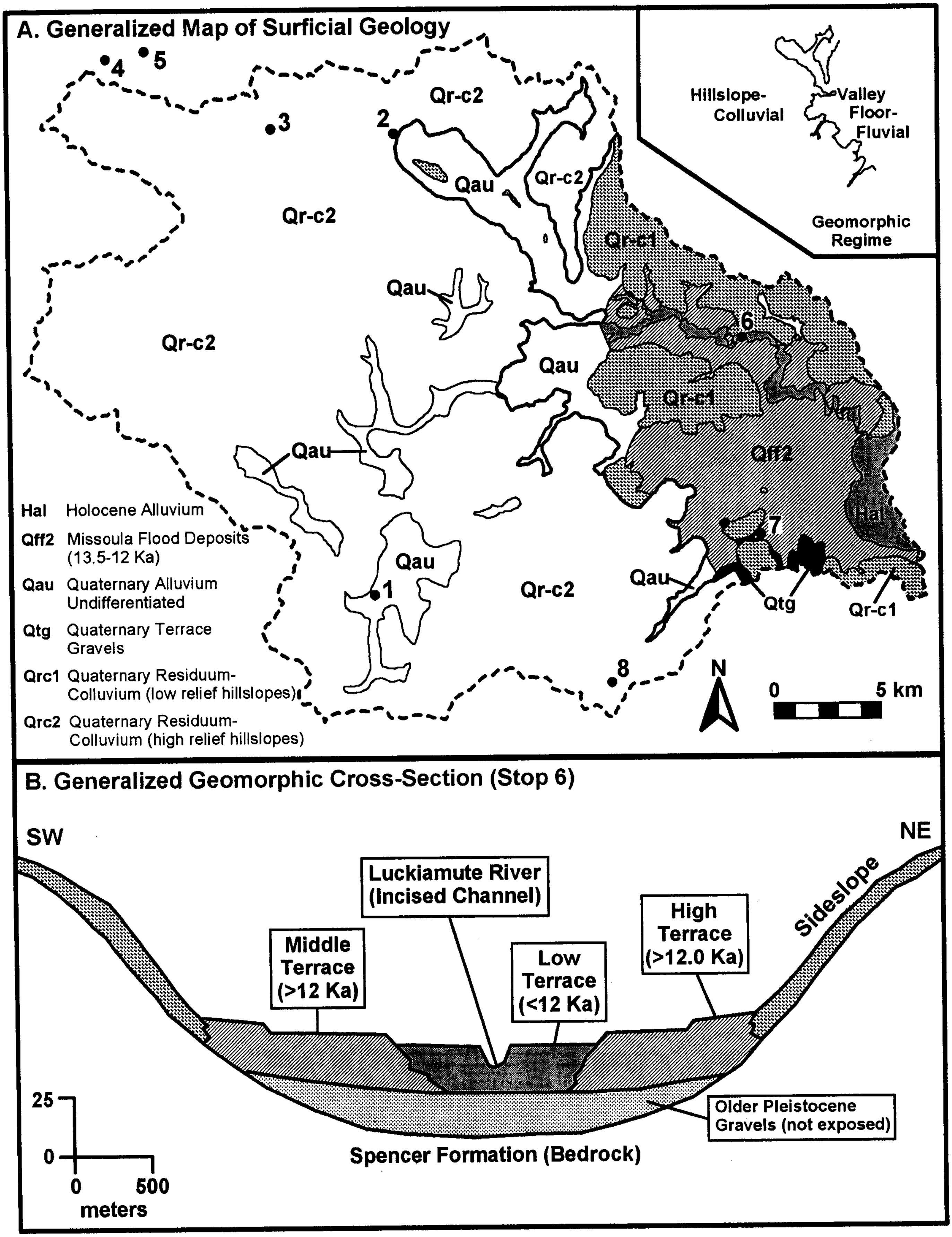
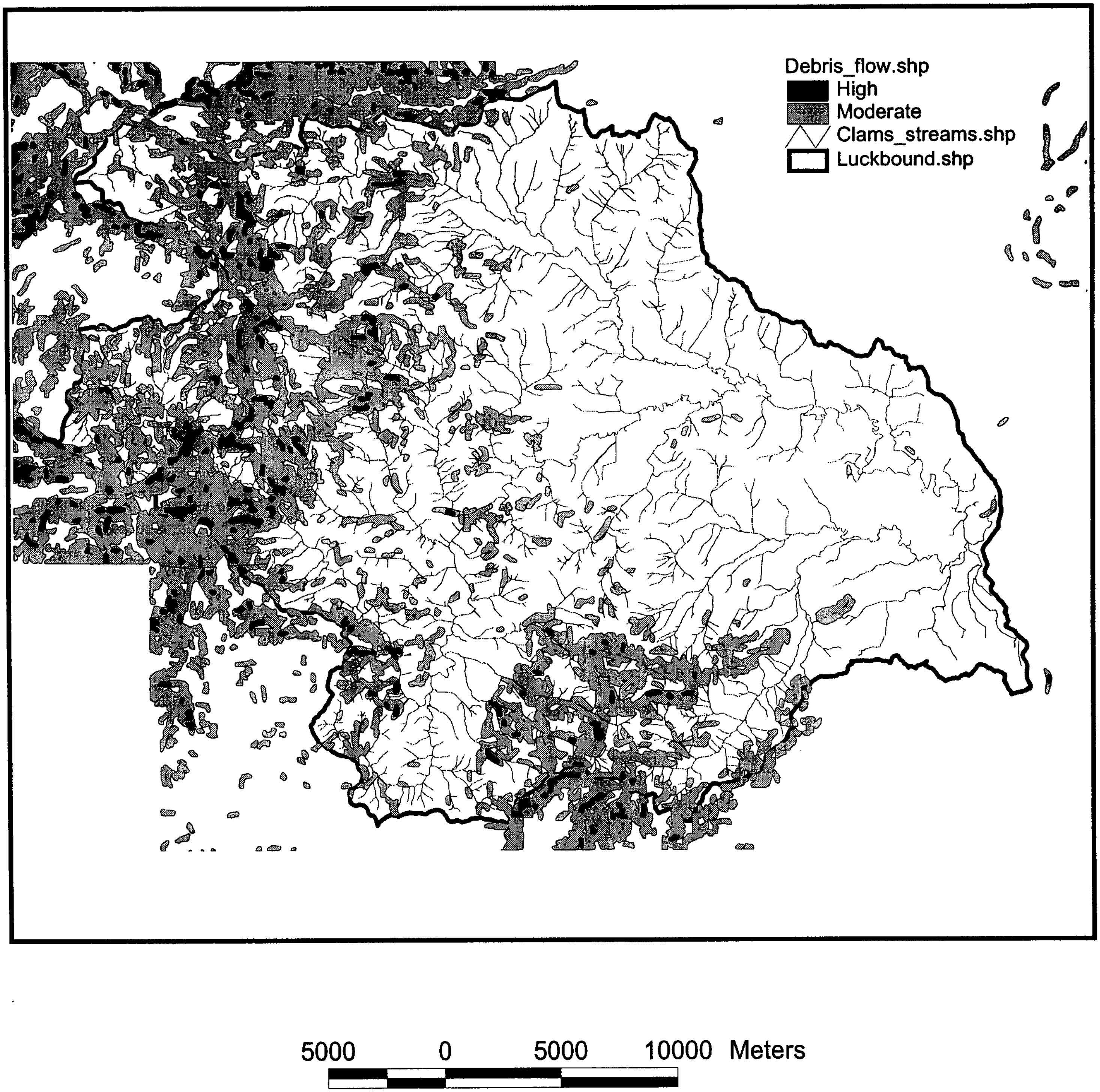


Figure 4. Surficial geology and geomorphology of the Luckiamute River Basin. Surficial map units are modified from O'Connor and others (2001), after Taylor and others (1996). Cross section shown in frame B represents generalized landform elements at Helmick State Park (Stop 6).

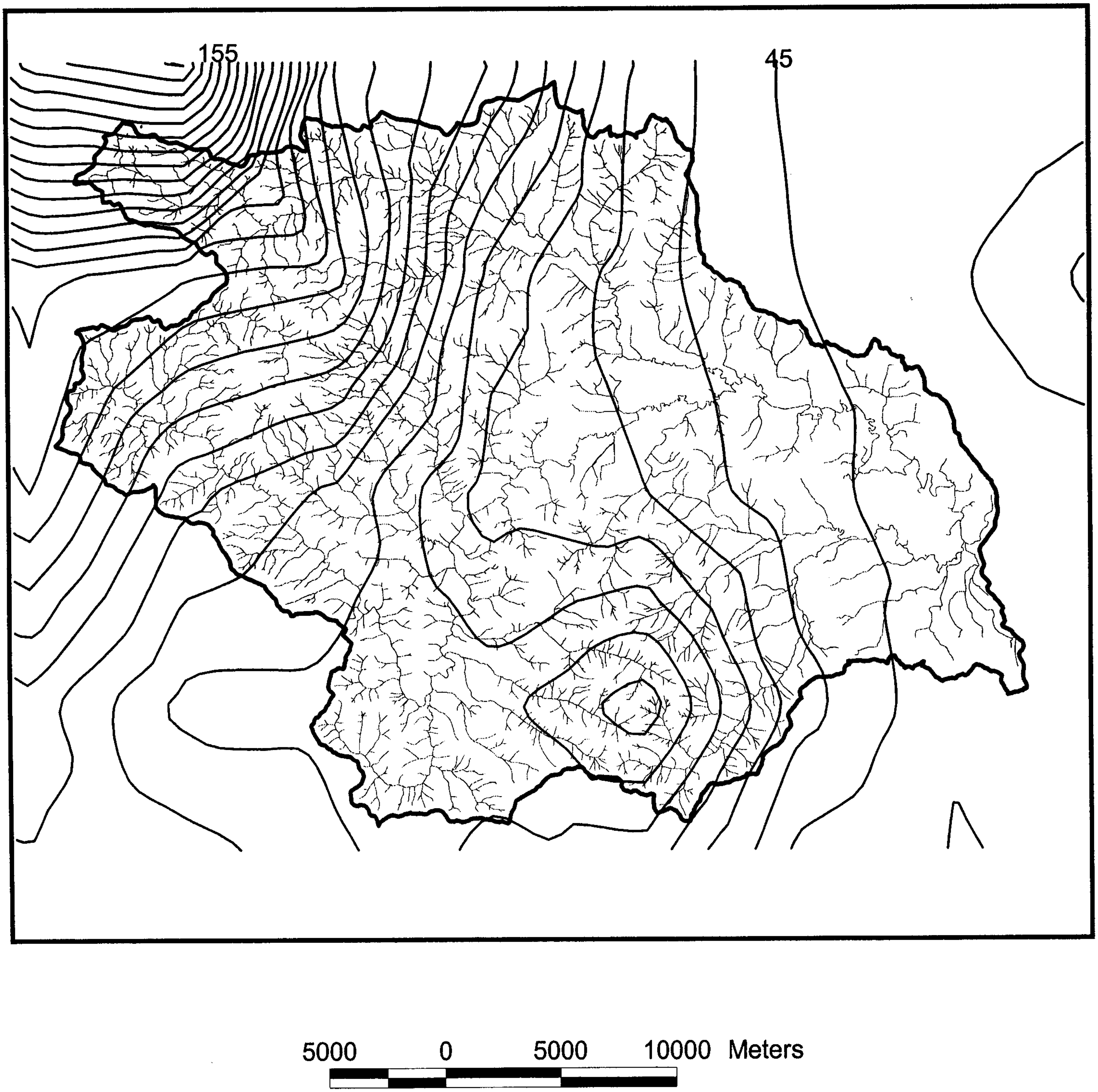
Table 1. Debris flow hazard potential ranked by lithospatial domain, Luckiamute Watershed (data derived from Robinson and others, 1999)

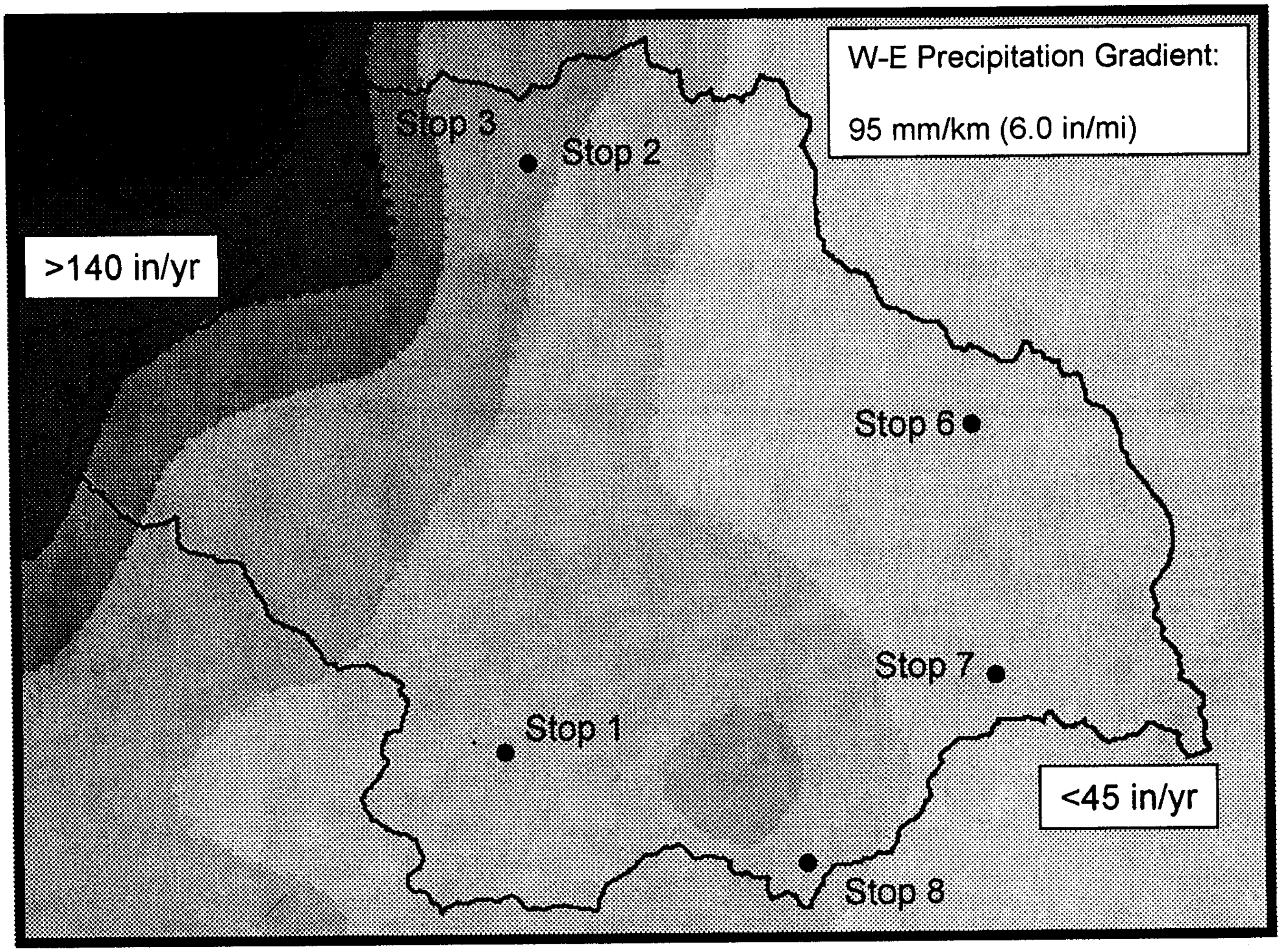
Lithospatial Domain	Domain Area (km^2)	Percent of Domain Area in Hazard Zone	Hazard Rank
Tyee	241	38.1	1
Yamhill-Ti	193	24.6	2
Siletz River	151	30.2	3
Spencer-Valley Fill	229	0.7	4

Luckiamute Basin Debris Flow Hazard Zones (OR Forestry)



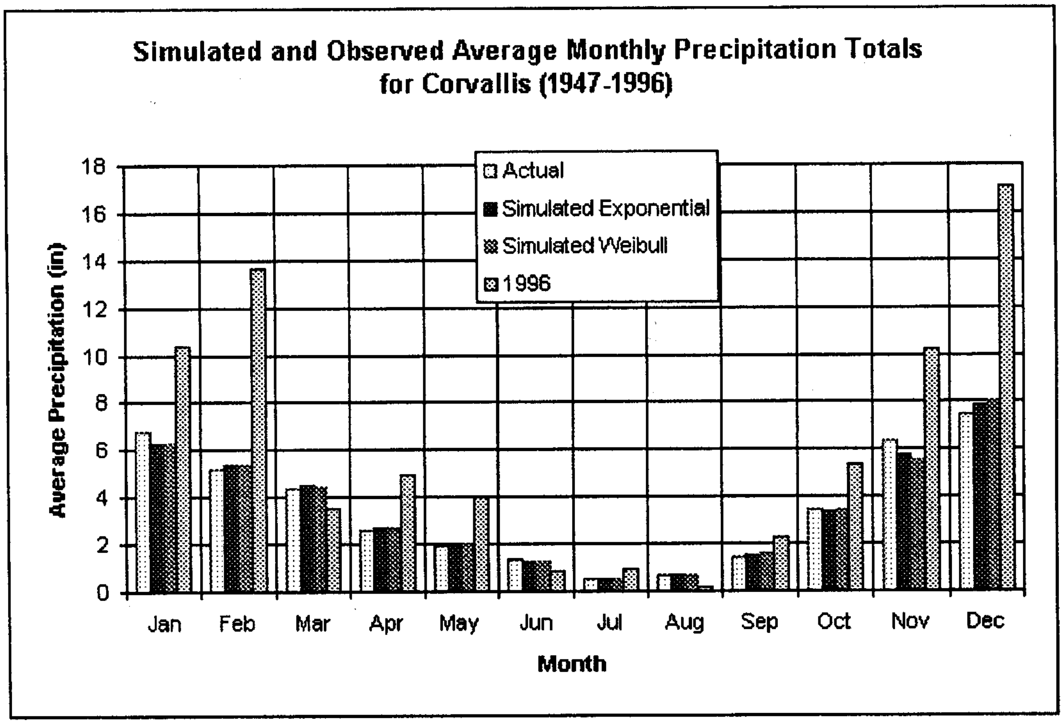
Luckiamute Basin Avg. Annual Rainfall (CI = 5 inches /yr)





1990 Average Annual Precipitation for the Luckiamute Watershed (inches) (from the Oregon Climate Service)

Annual Precipitation
- Basin Maximum: 3600 mm (>140 in) – Divide
- Basin Minimum: 1140 mm (~45 in) – Willamette Valley
- Basin-wide Precipitation Average = 1894 mm (~75 in)
- Seasonal Precipitation Cycle (October – March)



(Waichler and others, 1997)

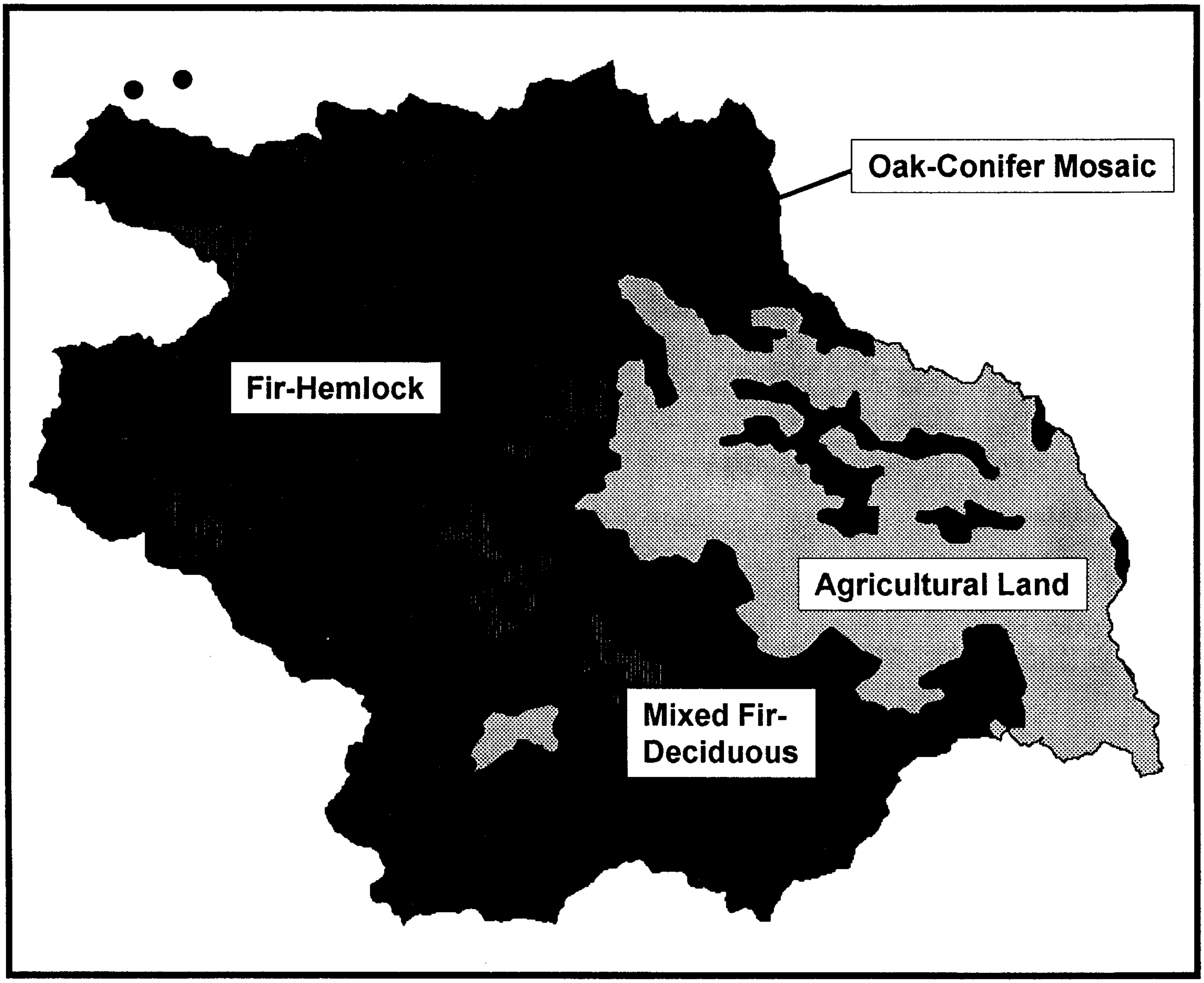
infiltration
groundwater
evaporation [illegible]
60 [illegible] avg%

Water Balance of Luckiamute Watershed

Period (1961-1990)	Mean Precipitation (mm)	Precip. (Input) (m^3)	Observed Mean Discharge (cfs)	Observed Total Discharge (m^3)	Difference (Precip-Discharge) (m^3)	Difference as % of Precip. ("%LOSS")
Annual	1894	1.23E+09		7.55E+08	4.77E+08	39%
Jan	335	2.18E+08	2232.146	1.69E+08	4.86E+07	22%
Feb	258	1.68E+08	1853.276	1.27E+08	4.09E+07	24%
Mar	216	1.41E+08	1472.097	1.12E+08	2.89E+07	21%
Apr	101	6.57E+07	795.9956	5.84E+07	7.27E+06	11%
May	51.9	3.38E+07	396.072	3.00E+07	3.72E+06	11%
Jun	41.7	2.71E+07	188.61	1.38E+07	1.33E+07	49%
Jul	11.3	7.35E+06	71.32473	5.41E+06	1.94E+06	26%
Aug	23.8	1.55E+07	37.25441	2.83E+06	1.27E+07	82%
Sep	50.3	3.27E+07	49.19311	3.61E+06	2.91E+07	89%
Oct	143	9.30E+07	124.4226	9.44E+06	8.36E+07	90%
Nov	284	1.85E+08	904.1411	6.64E+07	1.18E+08	64%
Dec	378	2.46E+08	2069.228	1.57E+08	8.89E+07	36%

Water budget for Luckiamute Watershed (Waichler and others, 1997)

Vegetation Distribution in the Luckiamute Watershed (from Oregon State Vegetation Map)

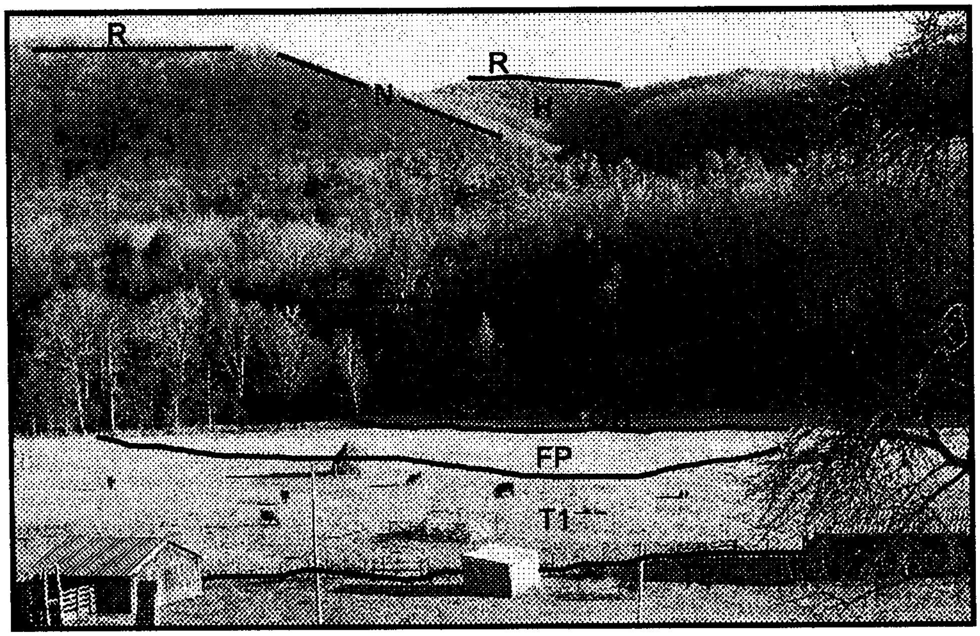


Stop 1. Kings Valley (Hoskins)

- Physiographic Location
    - Main Stem of Luckiamute River (southern watershed)

- Bedrock and Surficial Geology
    - Stop is at location of prominent occurrence of Quaternary alluvium
    - Hoskins lies just west of Kings Valley Fault (Figure 3, p. 10)
    - Stop is near boundary of Tyee and Siletz River lithospatial domains

- Content Piece – Geomorphic Mapping
    - Systematic geomorphic mapping forms basis of watershed analysis
    - Refer to Table 2 (p. 18) for map criteria from Taylor and others (1996)



Principal landform elements recognized in the unglaciated, humid-mountainous landscape of the central Appalachians, analogous to the Oregon Coast Range. Label identification is as follows: R = ridge, N = nose, S = side slope, H = hollow, CH = channel, FP = floodplain, T1 = low terrace, T2 = intermediate terrace, F-t = Fan terrace. Photograph is from the North Fork basin, Pocahontas County, West Virginia. See text for discussion.

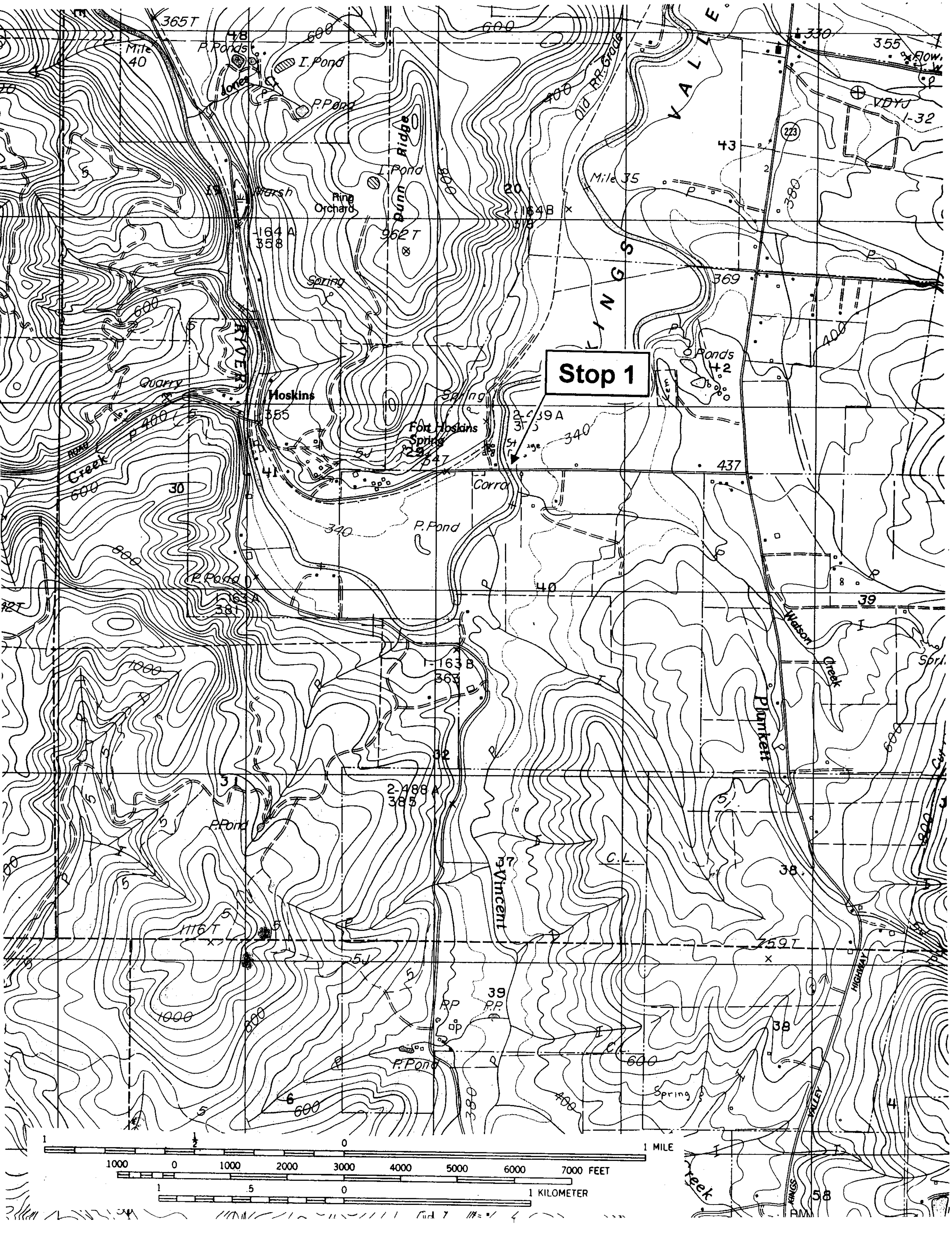

Stop 1
Hoskins
Fort Hoskins Spring
RIVER
Creek
ROAD
Quarry
Marsh
Ring Orchard
Dunn Ridge
962 T
Spring
I. Pond
P. Ponds
P. Pond
Jones Cr.
Mile 40
Mile 35
Old RR Grade
KINGS VALLEY
Ponds
Cem
Corral
Watson Creek
Plunkett
Vincent
Spring
C.L.
HIGHWAY
VALLEY
KINGS
VDYJ
I-32
223
I-164 A 358
I-164 B
2-439 A
I-163 A 381
I-163 B 363
2-488 A 385
355
365T
330
369
437
340
400
600
800
1000
1116 T
759 T
380
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

Table 2. Four-fold surficial map protocol for unglaciated mountainous landscapes (after Taylor and others, 1996).

1. Age of surficial material
- H = Holocene (< 10,000 years old)
- W = Wisconsin (89 to 10 ka)
- I = Illinoian
- P = Pleistocene undifferentiated
- EP = early Pleistocene
- MPl= middle Pleistocene
- LP = late Pleistocene
- Q = Quaternary undifferentiated
- CZ = Cenozoic undifferentiated

2. Origin of surficial process
- A. Hillslope
  - r = residuum (in situ regolith)
  - c = colluvium (mass wasting)
  - ds = debris slide
  - rf = rock fall or topple
- B. Valley bottom
  - a = stream alluvium (normal flow)
  - hcf = hyperconcentrated flow
  - df = debris flow
  - sw = slackwater deposition
- C. Lacustrine
  - l = lacustrine deposit, undiff.
  - lb = lake-bottom deposit
  - ld = lacustrine deltaic
- D. Other
  - g = glaciofluvial, undifferentiated
  - go = glacial outwash
  - e = eolian
  - cr = cryoturbation
  - x = anthropogenic disturbance
  - f = artificial fill
  - rk = bedrock

3. Landform Units
- A. Hillslope
  - n = nose
  - sl = side slope
  - h = hollow
  - veneer = < 2 m of regolith
  - blanket = > 2 m of regolith
  - bf = boulder field
  - bs = boulder stream
  - pg = patterned ground
  - tls = talus
- B. Valley bottom
  - ch = channel
  - fp = floodplain (R.I. </= 2-3 yr)
  - t = terrace (t1, t2 ...tn; height above river)
  - f = fan
  - f-t = fan terrace (f1, f2 ...fn; height above river)
  - a = apron (footslope deposit)
  - lo = lobe
  - lv = levee
  - ox = oxbow, abandoned channel
- C. Other
  - ft = flow track (debris flow)
  - hm = hummocky topography
  - rb = rock block-slide deposit
  - x = excavated, fill, disturbed ground
  - d = delta

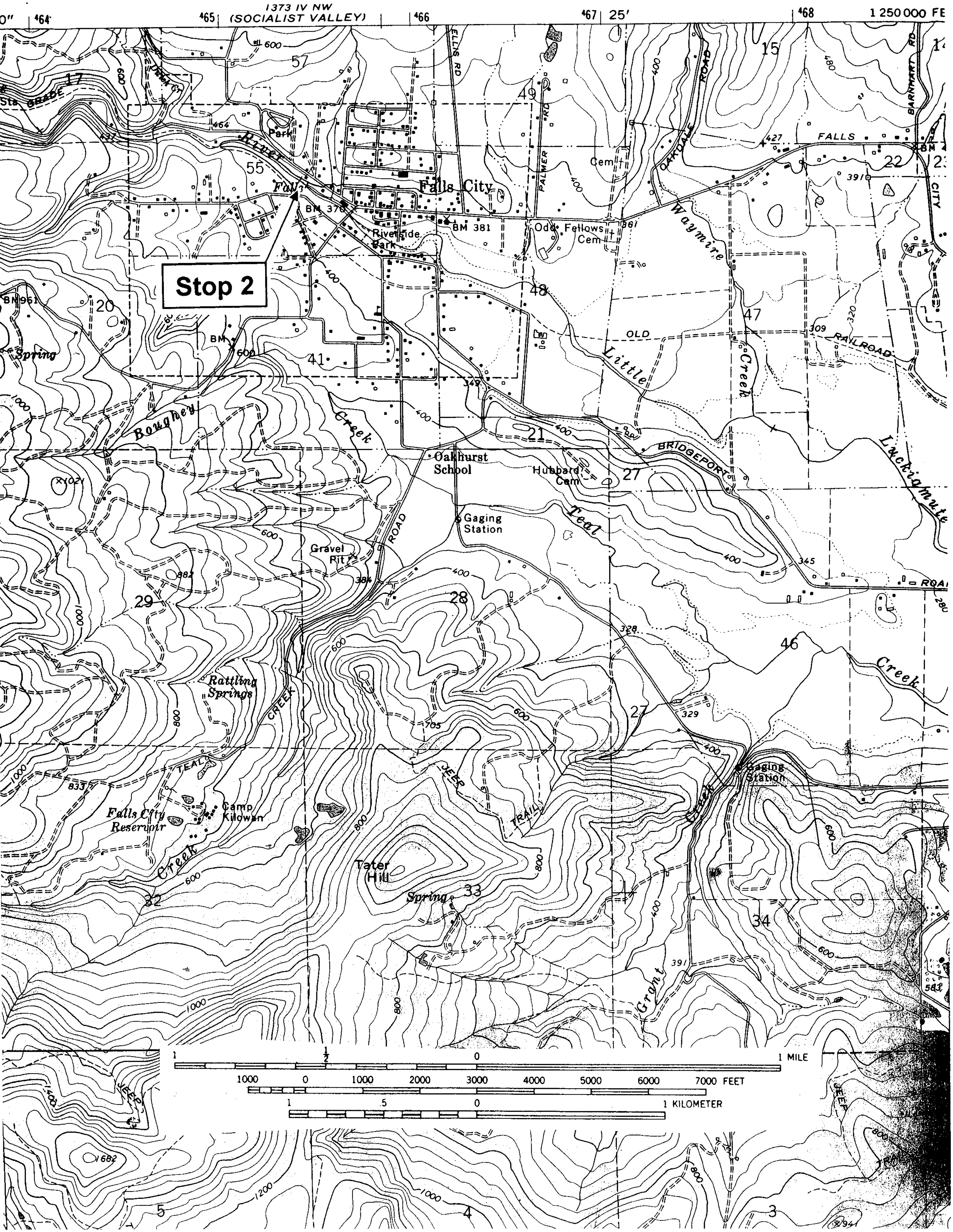
4. Material (composition and texture)
- b = boulders (>256 mm clast supported)
- c = cobbles (64-256 mm clast supported)
- p = pebbles (4-64 mm clast supported)
- g = gravel (>2 mm clast supported)
- sg = mixed sand and gravel
- s = sand (0.05-2.0 mm)
- st = silt (0.002-0.05 mm)
- cy = clay (<0.002 mm)
- l = loam (mix of sand, silt, clay)
- d = diamicton undifferentiated
- bbd = very bouldery diamicton
- bd = bouldery diamicton
- cd = cobbly diamicton
- pd = pebbly diamicton
- ds = sandy matrix diamicton
- dt = silty matrix diamicton
- dy = clayey-matrix diamicton
- rk = bedrock (modify by lithology)
- rs = rotten stone, saprolite
- tr = travertine
- tu = tufa
- ma = marl
- og = organic-rich sediment
- w = water
- u = unkown

Stop 2. Falls at Falls City

- Physiographic Location
    - Little Luckiamute River (northern watershed)

- Bedrock and Surficial Geology
    - Stop is located at prominent knick point of Little Luckiamute
    - Stop is located in the Yamhill-Intrusive lithospatial domain (Figure 3, p. 10)

- Content Piece – Fluvial Erosion Dynamics
    - Knickpoint = hydraulic step in gradient
    - Falls are fracture and bedrock controlled
    - Headward erosion, block plucking, and wall-rock undercutting
    - Stream Stream Power = (Discharge) x (Gradient) x (Specific Wt.)
        - Stream Power > Load = Erosion
        - Stream Power < Load = Deposition
    - Little Luckiamute Channel Condition at Stop 2
        - Channel under capacity with respect to sediment load
        - Power > sediment load


1373 IV NW
(SOCIALIST VALLEY)
464
465
466
467
25'
468
1 250 000 FE
Stop 2
Falls City
River
Falls
Park
BM 370
BM 381
Riverside Park
Odd Fellows Cem
Cem
ELLIS RD
PALMER RD
OAKDALE ROAD
BARNHART RD
FALLS
CITY
Waymire
Little
Creek
OLD RAILROAD
BRIDGEPORT
ROAD
Luckiamute
Teal
Creek
Boughey
Creek
Oakhurst School
Hubbard Cem
Gaging Station
Gravel Pit
Rattling Springs
CREEK
TEAL
Falls City Reservoir
Camp Kilowan
Creek
JEEP TRAIL
Tater Hill
Spring
Grant
Creek
Spring
Sta. GRADE
BM 961
X1021
57
49
15
17
55
22
23
20
48
47
41
21
27
28
29
46
27
33
32
34
5
4
3
1
1/2
0
1 MILE
1000
0
1000
2000
3000
4000
5000
6000
7000 FEET
1
.5
0
1 KILOMETER

Stop 3. Black Rock

- Physiographic Location
    - Little Luckiamute River (northern watershed)

- Bedrock and Surficial Geology
    - Stop is located in the Yamhill-Intrusive lithospatial domain (Figure 3, p. 10)
    - Yamhill Formation outcrops in channel bottom
    - Note colluvial hillslopes, alluvial deposits, channels, floodplains, terraces

- Content Piece – Field Botany
    - Botanical Survey Techniques
    - Invasive Plant Species
    - Riparian Habitat

REFER TO DUTTON HAND OUTS AND TABLE 3 (P. 26)

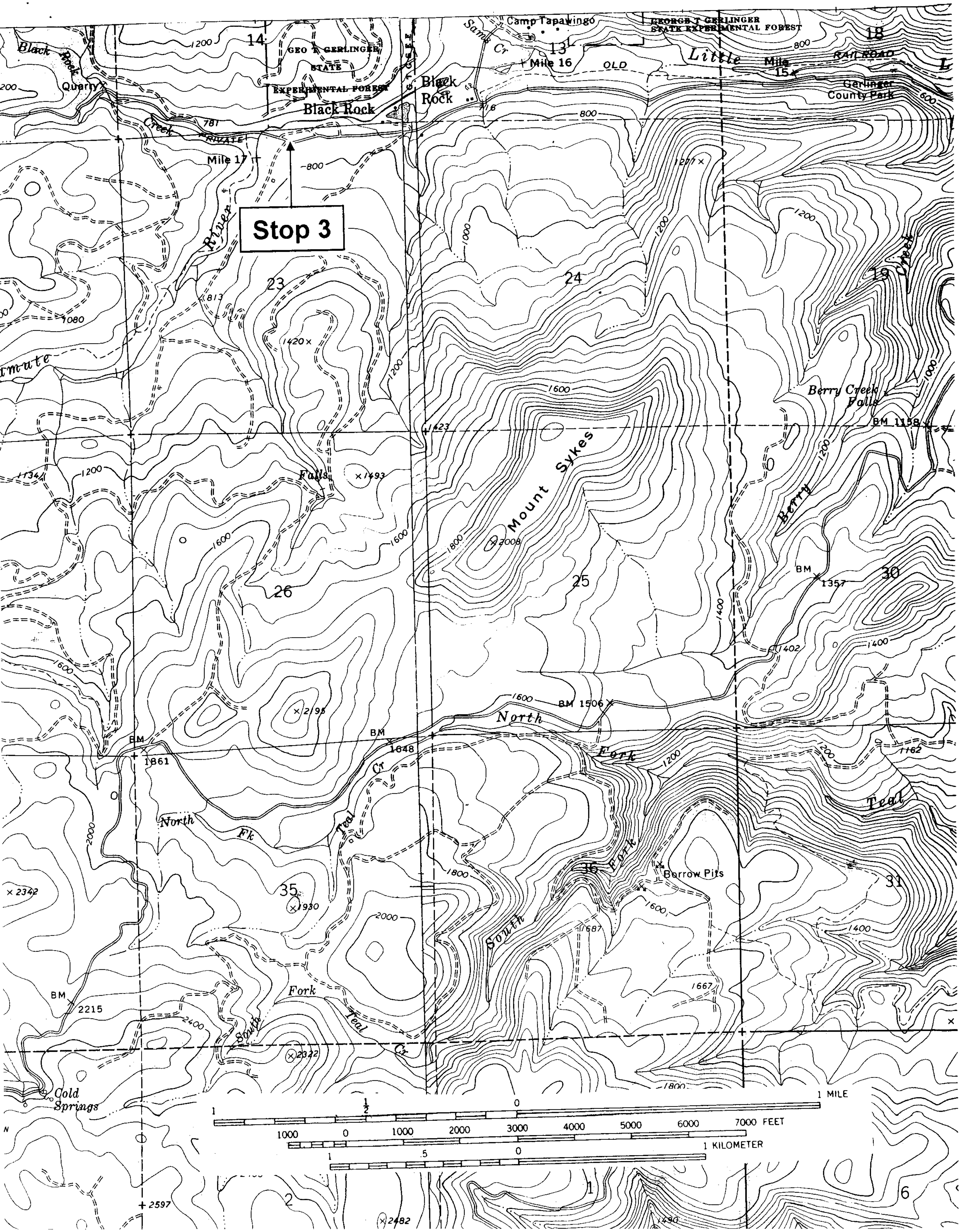

Stop 3
Black Rock Quarry
Camp Tapawingo
GEORGE T GERLINGER STATE EXPERIMENTAL FOREST
GEO T GERLINGER STATE EXPERIMENTAL FOREST
Black Rock
Sams Cr
Mile 16
Mile 17
Mile 15
OLD RAILROAD
PRIVATE
Little
Gerlinger County Park
Creek
River
Mount Sykes
Falls
Berry Creek Falls
Berry Creek
North Fork Teal Cr
North Fk
South Fork Teal Cr
South Fork
Teal
Borrow Pits
Cold Springs
BM 1158
BM 1357
BM 1506
BM 1648
BM 1861
BM 2215
1277
1420
1493
2008
2195
1930
2342
2322
2597
2482
1423
1402
1162
1687
1667
813
1080
1134
781
14
13
18
23
24
19
26
25
30
35
36
31
2
1
6
1 MILE
7000 FEET
1 KILOMETER

Table 3. Occurrence of common invasive plant species at select field trip localities in the Luckiamute Watershed (BR = Black Rock—Stop 3, HSP = Helmick State Park—Stop 6, SSp = Sulphur Springs—Stop 8).

Species	Origin	Occurrence		
		BR	HSP	SSp
Capsella bursa-pastoris (shepherdspurse)	Europe	X	X	X
Cichorium intybus (cichory)	Mediterranean		X	X
Cirsium arvense (Canada thistle)	Eurasia		X	X
Cirsium vulgare (bull thistle)	Eurasia		X	X
Conium maculatum (poison hemlock)	Europe		X	X
Cytisus scoparius (Scotch broom)	Europe	X		X
Daucus carota (wild carrot)	Europe		X	X
Digitalis purpurea (foxglove)	Europe	X		X
Dipsacus fullonum (common teasel)	Europe	X	X	X
Hedera helix (English ivy)	Eurasia Africa	X		
Hypericum perforatum (common St. Johnswort)	Europe		X	X
Lamium purpureum (purple deadnettle)	Europe	X	X	X
Leucanthemum vulgare (oxeye daisy)	Europe			X
Rubus armeniacus (Himalayan blackberry)	Armenia	X	X	X
Rumex acetosella (red sorrel)	Europe	X	X	X
Senecio jacobaea (tansy ragwort)	Europe	X	X	
Solanum dulcamara (bittersweet nightshade)	Europe		X	X
Tanacetum vulgare (common tansy)	Europe		X	X
Taraxacum officinale (dandelion)	Europe	X	X	X
Verbascum thapsus (common mullein)	Eurasia	X	X	X

En Route to Stop 4

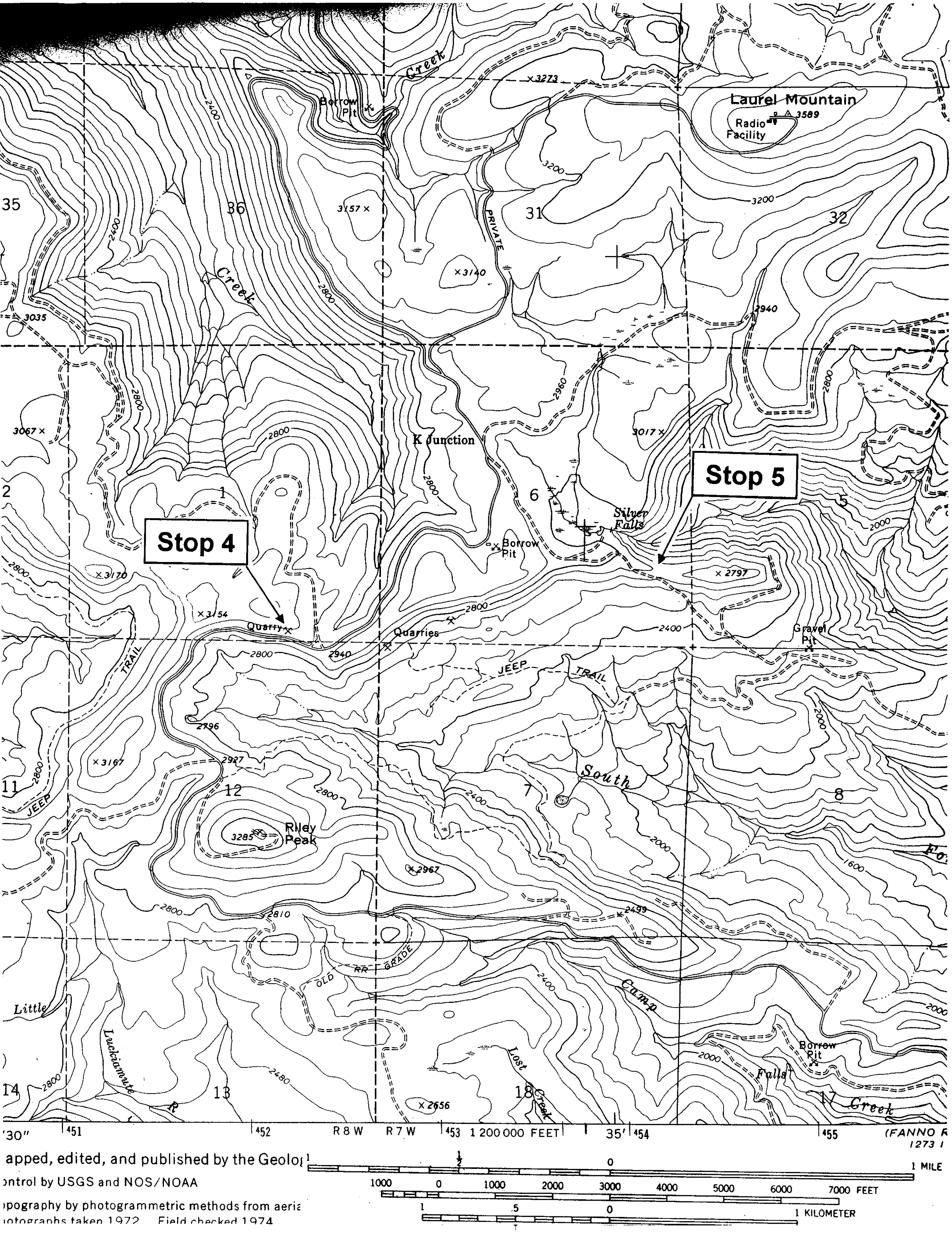
- Views of Laurel Mountain
  - Elevation = 3589 ft
  - Average annual rainfall >3800 mm/yr (one of three local maxima in Coast Range (refer to precipitation map, p. 16)
  - 1996 Debris Slide / Flow Scars
    - Erosion rate = 42 m^3/ha
- Note Intensive Land use and Forestry Practice

Stop 4. Road Aggregate Quarry

- Physiographic Location
  - Little Luckiamute River (northern watershed), crosses over divide into Rickreall Watershed

- Bedrock and Surficial Geology
  - Stop is located in the Yamhill-Intrusive lithospatial domain (Figure 3, p. 10)

- Content Piece – Rock Outcrop of Oligocene Intrusives and Yamhill Fm
  - Note intrusive contacts
  - Regolith (colluvium) overlying bedrock
  - Spheroidal weathering patterns
  - Interpretation of rounded fluvial gravel vs. weathered spheroidal blocks
  - Seondary mineralization (zeolites)


Stop 4
Stop 5
Laurel Mountain
Radio Facility
3589
3273
Borrow Pit
Creek
3200
3157
3140
PRIVATE
35
36
31
32
3035
2400
2800
2940
2960
3067
3017
K Junction
1
2
6
5
Silver Falls
Borrow Pit
3170
3154
Quarry
Quarries
2797
2000
Gravel Pit
JEEP TRAIL
TRAIL
2796
2927
3167
11
12
7
8
South
Riley Peak
3285
2967
2499
1600
2810
OLD RR GRADE
Camp
Little
Luckiamute R
Lost Creek
Falls
Borrow Pit
2480
2656
14
13
18
17
Creek
'30"
451
452
R 8 W
R 7 W
453
1 200 000 FEET
35'
454
455
(FANNO R
1273 I
apped, edited, and published by the Geolo
ontrol by USGS and NOS/NOAA
pography by photogrammetric methods from aeria
otographs taken 1972   Field checked 1974
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

Stop 5. Coast Range Drainage Divide

- Physiographic Location
  - Rickreall Watershed; Coast Range drainage divide

- Content Piece
  - Overview of east flanks of Coast Range, Willamette Valley, western Cascades in the distance
  - Ridge residuum as a regolith deposit
  - Concept of weathering rinds as a relative dating tool
  - Note intensive logging practices
    - Discussion of effects of logging practice on geomorphic process

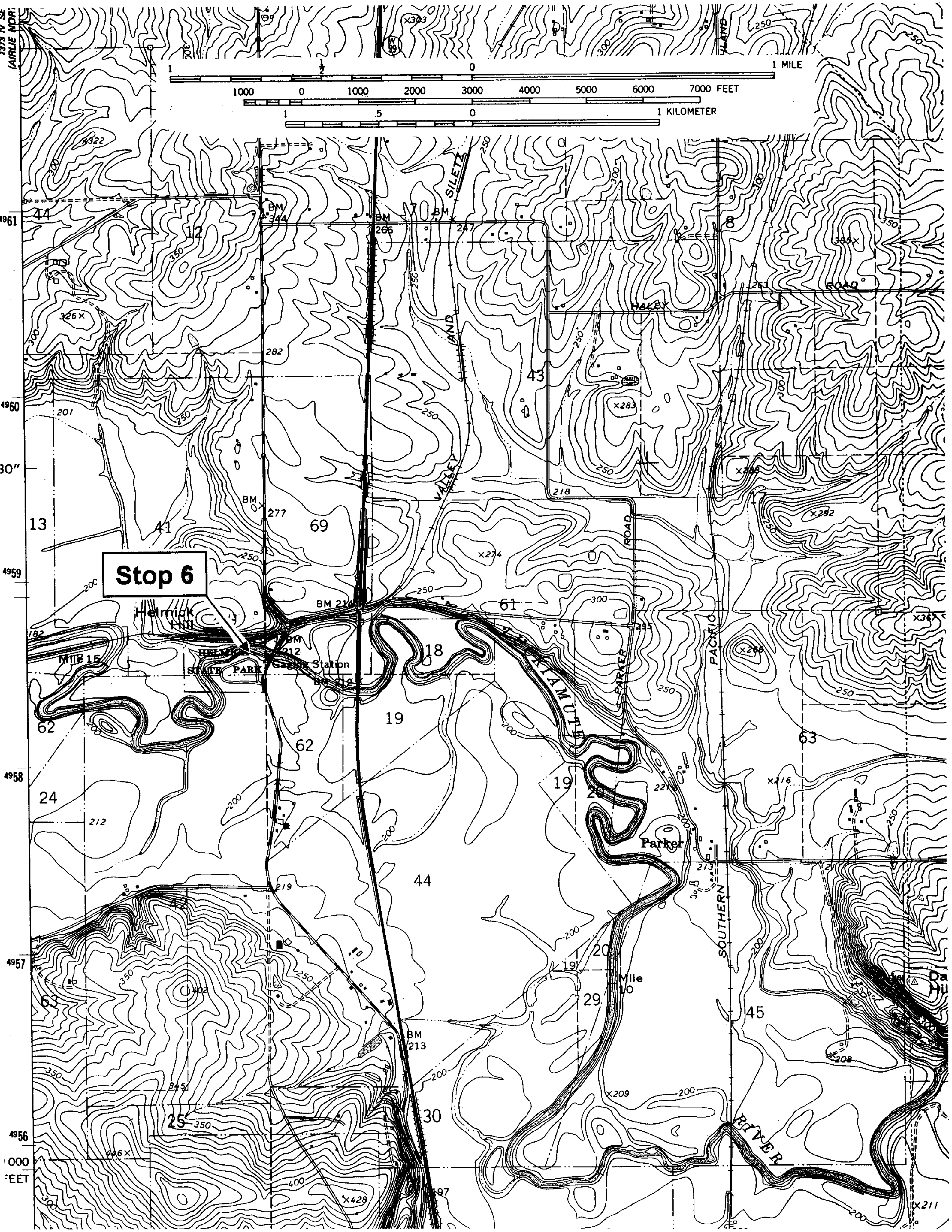
LUNCH STOP

En Route to Stop 6

- Drive from Falls City, out of Yamhill-Intrusive Domain, into Spencer Fm-Valley Fill Domain (refer to Figure 3, p. 10)
- Note change in land use from forestry to agriculture
- Stop at Western Oregon University, Natural Sciences Building, for brief slide show discussion of the Polk County Flora Project and Interactive Flora Identification Key

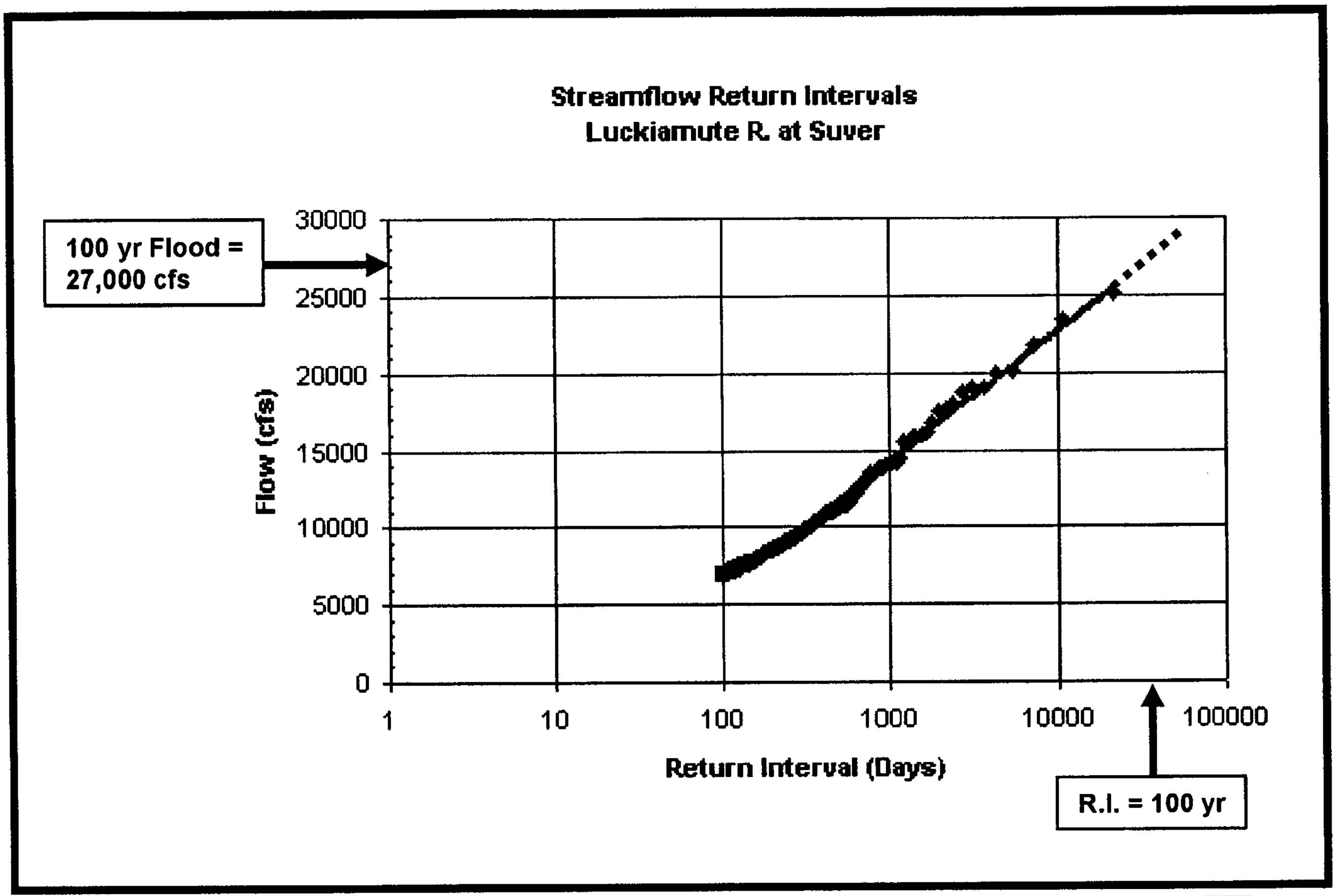
Stop 6. Helmick State Park

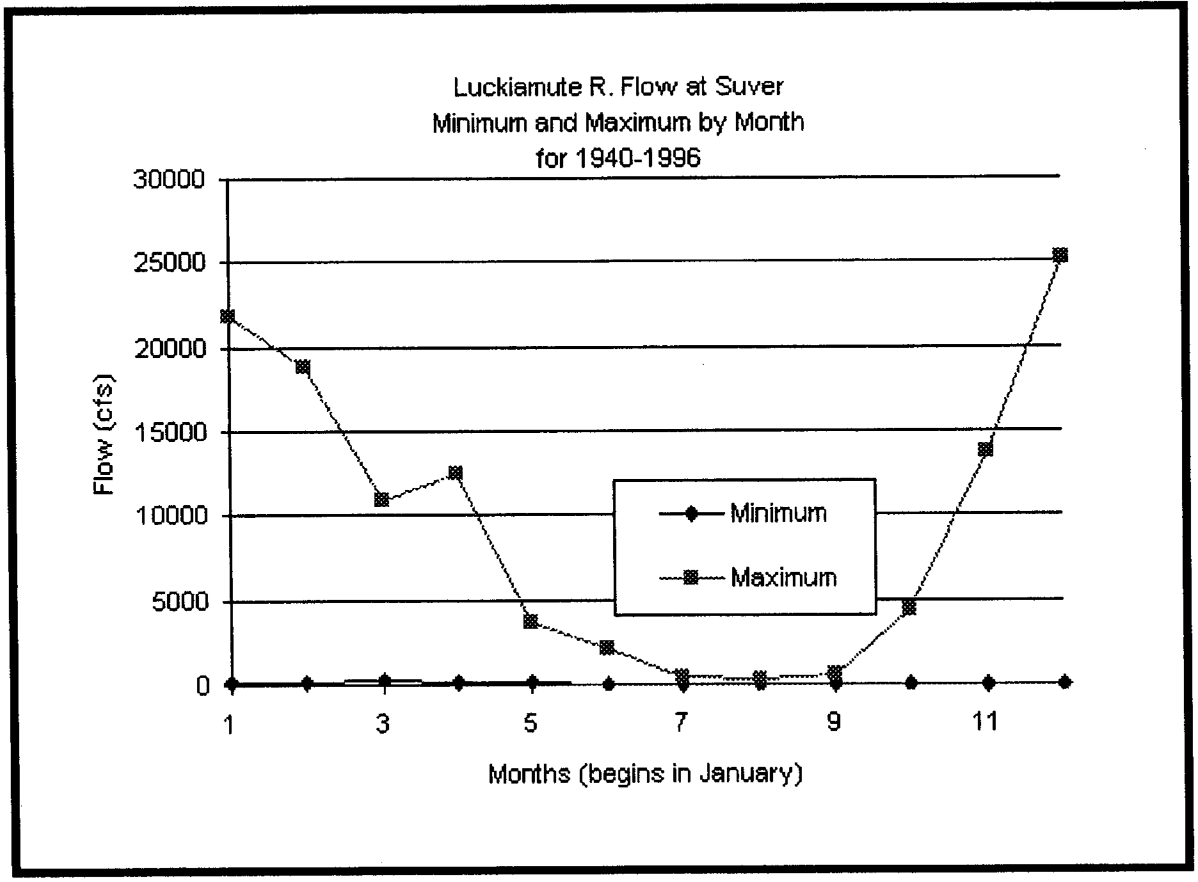
- Physiographic Location
  - Lower Luckiamute River, 18 km upstream from watershed outlet into the Willamette River
- Bedrock and Surficial Geology
  - Stop is located in the Spencer Fm-Valley Fill lithospatial domain (Figure 3, p. 10)
  - Note incised channel characteristics and low terraces
- Content Piece – Field Botany and Flood Hydrology
  - Field Botany
    - Participants are provided an opportunity to use Dutton's interactive flora identification key
  - Flood Hydrology
    - USGS Suver Gaging Station
    - Recurrence intervals and seasonal discharge patterns (p. 32)
    - Paleoflood hydrology



Stop 6

1 1/2 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
Helmick Hill
Helmick State Park
Gaging Station
BM 214
BM 212
BM 344
BM 266
BM 247
BM 277
BM 213
Siletz
And
Valley
Haley
Road
Parker
Road
Pacific
Southern
Luckiamute
River
Parker
Mile 15
Mile 10
4961
4960
4959
4958
4957
4956
30″
000
FEET
x303
x322
326x
x283
385x
x288
x292
x274
x266
x367
x216
x208
x209
x211
x428
446x
402
345
263
282
218
201
182
212
219
221
213
197
295
250
300
350
200
400
44
12
7
8
43
13
41
69
61
18
17
62
19
63
24
20
42
44
29
45
30
25





Discharge characteristics for Luckiamute River, Helmick State Park (from Waichler and others, 1997).

En Route to Stop 7

- Poston discussion of agricultural land use, crop mapping, and related environmental chemistry

SEE ATTACHED POSTON FIGURES ON P. 34-37

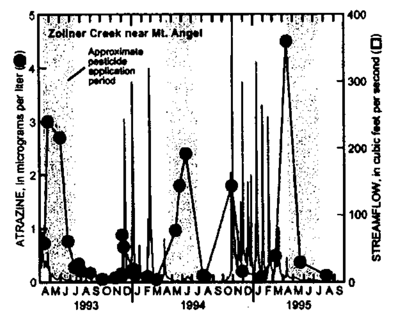
Water Quality Standards

Borrowed from Table 21.9, "Principles and Applications of Inorganic Geochemistry", Gunter Faure, MacMillan Publishing, 1991

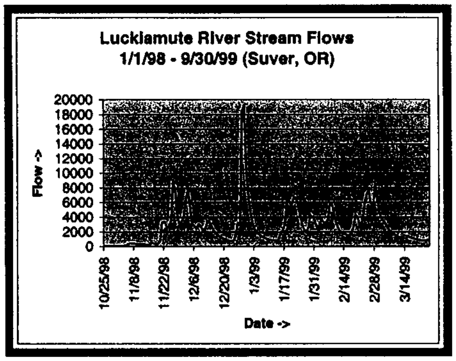
Element or Compound	Acceptable Concentration, mg/L	Sources of Contamination
Cations and Anions		
Arsenic	0.05	herbicide used on land and water
Barium	1.0	barite ($BaSO_4$) and witherite ($BaCO_3$)
Cadmium	0.01	mine tailings and industrial effluents
Chromium	0.05	industrial effluents
Copper	1.0	aquatic herbicide
Iron	0.3	minerals of iron
Lead	0.05	industrial effluents and uses
Manganese	0.05	minerals of manganese
Mercury	0.002	minerals of Hg, antifungal agent, combustions of coal and petroleum, mining and smelting of Hg
Silver	0.05	bactericide, natural occurence
Zinc	5	natural occurence, industrial effluent
Fluoride	2.0	natural occurence, industrial effluent
Chloride	250	NaCl brines
Nitrate (as N)	10	farm runoff
Selenium	0.01	natural occurence, fertilizer, combustion of coal and paper
Sulfide	0.002	oxidation of organic matter
Sulfate	250	oxidation of sulfides, oilfield brines, brine lakes
Acidity and Dissolved Solids		
pH	6.5-8.5	acid rain, mine drainage, industrial effluent
TDS	500	evaporative concentration discharge of brines
Chlorinated Hydrocarbons		
Endrin Lindane Methoxychlor Toxaphene	0.0002 0.004 0.1 0.005	pesticides
Chlorophenoxys		
2,4-D 2,4,5-TP (Silvex)	0.1 0.01	herbicides
Radioactivity		
Ra Gross Alpha Gross Beta	5 pCi/L 15 pCi/L 4 millirem/yr	-----

Source: United States Environmental Protection Agency, 1986, EPA national drinking water regulations, *Code of Federal Regulations*, **40**(143), Appendix V, p. 187 and **40**(265), Appendix V, p. 621

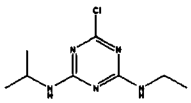
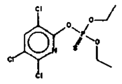
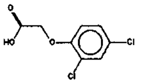
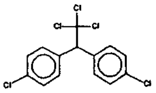
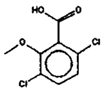
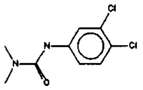
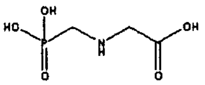
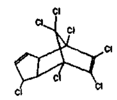
Storm Hydrographs Track Pesticide Mobility

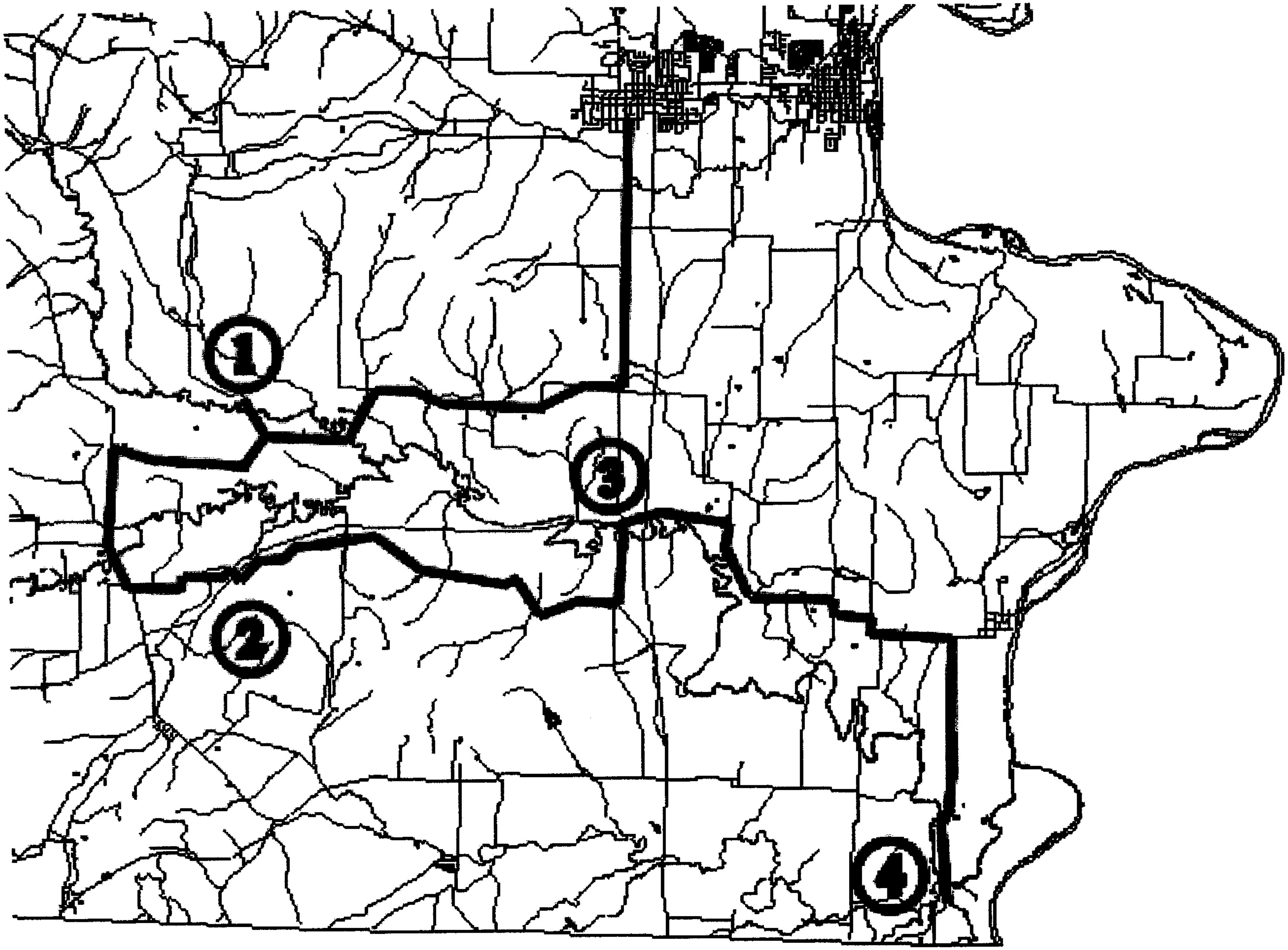


Atrazine concentrations were highest during spring following pesticide application, but relatively high concentrations also occurred during fall runoff.



Past and Present Willamette Valley Pesticides and Uses

"BRAND NAME" (CHEMICAL NAME)	STRUCTURE	USE	CROPS
"Farmco Atrazine" Atrazine		broadleaf and grassy weeds	corn, Christmas trees, conifer reforestation plantings
"Lorsban" Chlorpyrifos		corn rootworm, cornstalk borer, corn maggot, termites, fire ants	grain, fruits, nuts
"Crossbow" 2,4-D		broadleaf weeds	cultivated agriculture, pastures, rangelands, forest management
"Chlorophenothane" 4,4'-DDT		insecticide	no longer used in the US
"Banvel" Dicamba		broadleaf weeds	grain crops, grasslands
"Karmex" Diuron		broadleaf and grassy weeds, mosses	friuts, alfalfa, wheat
"Roundup" Glyphosate		broad spectrum and nonselective herbicide	grasses
"Heptamul" Heptachlor		termites, ants, and soil insects	seed grains


1
2
3
4

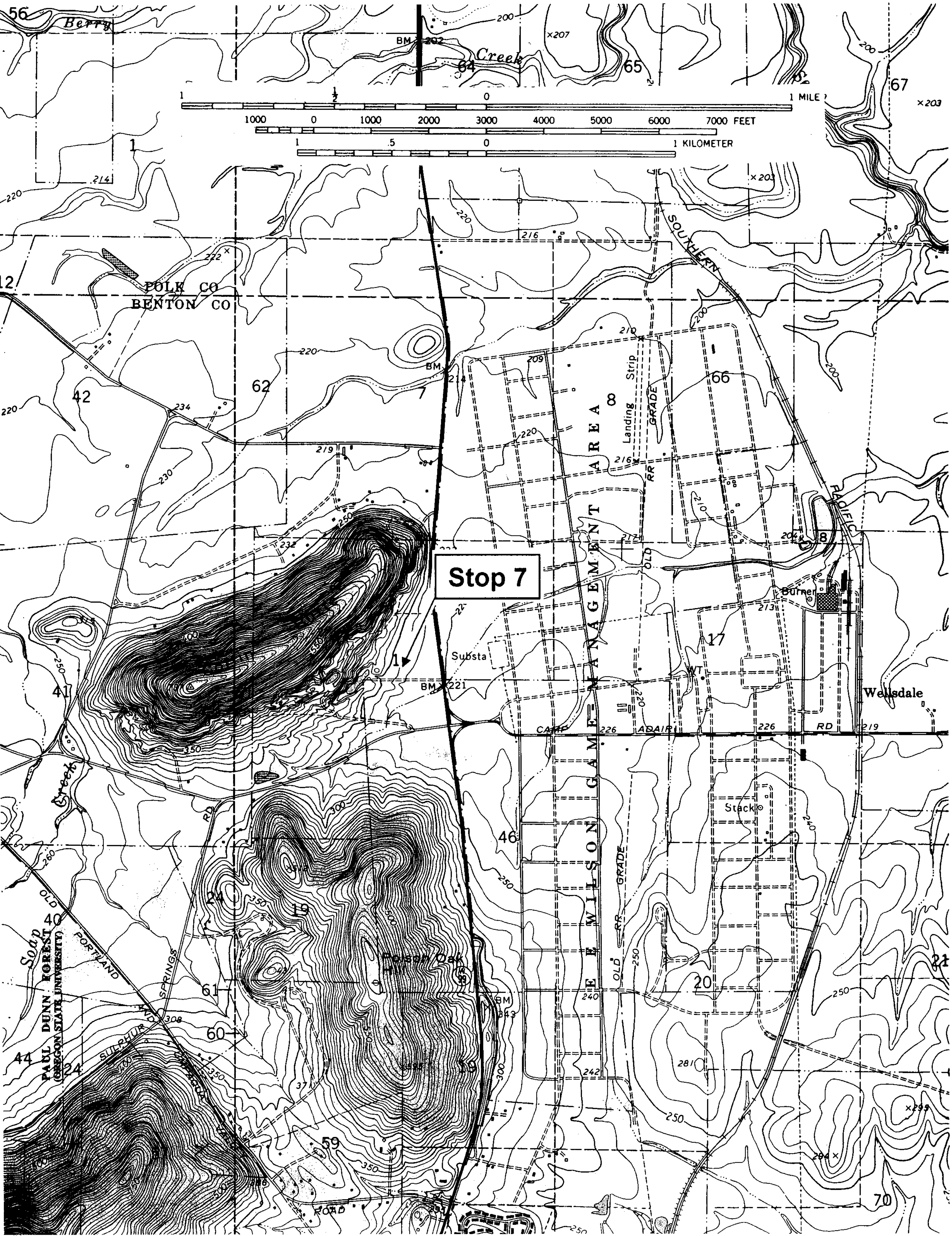
Stop 7. Coffin Butte Landfill

- Physiographic Location
    - Unnamed tributary of Soap Creek
    - Note EE Wilson Wildlife Refuge to east
- Bedrock and Surficial Geology
    - Stop is located at quarry exposure of Siletz River Volcanics (Figure 3, p. 10)
    - Note pillow basalts, secondary zeolite mineralization, and regolith-bedrock contact

- Content Piece – Landfill Technology

    - Overview of Coffin Butte Landfill
        - 700 ac, former Camp Adair Army facility
        - Second largest landfill in Oregon, 1200-1700 tons/day
        - Landfill set on top of 10-20 m of terrace gravels and Siletz River Volcanics (refer to p. 40 diagram of landfill)

    - Landfill Technology
        - Liner System / Leachate Collection System
        - Groundwater Monitoring Network
        - Methane Extraction Wells
        - Waste Water Treatment Plant
        - Methane Electrical Generation Plant


Stop 7
Berry Creek
BM 202
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
POLK CO
BENTON CO
SOUTHERN PACIFIC
E. E. WILSON GAME MANAGEMENT AREA
Landing Strip
OLD RR GRADE
BM 214
BM 221
BM 343
Substa
Burner
WT
Stack
Wellsdale
CAMP ADAIR RD
Poison Oak Hill
PAUL DUNN FOREST (OREGON STATE UNIVERSITY)
OLD PORTLAND RD
SULPHUR SPRINGS RD
Soap Creek
ROAD
1

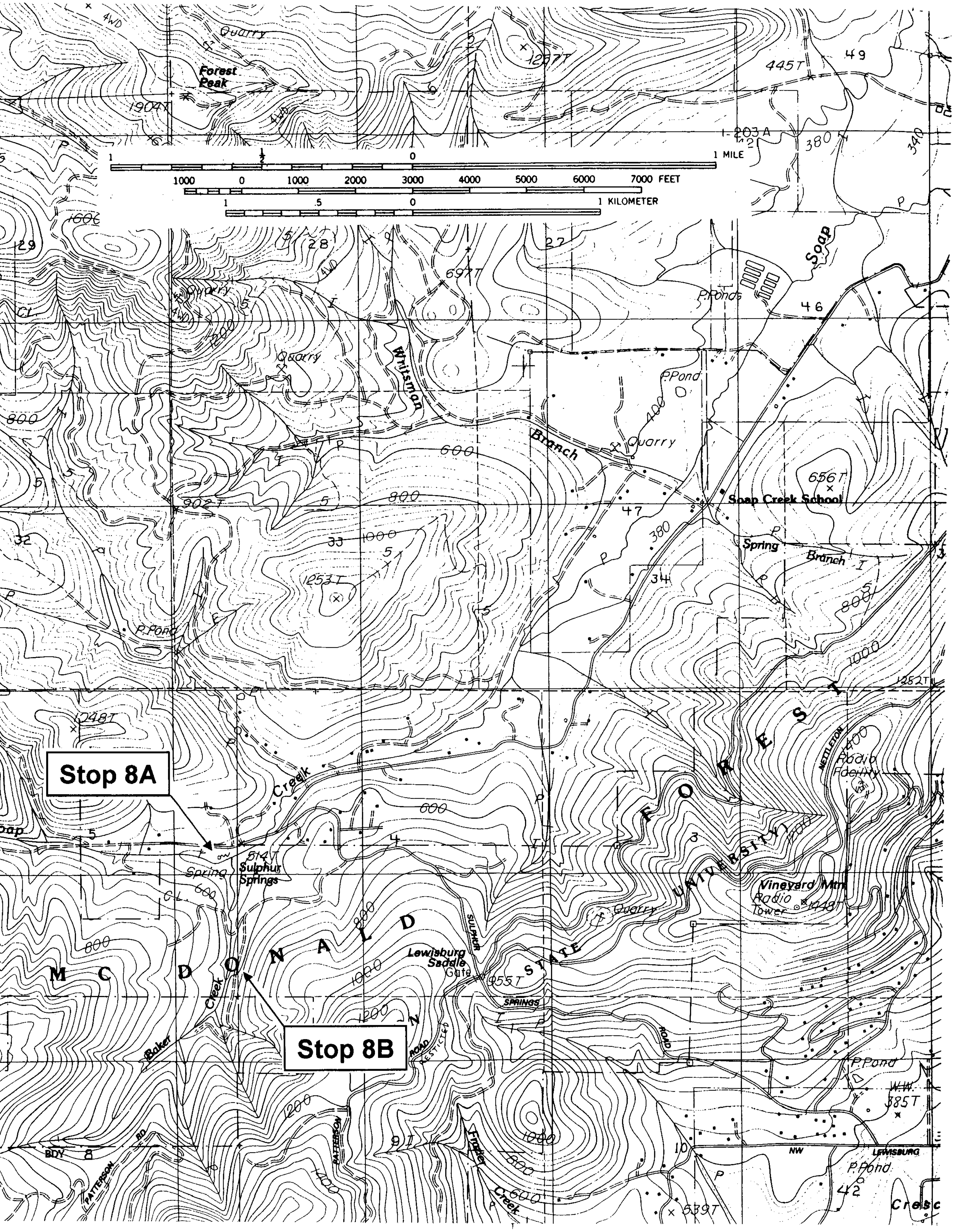
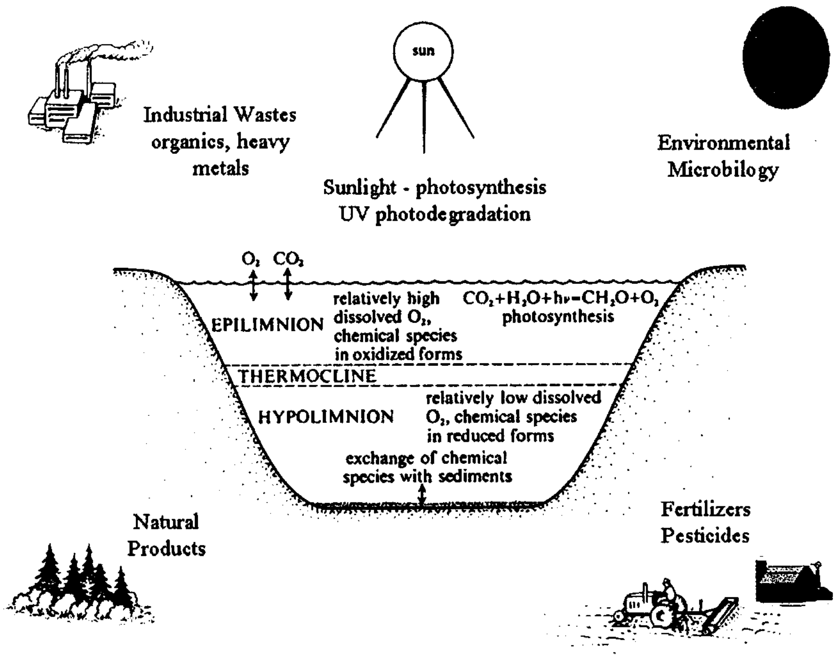
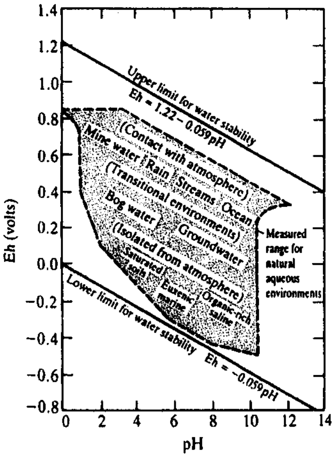

Stop 8A
Stop 8B
Forest Peak
Quarry
1904T
1257T
445T
49
1-203 A
380
340
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
29
28
27
Soap
P.Ponds
46
697T
Whitsman
Branch
P.Pond
Quarry
600
800
1000
1200
656T
Soap Creek School
47
902T
32
33
1253T
380
34
Spring
Branch
P.Pond
1252T
1048T
Creek
NETTLETON
Radio Facility
F O R E S T
UNIVERSITY
STATE
M C D O N A L D
Vineyard Mtn
Radio Tower
1448T
514T
Spring
Sulphur Springs
Quarry
SULPHUR
SPRINGS
ROAD
Lewisburg Saddle
Gate
955T
Baker
Creek
RESTRICTED
PATTERSON
RD
BDY
8
9
10
Frazier
Creek
P.Pond
W.W.
385T
NW
LEWISBURG
42
539T
Cresc

Table 4. Field chemistry of Sulphur Springs and upper Soap Creek at Stop 8. Explanation of units: mS = microSiemens/cm, S.U. = Standard pH Units, mV = millivolt, ppm = parts per million.

Field Parameter	Sulphur Spring	Soap Creek
Conductivity (mS)	371	104
pH (S.U.)	6.7	7.3
Eh (mV)	-287	137
O2 (ppm)	1.2	10.0
CO2 (ppm)	15.0	4.0
Sulfide (ppm)	1.0	0.2
Total hardness (ppm)	280	90

Factors Influencing Water Quality and Oxidation/Reduction Profiles





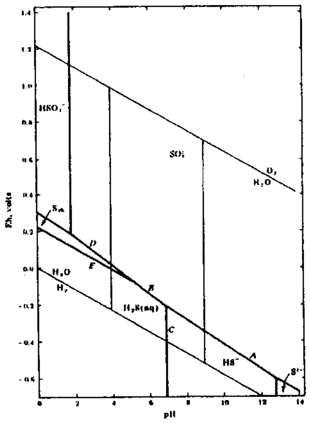
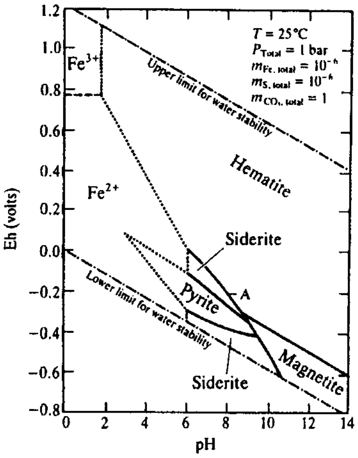
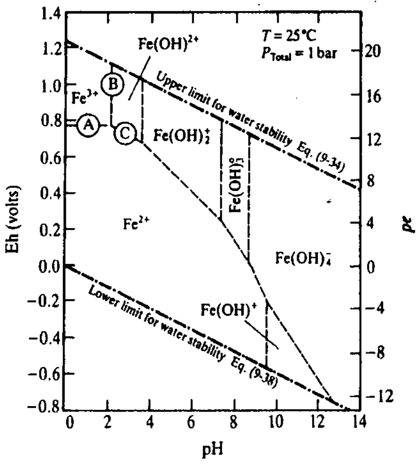


Figure 10-2 Eh-pH diagram for stable sulfur species at 25°C and 1 atm total pressure. At total concentration of dissolved sulfur species = 0.001M.

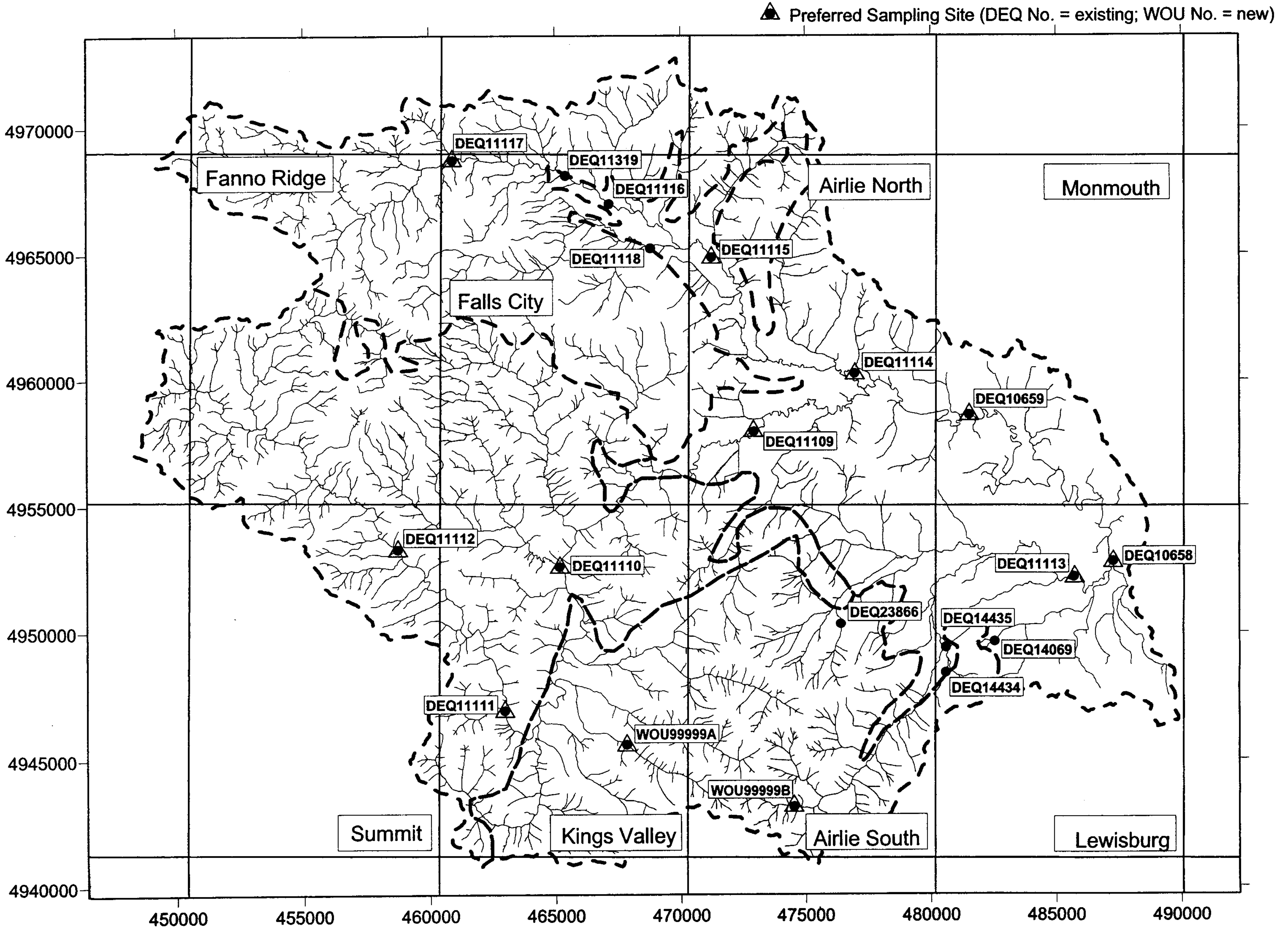




Sulfur Spring Water Data

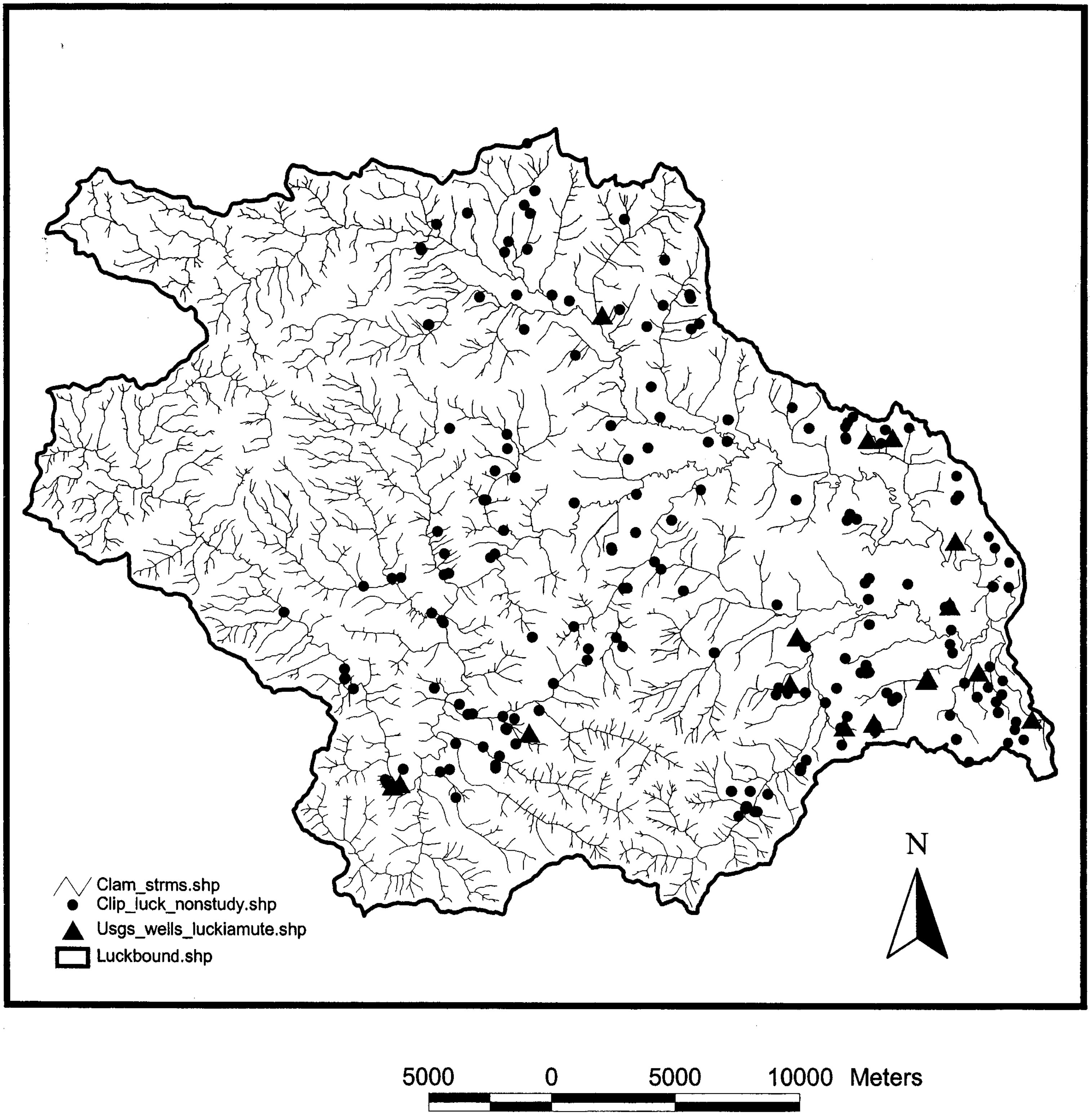
Locality	Temp (°C)	Cond (µS)	Total Hardness	pH	Eh (mV)	O_2 (ppm)	CO_2 (ppm)	Fe (ppm)	sulfide (ppm)
Soap Creek	12.8	104	90	8	233	10	4	0	0.2
Sulfur Spring	10.8	371	280	7.3	-98	1.2	15	0	1.0

Luckiamute Watershed Proposed Sampling Sites
Collaborative Research and Monitoring Project (CRAMP@WOU)



c:research:luckiamute:sample_pts.srf

Luckiamute USGS Groundwater Study Well Locations



T-test analysis of drainage density vs. lithospatial domain, Luckiamute Watershed.

	Mean (Dd_m/km)	Variance	No.	Alpha	df	t Stat	t Critical one-tail	Result
Siletz	2224.3	97990.7	6	0.05	9	-0.98055	1.833114	No Significant Difference
Tyee	2367.5	8419.0	5	0.05				
Siletz	2224.3	97990.7	6	0.05	10	4.924253	1.812462	Significant Difference
Spencer	1367.8	83518.7	6	0.05				
Siletz	2224.3	97990.7	6	0.05	9	1.281186	1.833114	No Significant Difference
Yamhill	2019.7	34061.1	5	0.05				
Tyee	2367.5	8419.0	5	0.05	9	7.372818	1.833114	Significant Difference
Spencer	1367.8	83518.7	6	0.05				
Tyee	2367.5	8419.0	5	0.05	8	3.773886	1.859548	Significant Difference
Yamhill	2019.7	34061.1	5	0.05				
Spencer	1367.8	83518.7	6	0.05	9	-4.33944	1.833114	Significant Difference
Yamhill	2019.7	34061.1	5	0.05				

Tyee has a higher drainage density compared to the Yamhill and Spencer (but is similar to Siletz)
Spencer has a lower drainage density than the other 3 blocks (Tyee, Yamhill, Spencer)
Siletz has a similar drainage density compared to the Tyee and Yamhill.

McDowell in
Dupré et al.,
1991

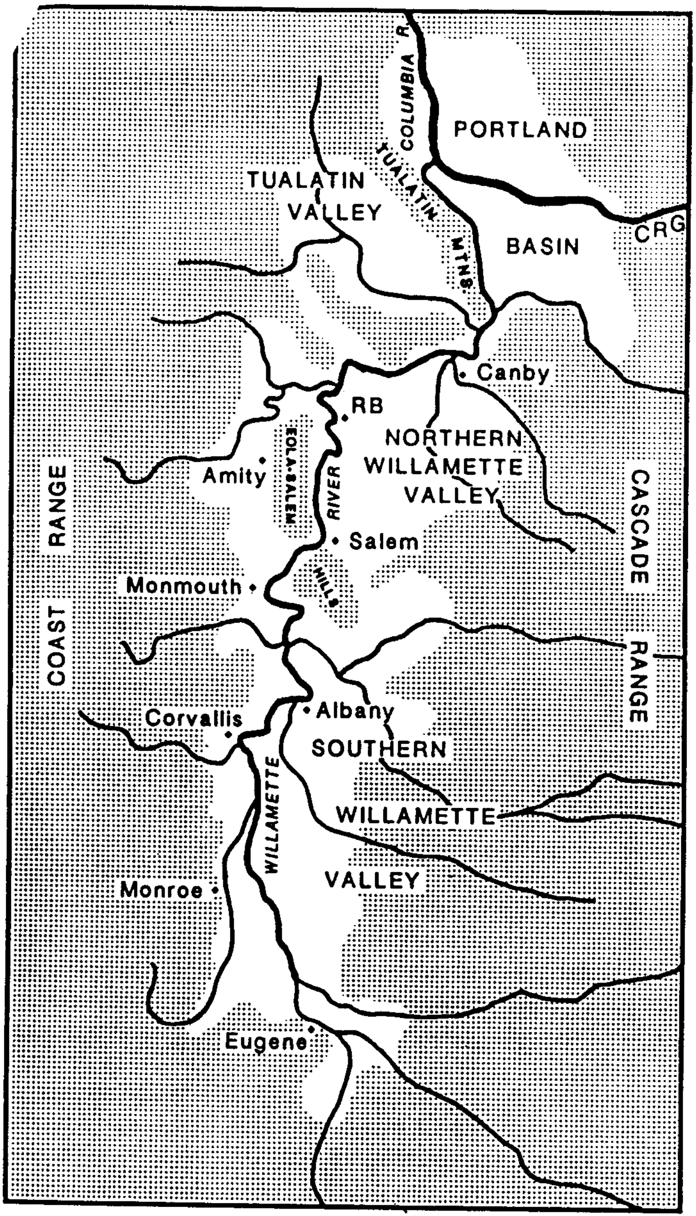


Figure 14. Willamette Valley region. CRG, Columbia River Gorge; RB, River Bend section of Glenn (1965).

Tentative correlations of stratigraphic units from the Portland Basin–Tualatin Valley area to the southern Willamette Valley are shown in Figure 15, but these correlations are not well established. Correlations among the sub-basins of the Willamette Valley are problematic, because the sub-basins may have had quite different histories of base-level and sediment supply. The essential questions that remain concerning these features are (1) the number and age of geomorphic surfaces and associated lithostratigraphic units, and (2) the genesis of each unit.

Early Pleistocene pediments

The highest Pleistocene landforms preserved in the Willamette Valley compose the Eola geomorphic surface (Balster and Parsons, 1968; Fig. 16). The surface consists of small pediment and strath-terrace remnants and rounded upland surfaces with hanging valleys. They are widely distributed around the margins of the Willamette Valley, typically occurring at 150 to more than 250 m above the present Willamette River level (Parsons and Balster, 1966; Balster and Parsons, 1968; Green, 1983; Parsons, 1985). Parsons and Balster (1966) recognized two topographically distinct pediment levels within the Eola surface, but it is not clear whether there are stratigraphic differences between them. The two levels presumably represent separate episodes of stability and geomorphic surface development as the Willamette River incised during Pliocene and early Pleistocene time. The pediments are characterized by distinctive soils—Haplohumults with deep, red profiles with thick argillic horizons—that are considered relict paleosols formed in pedisediment (Balster and Parsons, 1968; Green, 1983; Parsons, 1985). The Eola surface probably formed during early Pleistocene time. Lower, less dissected pediments mapped along the western margin of the southern Willamette Valley (Bela, 1979) are probably younger.

Mid- and Late Pleistocene gravel deposits

Intermittently throughout Pleistocene time, a series of gravelly fluvial or fluvioglacial sediments was deposited in the Willamette Valley, and they are preserved today as high gravel terraces standing 30 to 100 m above the present Willamette River level. Allison (1953) recognized three terrace gravel units—the Lacomb (oldest and highest), Leffler, and Linn (youngest and lowest)—along the eastern margin of the southern Willamette Valley. He tentatively correlated them with the pre-Kansan, Kansan, and Illinoisan or early Wisconsinan glaciations, respectively (Allison 1936, 1953), but actual correlations are uncertain. The gravel units generally are considered to range in age from middle to late Pleistocene (Beaulieu, 1971). The Lacomb and Leffler gravels form high terrace remnants and dissected fans at the mouths of tributary valleys, and the Linn gravels occur at or below the level of the main valley floor. Allison (1953) indicated that the three gravel units have progressively deeper and more intense weathering, from younger to older, and he distinguished them on the basis of depth of weathering and topographic position.

In other parts of the Willamette Valley, later workers generally have correlated gravel units and terraces with Allison's stratigraphy, or they have used a simpler stratigraphic scheme (Schlicker and Deacon, 1967; Beaulieu and others, 1974; Bela, 1979). Piper (1942) compiled the most extensive map of the Pleistocene gravel, covering the entire Willamette Valley, but he recognized only one gravel unit. Working in the Portland Basin, Trimble (1963) identified three terrace gravel units. He named them the Springwater, Gresham, and Estacada Formations, al-

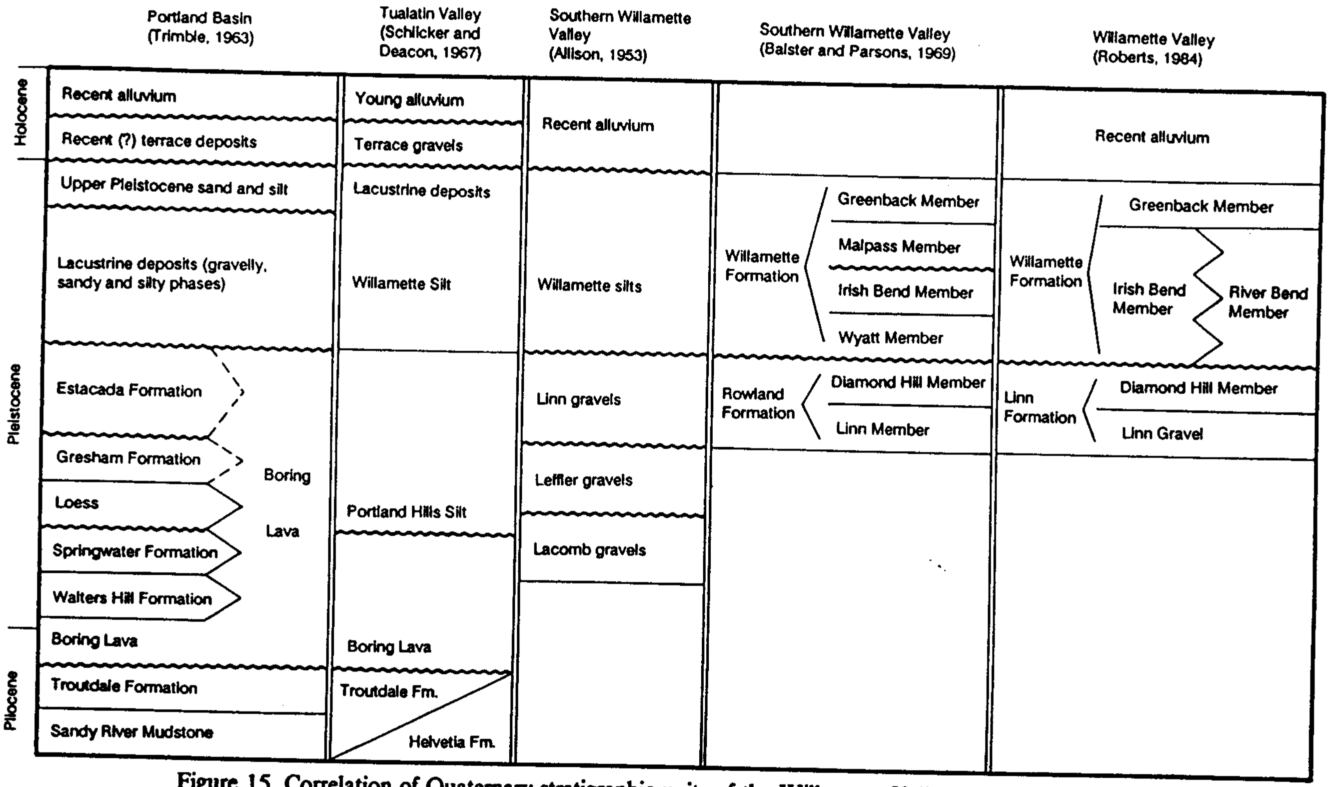


Figure 15. Correlation of Quaternary stratigraphic units of the Willamette Valley and adjacent areas. Alternative stratigraphic schemes for the Willamette Silt/Willamette Formation are shown in the three columns to the right.

Relief
elev.
Above
Channel
Grade

[illegible] 100 m
[illegible] 60 m
[illegible]

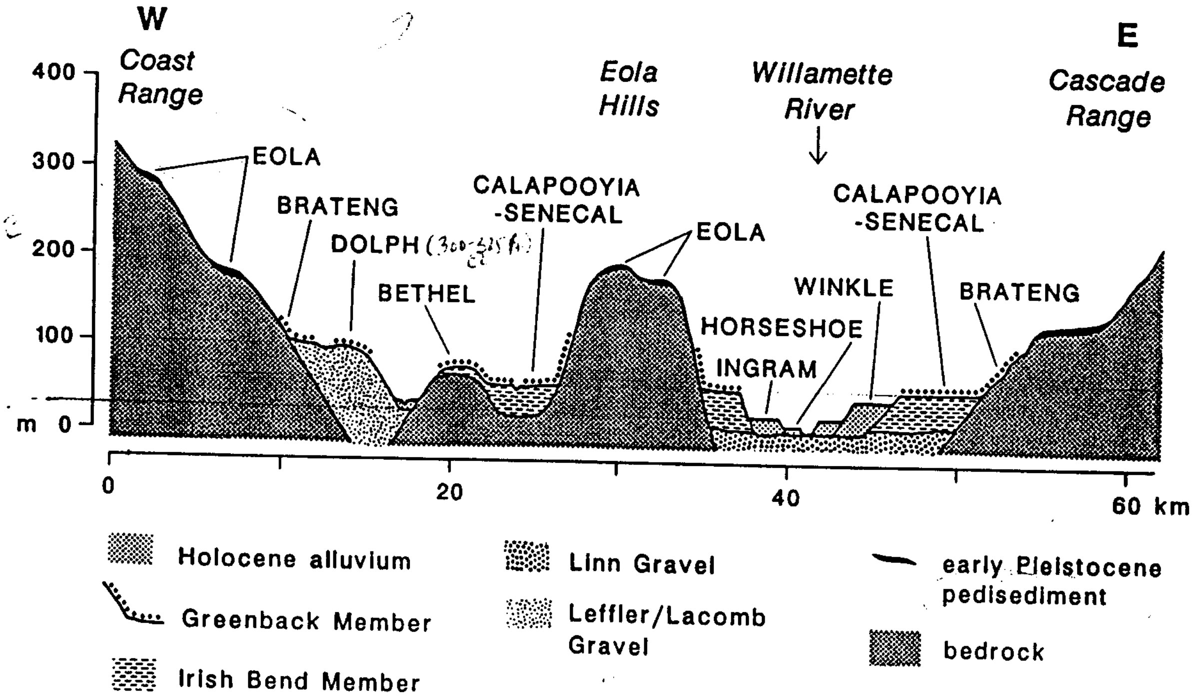


Figure 16. Generalized cross section of geomorphic surfaces at about the latitude of Salem. Subsurface distribution of the Linn Gravels shown here is speculative.

foothills at the southwestern edge of the northern Willamette Valley. This suggests that thin eolian deposits, possibly related to the Portland Hills Silt, may be found elsewhere in the Willamette Valley.

THE LATE WISCONSIN WILLAMETTE FORMATION AND RELATED DEPOSITS

Early work

Much of the floor of the Willamette Valley is underlain by horizontally bedded silt and associated deposits, whose petrology indicates derivation from a source outside the Willamette watershed. Condon (1871, 1902) originally proposed that these are estuarine deposits that accumulated in a "Willamette Sound" created by eustatic sea-level rise. Allison (1933, 1935, 1936, 1953, 1978) postulated that they are lacustrine slackwater deposits that followed glacier-outburst floods down the Columbia River from Glacial Lake Missoula and during the Wisconsinan Stage (Bretz, 1925). Allison named them the Willamette Silt. The Willamette Valley deposits are very similar to the Touchet Beds of southern Washington, which also are slackwater deposits of the catastrophic floods.

The Willamette Silt originally was defined as parallel-bedded silt and fine sand, with erratic pebbles and boulders (Allison, 1953; Allison and Felts, 1956). It is thickest beneath the valley floor at 60 to 90 m above sea level, but a thin layer extending up to an elevation of 122 m at the valley margins also was included. The Willamette Silt occurs as fill over the Linn gravels and older deposits. Erratic boulders to pebbles, of granite, granodiorite, gneiss, slate, and other rock types foreign to the Willamette River watershed, are widespread on the surface of the Willamette Silt at all elevations. Allison (1935) recognized the glacial origin and upper Columbia River basin provenance of these erratic boulders and concluded that they were ice-rafted into the Willamette Valley through ponded water of the "Spokane Flood" on the Columbia River. Pugh (1986) proposed that the Willamette meteorite, the largest meteorite found in the United States, was ice-rafted into the Willamette Valley during these floods.

Description and origin of the Willamette Formation

Deposits overlying the Linn Formation are known to be stratigraphically more complex than Allison's original concept of the Willamette Silt (Glenn, 1965; Balster and Parsons, 1969). A developmental model has evolved that includes two distinct phases of flood deposition from the Columbia River in the Willamette Valley (Allison, 1933, 1935, 1978; Glenn, 1965; Schlicker and Deacon, 1967; Roberts, 1984). In the first phase, a thick body of low-energy, silty to sandy deposits was laid down, probably by multiple floods. The second phase, resulting from a single very large flood, resulted in erosion and deposition of smaller volumes of (1) sandy to bouldery high-energy deposits near gaps where the flood entered the valley, and (2) silty low-energy deposits across the valley floor. Several additional models have been proposed, including deposition of both phases by a single large flood (Trimble, 1963), and deposition of the first-phase deposits in an environment similar to Condon's proposed Willamette Sound (Lowry and Baldwin, 1952; Balster and Parsons, 1969; Beaulieu, 1971; Parsons, 1985). The latter explanation requires uplift and/or eustatic sea-level fall to elevate the deposits to 60 to 120 m above sea level. The alternative models are not as strongly supported as is Allison's two-phase model. Following is my synthesis of the stratigraphy and origin of these deposits, based on the work of these researchers.

Balster and Parsons (1969) proposed that the Willamette Silt be renamed the Willamette Formation, consisting of four members: in ascending order, the Wyatt, Irish Bend, Malpass, and Greenback. The morphology, lithology, and provenance of these members are collated in Table 2. The lowermost Wyatt Member probably represents infilling of river channels, caused by damming or ponding of the Willamette River at the beginning of the first phase of slackwater flooding. Unit II at Glenn's (1965) River Bend section may be equivalent to the Wyatt Member.

The Irish Bend Member also was deposited during the first phase of flooding. This member accounts for most of the Willamette Silt as conceived by Allison, but it does not include the thin silt mantle that lies on slopes above the valley floor. Based on

TABLE 2. WILLAMETTE FORMATION CHARACTERISTICS*

Willamette Formation Member	Geometry and Distribution	Lithology	Provenance
Greenback	<1 m thick; continuous mantle over valley floor and foothills as much as 122 m a.s.l.†	Pale gray massive silts, with erratic pebbles and rock chips	Columbia River system
Malpass	Discontinuous lenses <1 m thick, widespread over valley floor	Dark gray massive clay	Willamette River system
Irish Bend	6 to 15 m thick body underlying the valley floor below 80 m a.s.l.†,§	Parallel-bedded tan silt and fine sand	Columbia River system
Wyatt	A few lenses ≤2 m thick, in center of valley	Fluvial-bedded sands and silts§	Willamette River system§

*Based on Balster and Parsons (1969), except as noted.
†Glasmann and others (1980). a.s.l. = above mean sea level.
§Glenn (1965).

TABLE 3. GEOMORPHIC SURFACES OF THE WILLAMETTE VALLEY[*]

Geomorphic Surface	Surface Type	Dominant Surface-forming Process	Final Surface-forming Event	Major Associated Deposits	Approximate Age (B.P.)	Typical Soils
Horseshoe	Depositional	Fluvial lateral accretion	Fluvial lateral accretion	Recent alluvium	<300	Fluventic Haploxeroll
Ingram	Depositional	Fluvial lateral accretion	Fluvial lateral accretion	Recent alluvium	<5,000	Cumulic Ultic Haploxeroll
Winkle	Depositional	Fluvial lateral accretion	Fluvial lateral accretion	Recent alluvium	12,000 to 5,000	Pachic Ultic Argixerol
Champoeg	Depositional	Phase 2 flood proximal facies deposition	Phase 2 flood proximal facies deposition	"Lacustrine deposits"[†]	13,000	Argiaquic Xeric Argialboll, Aquic Xerocherpt
Senecal	Erosional	Local fluvial incision of Calapooyia surface	Deposition of Greenback Member	Willamette Formation	13,000	Aquultic Argixerol, Pachic Ultic Argixeroll
Calapooyia	Erosional/ depositional	Plantation of Irish Bend Member and older deposits	Deposition of Greenback Member	Willamette Formation	13,000	Typic Albaqualf, Argiaquic Xeric Argialboll
Quad[§]	Uplifted(?)	Uplift of Willamette Formation deposits	Deposition of Greenback Member	Willamette Formation	13,000	Pacific Ultic Argixeroll
Bethel[**]	Depositional/ draped on erosional	Willamette Formation deposits draped on low bedrock knolls	Deposition of Greenback Member	Willamette Formation	13,000	Aquultic Argixeroll
Brateng[‡]	Depositional/ draped on erosional	Greenback Member deposits draped on hillslopes	Deposition of Greenback Member	Greenback Member over Tertiary bedrock	13,000	Ultic Haploxeralf
Dolph	Depositional/ some erosional	Fluvial/glaciofluvial aggradation	Deposition of Greenback Member	Lacomb and Leffler gravels, with Greenback Member in places	Mid-Pleistocene or younger	Ultic Haploxeroll, Ultic Haploxeralf
Eola	Erosional	Pedimentation	Deposition of loess, gravels, or pedisediment	Unnamed pedisediment, Lacomb and Leffler gravels, Helvetia Formation, Portland Hills Silt[§§]	Early Pleistocene	Xeric Haplohumult
Looney	Erosional	Mass movement	Ongoing mass movement and slope erosion	Colluvium	Time-transgressive	Typic Haplohumult, Typic Haplumbrept

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[*] Based on Balster and Parsons (1968, 1969) and Parsons and others (1970), except as noted.

[†] Schlicker and Deacon (1967).

[§] No direct evidence for uplift; probably should be subsumed under the Bethel geomorphic surface.

[**] Recognized by Gelderman and Parsons (1972) near Amity (Fig. 14).

[‡] Recognized by Glasmann and others (1980) in a small study site 3 miles south of Monmouth (Fig. 14), but probably widespread.

[§§] Green (1983), Parsons (1985).

Reckendorf, 1993

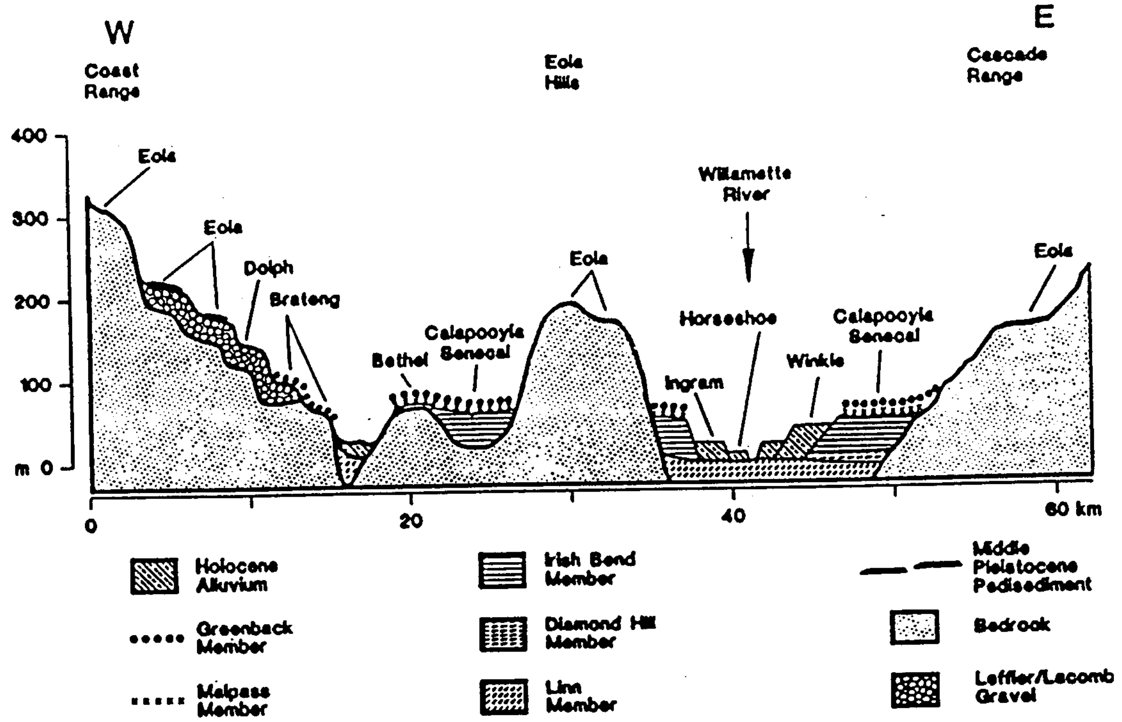


Figure 1. Generalized cross section of geomorphic surfaces at about the 45° latitude of Salem, Oregon. Subsurface distribution of Linn and Leffler/Lacomb Gravels shown here is speculative. Modified from McDowell (1991).

associated Greenback Member as described by Glassman and Kling (1980). Allison's (1935) original work reported no erratics lower than 30 m in the main valley but some as low as 10.5 m in the Portland area. Dozens of erratics locations are shown below 76 m and only rarely are erratics described at the maximum elevation of 122 m.

According to Allen et al. (1986), one small group of six boulders on Judkins Point east of Eugene occurs at an elevation of 198 m. It is assumed that these particular erratics are on the Eola surfaces rather than on Dolph Surfaces. Allen et al. (1986), attribute these high erratics to Indian transport, but an old Lake Missoula flood origin is also a possibility. Taken collectively, the data shows that erratics occur at various elevations above 30 m in the main valley, and they could be represent several different glacial Lake Missoula floods, rather than just the highest flood.

In general, the erratics range in size from small pebbles to boulders. They are composed of granites, granodiorites, gneisses, quartzites, schist, argillites, and phyllites. Allison (1935, 1936) noted at least 300 occurrences of erratics in the Willamette Valley. According to Allen et al. (1986), probably fewer than 50 of the erratic boulders still exist today.

The erratic rocks all require some outside source. Since the Willamette Valley lacks late Pleistocene continental till and associated outwash, and areas to the north show the definite presence of unmodified (by glaciers) Pleistocene non-glacial soil, it seems unlikely that the erratics were brought in by glaciers from the north. Allison (1935) related the erratics and the Willamette Silts, to be discussed later, to surges of glacial meltwater. This happened when the ice dams at the mouth of the Clark Fork River in Montana failed on different occasions, releasing the flow of Glacial Lake Missoula, to create the "Spokane Floods," between about 15 ka and 12.8 ka years before present (Allen et al., 1986).

The "Spokane Flood" (Bretz, 1919) was later named the "Missoula Flood," when the Montana Lake source for the flood water was discovered. It is commonly published (Allen et al., 1986) that, between 15 ka and 12.8 ka years ago, there were as many as 40 "Missoula Floods", so the term "floods" is

Table 1. Willamette Valley Geomorphic Surfaces
(Balster and Parsons, 1968, 1969, and Parsons, Balster, and Ness, 1970)

Geomorphic Surface	Type Locations	Geomorphic Expression	Stratigraphy	Age
Eola	Salem Hills, Waldo Hills, Eola Hills, Red Hills of Dundee, Hills near Lacomb	Crest and upper parts of hills.	Weathered soils and deeply weathered gravels.	Middle Pleistocene
Dolph	Three miles north of Dallas, OR Dolph Comers. Also, near Alvadore.	Variable but as many as three dissected flats. Numerous small pediments.	Extensive flats underlain by weathered gravels, sand and clays and surface erratics.	Middle Pleistocene
Quad	Quadrangle on campus of Oregon State University	Terrace flat that is similar to next lower Calapooyia unit.	Essentially the Willamette silts in an upfaulted position.	Late Pleistocene
Calapooyia	Southern part of Willamette Valley particularly along the eastern part of Calapooyia River.	Flat main valley floor, little relief, light colored areas on photos are poorly drained depressions separated by intervening, slightly higher and better drained dark colored areas.	Greenback Member and Malpass or Irish Bend Members. Or, Greenback and/or Malpass over buried paleosol or weathered gravels.	Late Pleistocene
Senecal	Area around Senecal Creek near Woodbum.	Modification of the Calapooyia surface and development of drainage. Locally appears like drainage organization produced by overland flooding of major streams shortly after Greenback Member deposited.	Greenback Member and Malpass or Irish Bend Members. Or, Greenback and/or Malpass over buried paleosol or weathered gravels.	Late Pleistocene
Champoeg	Two miles southwest of Newberg near Champoeg Park.	Modification of Calapooyia and Senecal surfaces. Small pediment-like landforms make up the greater part of the Champoeg.	Torrentially, cross-bedded sands or gravel, probably of Glacial Lake Missoula flood origin.	Late Pleistocene
Winkle	Winkle Butte, 10 miles south of Corvallis.	Broad abandoned flood plain in the Willamette Valley and oldest surface related to present drainage system. Also, old lake beds like Lake Labish.	Fine textured sediment, over gravel. Lake beds of peat and muck.	Late Pleistocene to Holocene

(continues on next page)

Table 1, cont. Willamette Valley Geomorphic Surfaces
(Balster and Parsons, 1968, 1969, and Parsons, Balster, and Ness, 1970)

Geomorphic Surface	Type Locations	Geomorphic Expression	Stratigraphy	Age
Ingram	Ingram Island along the Willamette River northeast of Harrisburg.	The higher of two flood plains of the Willamette River and its tributaries.	Flood plain sediments.	Late Holocene
Horseshoe	Horseshoe Island near Corvallis, OR.	The lower flood plain of the Willamette River and tributaries.	River channel bars, point bars and channel fillings. Usually sandy alluvium and gravel.	Predominantly Post Settlement
Looney	The southern margin of the Salem Hills near Looney Butte.	The geomorphic surface is a complex of valleys, and ridges that make up the dissected steeply sloping landscape.	Side valley alluvium of mixed lithology.	Of Any Age
Luckiamute	Luckiamute River Valley near town of Pedee.	Flood plains of streams that flow out of terrains composed of Eola, Dolph, and Looney surface, and associated alluvial fans.	Flood plain and alluvial fan deposits of tributary streams too small to map as Horseshoe or Ingram.	Of Any Age
Mass Movement	No formal location.	Hilly areas of the Willamette Valley with mass movement, slump blocks and mud flows. Frequently hummocky, irregular topography with poorly drained depressions.	Mixed side valley alluvium, and slumped materials.	Of Any Age

Flood deposits 15 ka to 12.8 ka yrs.). The remainder of this discussion will use this concept.

Brateng

Glassman and Kling (1980) and Glassman, Kling, and Brown (1980) redefine the two lower Dolph surfaces in the south central Willamette Valley that were included in the Dolph by Balster and Parsons (1968). The separation was based on stratigraphy, mineralogy, and soil discontinuities, that will be discussed in the Stratigraphy Section. Two surfaces called Brateng were defined, between elevation 80 m and 122 m in the Glassman and Kling (1980) study area. The name Brateng was assigned to represent the area where Brateng Road crosses the Brateng surfaces at Elkins Road in Polk County.

These surfaces are similar to the equivalent Middle and Low Dolph surfaces that I previously studied in the Airlie Hills in Polk County in the Willamette Valley. The Airlie Hills are about 9.6 km south of the Brateng type locality. I also consider the Brateng surfaces to be the Middle Dolph and Low Dolph that I previously identified in the Willamette Valley and elsewhere in Oregon and Washington.

The complex depositional history of the unconsolidated materials that lie beneath the Brateng surface will be discussed later under the Stratigraphy and Age section. However, to keep the chronology in perspective, the Brateng should be thought of as a middle to late Pleistocene landscape that has been modified by late Pleistocene erosion and associated glacial lacustrine deposits.

Table 2. Willamette Valley Geomorphic Surfaces, Representative Soils and Stratigraphy

Geomorphic Surface	Series	Subgroup	Particle Size Class	Stratigraphy and Other	Special Interpretation
Eola	Bellpine	Xeric Halplohumult	Clayey	Side valley alluvium over paleosol, and weathered soils over saprolite.	Erosion
	Bacona	Typic Halpohumult	Fine-silty	Side valley alluvium over paleosol and weathered soils over saprolite. Erratic pebbles.	Erosion
	Olyic	Typic Haplohumult	Fine-loamy	Side valley alluvium over paleosol, and weathered soils over saprolite.	Erosion
	Jory	Xeric Haplohumult	Clayey	Side valley alluvium over paleosol, and weathered soils over saprolite.	Erosion
	Cascade	Typic Fragiumbrept	Fine-silty	External depositional silt over reddish paleosol. Erratic pebbles & cobbles in depositional unit.	Erosion
	Goble	Andic Fragiumbrept	Medial	Volcanic ash & upland silt over fragipan paleosol.	Erosion Phosphorus in runoff
	Melby	Umbric Dystrochrept	Fine	Side valley alluvium.	Erosion
Dolph	Cornelius	Mollic Fragixeralf	Fine-silty	Fragipan	Erosion
	Willakenzie	Ultic Haploxeralf	Fine-silty	Side valley alluvium over brownish paleosol	Erosion
	Salkum	Xeric Haploxeralf	Clayey	Side valley alluvium over weathered gravels. Lacomb & Leffler weathered gravels	Erosion
High Brateng Low Brateng	Willakenzie variant, deep	Ultic Haploxeralf	Fine-silty	Depositional glacial silts on brownish paleosol. Erratics	Generally the highest glacial flood level. Variable shape on the landscape.
	Helmick variant, moderately deep	Aquic Xerochrept	Very-fine	Side valley alluvium over depositional clay over Cr. Associated with the upslope claystones, siltstones, & tuff sources of clay.	Commonly in swale shape. One source for lower lying depositional clay. Variable shape on the landscape.
Bethel	Willamette variant	Pachic Ultic Argixeroll	Fine-silty	Greenback over Irish Bend Members. Abundant erratics.	Stratified soils, well drained, wide crop variety.

(continues on next page)

Table 2, cont. Willamette Valley Geomorphic Surfaces, Representative Soils and Stratigraphy

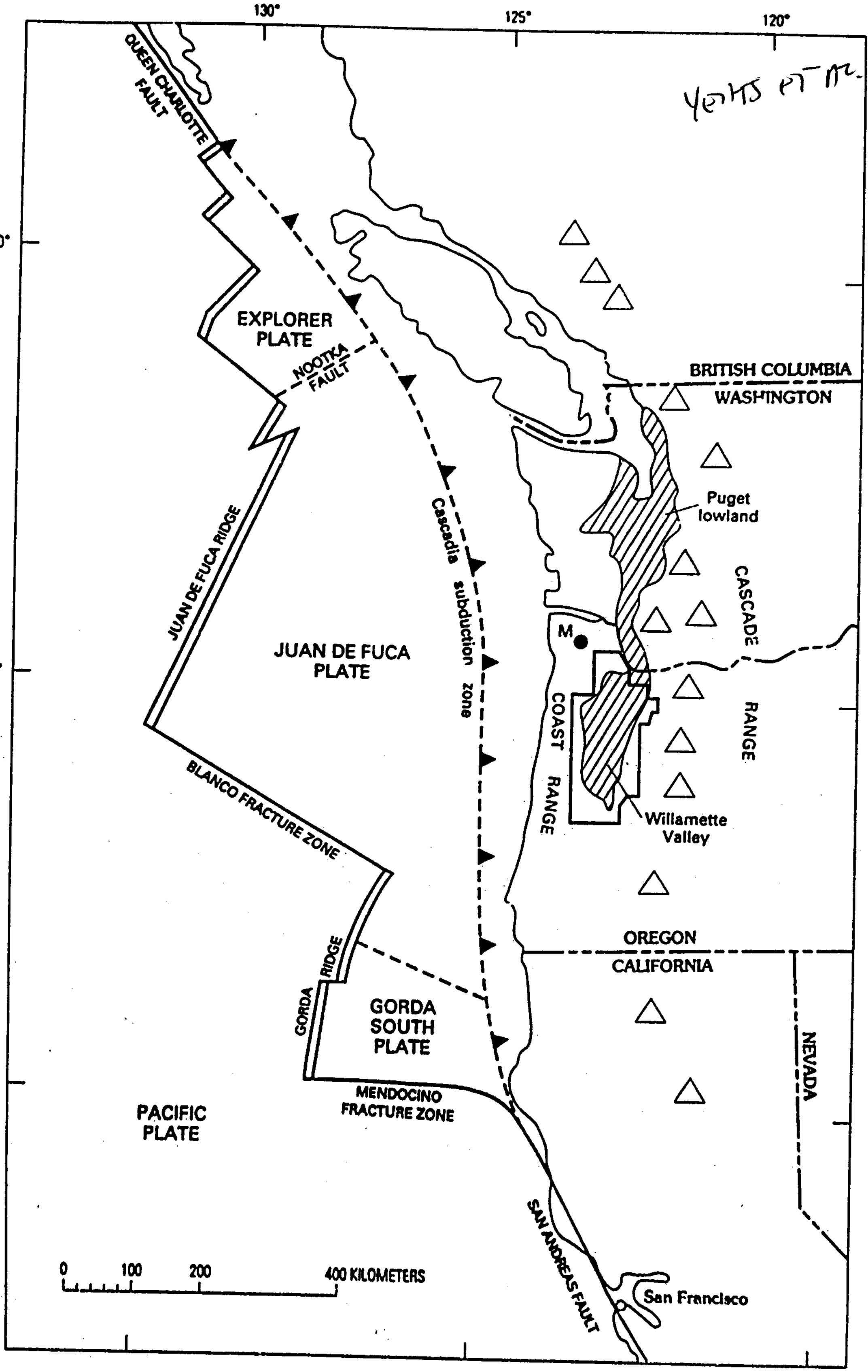
Geomorphic Surface	Series	Subgroup	Particle Size Class	Stratigraphy and Other	Special Interpretation
Calapooyia	Dayton	Typic Albaqualf	Fine	Greenback in Dayton soil is A & E, 2BT is Malpass & 3C is the Irish Bend.	Drainage problem limits crop varietys and stratified soils.
Senecal	Willamette	Pachic Ultic Argixeroll	Fine-silty	Derived from minor incision of Calapooyia	Stratified soils, well drained, wide crop variety.
Champoeg	Multnomah	Dystic Xerochrept	Fine-loamy	Torrentially cross-bedded gravels and sands. Reflects Glacial Lake Missoula flooding.	Well drained coarse soils.
Winkle	Malabon	Pachic Ultic Argixeroll	Fine	Primarily vertical accretion deposits. Associated with modern drainage.	Rarely flooded, well drained, wide crop variety.
	Sifton	Andic Xerumbrept	Medial over sandy	Gravelly alluvium and volcanic ash.	Andic properties
	Labish	Cumulic Humaquept	Fine	Muck and peat in ponded areas. Phosphorus sink.	High organics and phosphorus
Ingram	Chehalis	Cumulic Ultic Haploxeroll	Fine-silty	Vertical & lateral accretion deposits. Infrequent flooding. Lacks Bt soil horizon.	Flooding
Horseshoe	Camas	Fluventic Haploxeroll	Sandy-skeletal	Essentially lateral accretion deposits. Lacks diagnostic soil horizon.	Frequent flooding

may be locally derived from the Paleosol and the saprolite of the Spencer Formation, underlying the High Dolph. Thickness of the Greenback member on the Brateng surfaces was reported to vary from 90 cm at lower elevations to less than 30 cm near the upper boundary. In the Airlie Hills, the author, using soil pits auger transects and mapping, correlated the Greenback Member to occur on the Lower Brateng surface with an average thickness of about 38 cm. It contains erratics.

The Dolph Corner erratics, therefore, are not consistent with the Glassman, Brown, and King (1980) and Glassman and King (1980) interpretations. Further investigations are needed to determine if the true High Dolph occurs at the Dolph type locality and if the erratics at that locality are older than the Greenback surface. Perhaps the Dolph type locality should be redefined as the Brateng surface, which is characterized by the presence of late Pleistocene erratics and the Greenback Member, both of which are associated with Glacial Lake Missoula flooding. Because of the elevation (76 m), the presence of a Greenback like onlap, and the erratics, this author believes that the Dolph type locality is what Glassman, Kling, and Brown (1980) include in the Brateng, and it probably represents the Low Brateng.

Understanding the Erratics

Understanding the age of the erratics in the Willamette Valley would greatly help in our understanding of the age of the associated deposits like the Greenback Member. The erratics have been reported in Balster and Parsons (1968) to occur mostly above 76 m in elevation, such as those that occur at Dolph Corners. However, many erratics are as high as 122 m, as described by Allison (1953), or with the



Yeats et al., 1996

Figure 76. Plate boundaries of the Pacific Northwest showing locations of tectonic features and the Willamette Valley study area. Heavy line, study-area boundary; hatched area, Willamette Valley and Puget lowland; sawteeth denote upper plate of thrust fault. Major stratovolcanoes are shown by open triangles. Dot labeled "M" in northwestern Oregon is the Mist gas field.

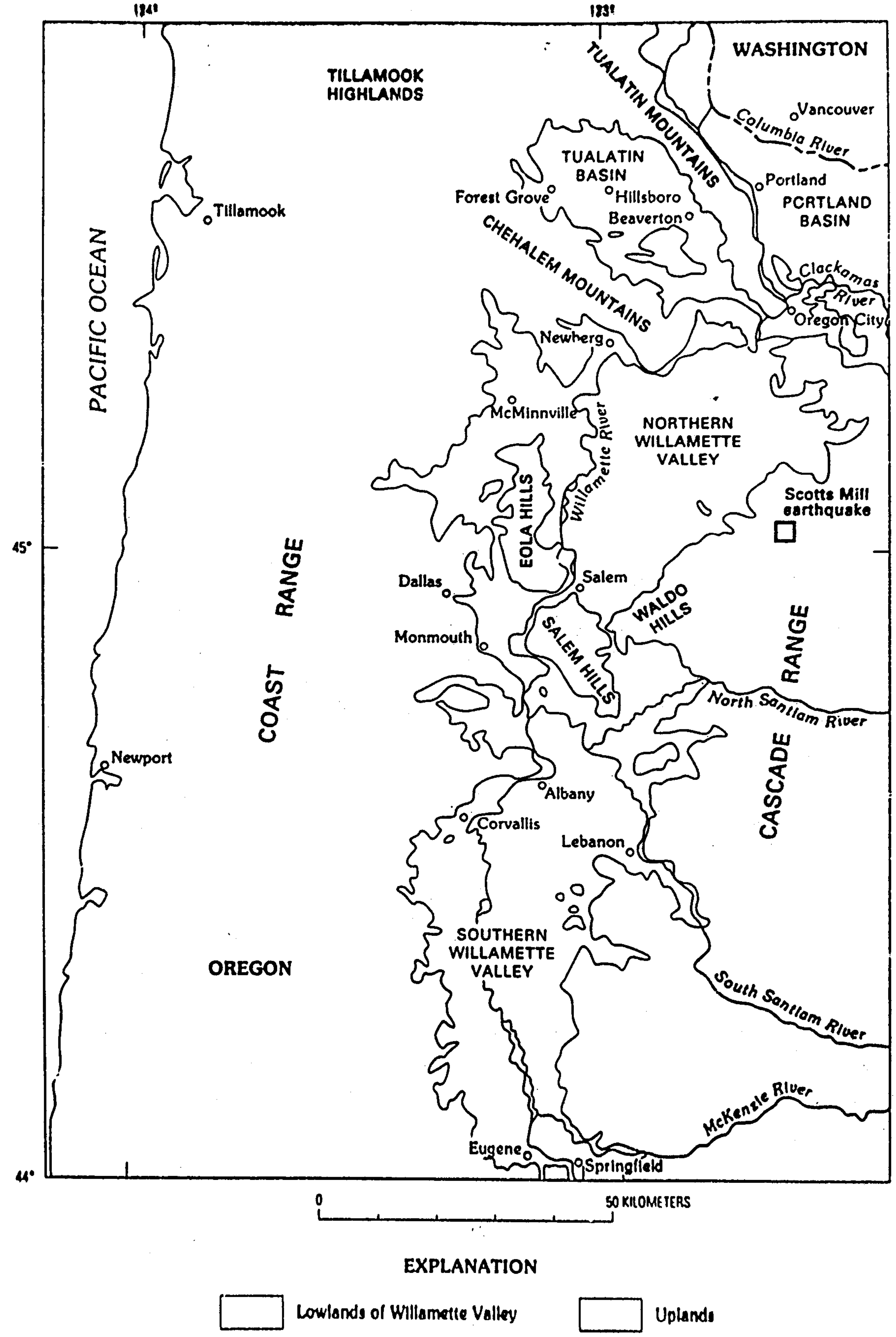
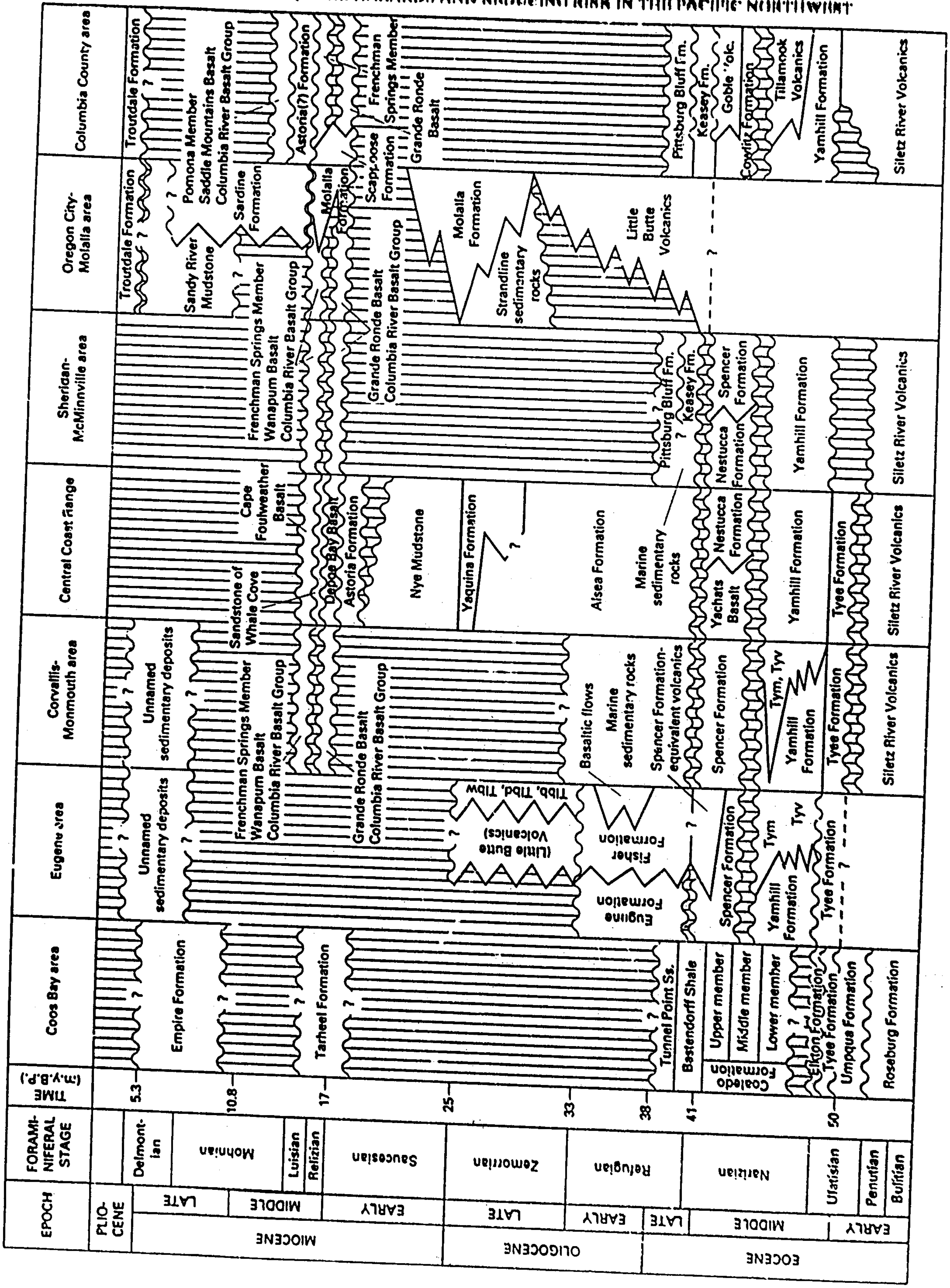


Figure 77. Geographic and physiographic features of the Willamette Valley and Portland and Tualatin basins, northwestern Oregon. The square indicates the epicenter of the March 25, 1993, Scotts Mills earthquake.


EPOCH
FORAMINIFERAL STAGE
TIME (m.y.B.P.)
Coos Bay area
Eugene area
Corvallis-Monmouth area
Central Coast Range
Sheridan-McMinnville area
Oregon City-Molalla area
Columbia County area
PLIOCENE
MIOCENE
LATE
MIDDLE
EARLY
OLIGOCENE
LATE
EARLY
EOCENE
LATE
MIDDLE
EARLY
Delmontian
Mohnian
Luisian
Relizian
Saucesian
Zemorrian
Refugian
Narizian
Ulatisian
Penutian
Bulitian
5.3
10.8
17
25
33
38
41
50
Empire Formation
Tarheel Formation
Tunnel Point Ss.
Bastendorff Shale
Coaledo Formation
Upper member
Middle member
Lower member
Elkton Formation
Tyee Formation
Umpqua Formation
Roseburg Formation
Unnamed sedimentary deposits
Frenchman Springs Member
Wanapum Basalt
Columbia River Basalt Group
Grande Ronde Basalt
Columbia River Basalt Group
Tibb, Tibd, Tibw
(Little Butte Volcanics)
Fisher Formation
Eugene Formation
Spencer Formation
Tym
Tyv
Yamhill Formation
Tyee Formation
Unnamed sedimentary deposits
Frenchman Springs Member
Wanapum Basalt
Columbia River Basalt Group
Grande Ronde Basalt
Columbia River Basalt Group
Basaltic flows
Marine sedimentary rocks
Spencer Formation-equivalent volcanics
Spencer Formation
Tym, Tyv
Yamhill Formation
Tyee Formation
Siletz River Volcanics
Cape Foulweather Basalt
Sandstone of Whale Cove
Depoe Bay Basalt
Astoria Formation
Nye Mudstone
Yaquina Formation
Alsea Formation
Marine sedimentary rocks
Nestucca Formation
Yachats Basalt
Yamhill Formation
Tyee Formation
Siletz River Volcanics
Frenchman Springs Member
Wanapum Basalt
Columbia River Basalt Group
Grande Ronde Basalt
Columbia River Basalt Group
Pittsburg Bluff Fm.
Keasey Fm.
Spencer Formation
Nestucca Formation
Yamhill Formation
Siletz River Volcanics
Troutdale Formation
Sandy River Mudstone
Sardine Formation
Molalla Formation
Molalla Formation
Strandline sedimentary rocks
Little Butte Volcanics
Troutdale Formation
Pomona Member
Saddle Mountains Basalt
Columbia River Basalt Group
Astoria(?) Formation
Frenchman Springs Member
Scappoose Formation
Grande Ronde Basalt
Pittsburg Bluff Fm.
Keasey Fm.
Goble Volc.
Cowlitz Formation
Tillamook Volcanics
Yamhill Formation
Siletz River Volcanics
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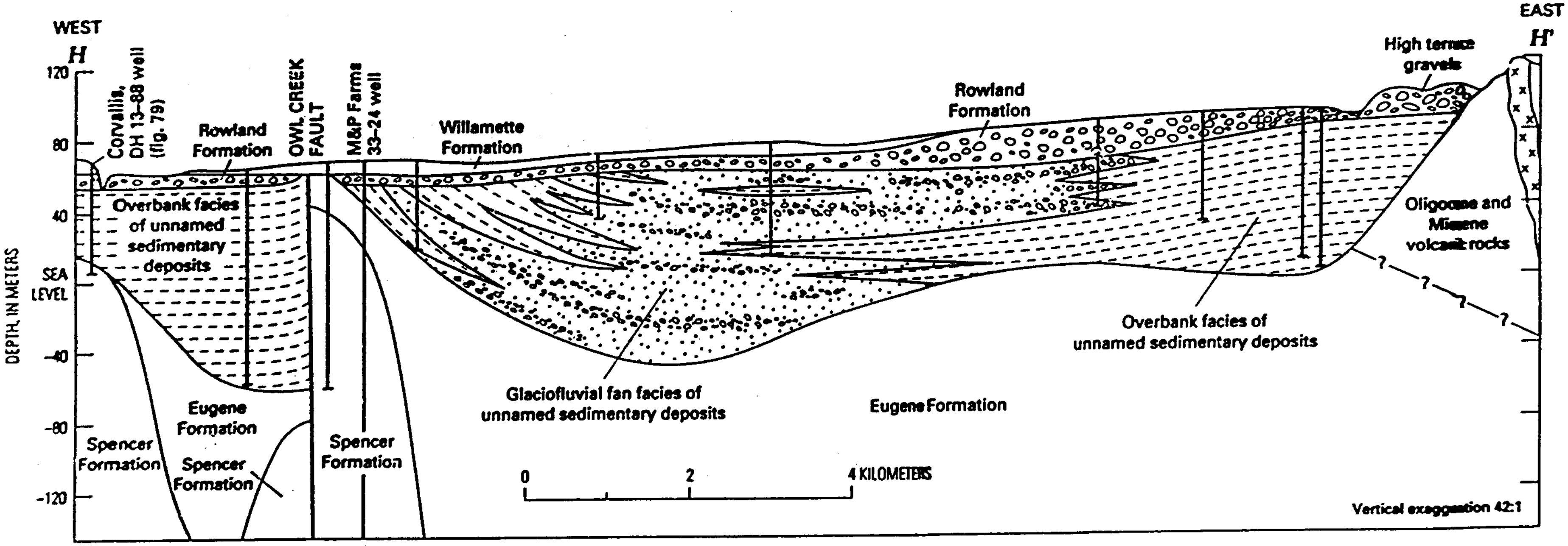

Figure 82. Structural cross section between Corvallis and Lebanon, Oreg., showing channel and overbank facies of unnamed fluvial sedimentary deposits, high-terrace gravels, late Pleistocene outwash deposits of the Rowland Formation, and catastrophic flood deposits of the Willamette Formation. Data are from water wells, engineering bore holes, and petroleum-exploration wells.

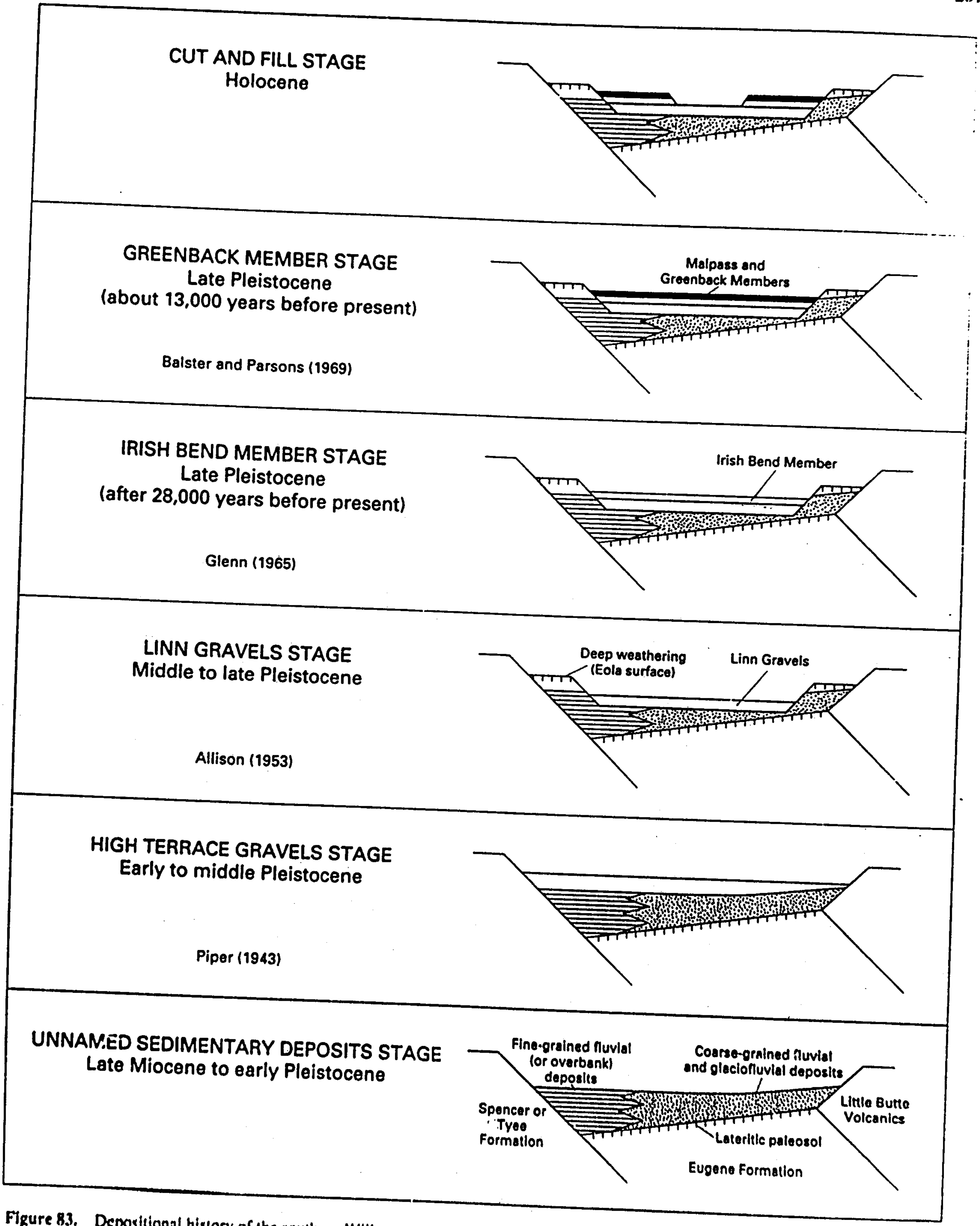

Figure 83. Depositional history of the southern Willamette Valley, Oregon, after Miocene time. Modified from Roberts (1984).

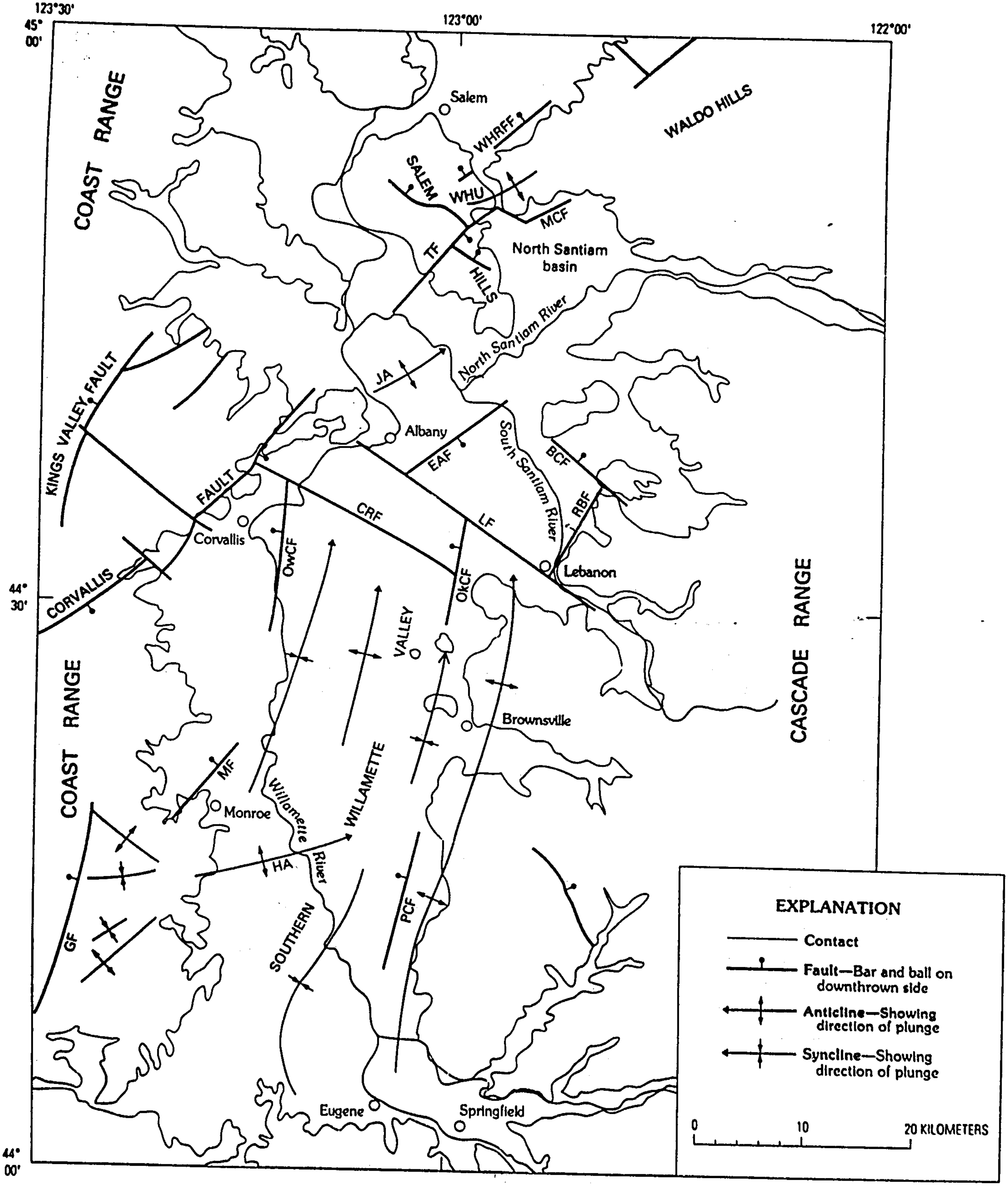

Figure 84. Tectonic map of the southern Willamette Valley, Oregon. Areas underlain by alluvial and fluvial deposits that postdate the Columbia River Basalt Group are unshaded; areas underlain directly by bedrock are shaded. BCF, Beaver Creek fault; CRF, Calapooia River fault; EAF, East Albany fault; GF, Glenbrook fault; HA, Harrisburg anticline; JA, Jefferson anticline; LF, Lebanon fault; MCF, Mill Creek fault; MF, Monroe fault; OwCF, Owl Creek fault; OkCF, Oak Creek fault; PCF, Pierce Creek fault; RBF, Ridgeway Butte fault; TF, Turner fault; WHRFF, Waldo Hills range-front fault; WHU, Waldo Hills uplift.

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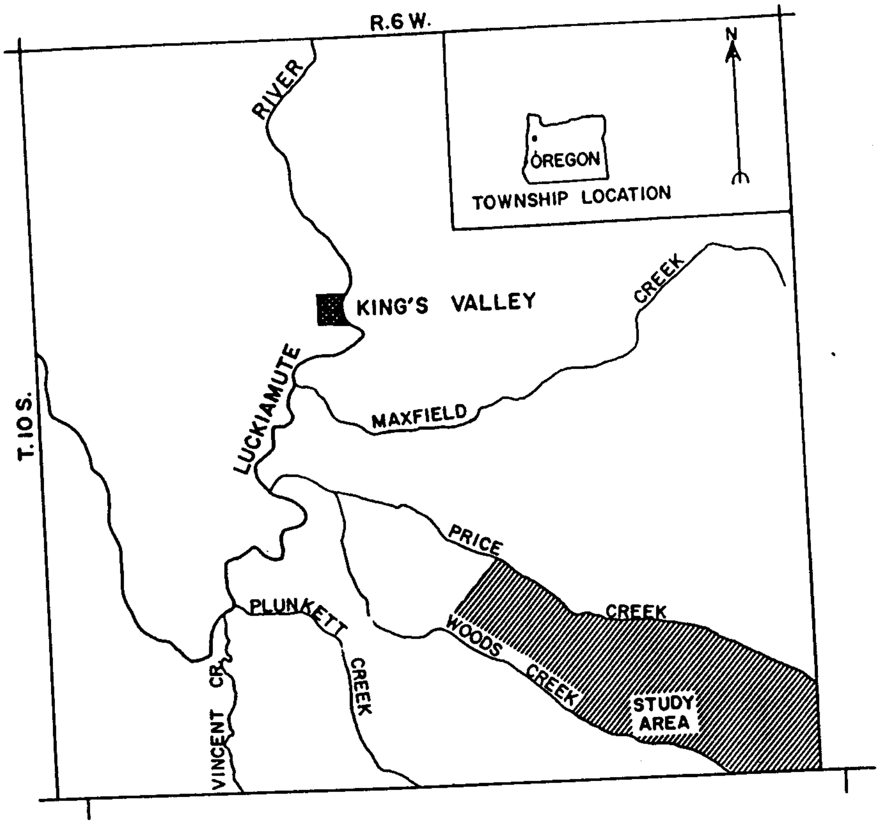

Figure 1. Index map.

Geology of the Area

Woods Creek and Price Creek drainages are underlain by pillow basalts, breccias, and pyroclastic sediments of the Eocene Siletz River Formation[3] (Snavely and Baldwin, 1948). Complex faulting and gentle folding are characteristic of the area and appear to have controlled the direction of development of Woods Creek and Price Creek canyons. Deerslayer and Oakpark gulches are probably not directly related to geologic structure, but they may be related to fracture patterns in the basalt.

Extent of weathering of the basalts in the area is highly variable. Relatively fresh, hard rock and soft, clayey saprolite represent extremes. Generally, the bedrock is highly fractured and has at least a thin rind of clayey, weathered material surrounding the fragments. Relatively fresh basalt is overlain by only a few feet of rocky soil on the more steeply sloping landforms of the area. Deep, soft saprolite was penetrated by hand-augering to a depth of 20 feet immediately northeast of Deerslayer Gulch on a high remnant of an old erosion surface. Relatively fresh, hard basalt crops out near the bottoms of both Deerslayer and Oakpark gulches (Figure 3).

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[3] Snavely and Baldwin (1948) named the unit "Siletz River volcanic series." Because this usage does not agree with the meaning of series as defined by the American Commission on Stratigraphic Nomenclature (1961), the authors use the unit as a formation in accord with present accepted terminology.

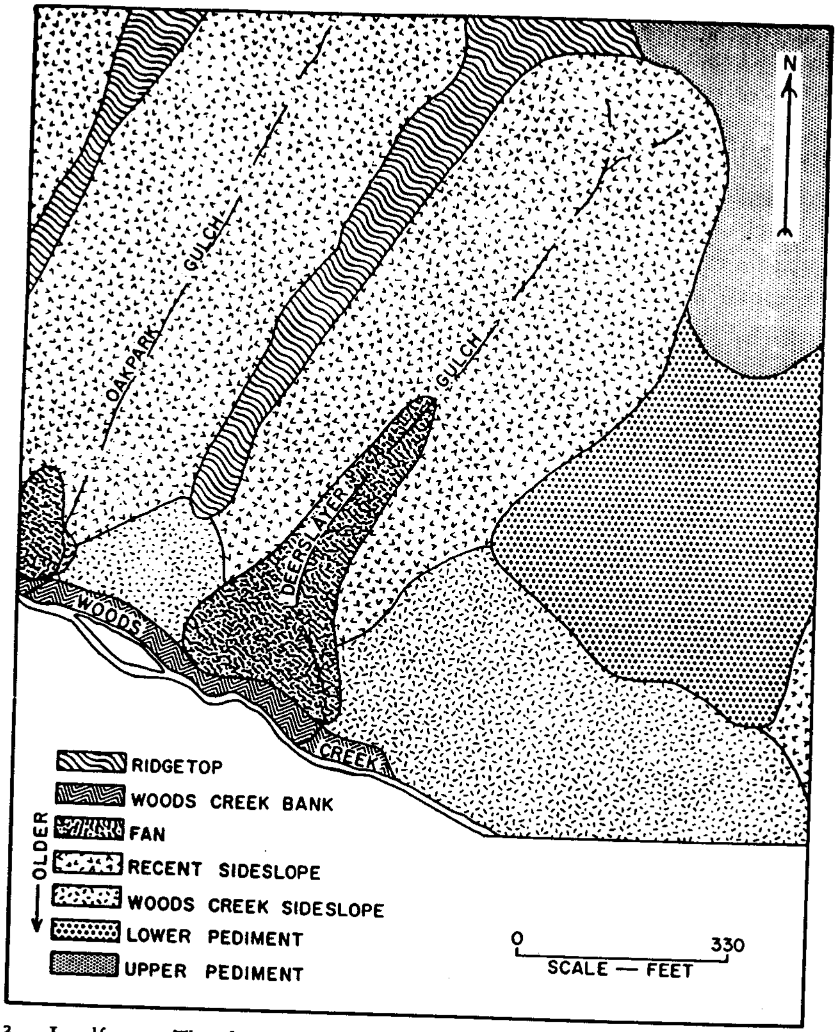

Figure 3. Landforms. The four upper map units are not strictly in age sequence but are morphologically separable.

snow cover that was saturated and subsequently melted by abundant warm rain. Mass movement by sliding and slumping was unusually abundant in the area during that period, and the degree of the "catastrophe" could undoubtedly have been intensified by a coincidental earthquake.

The base of the fan from Deerslayer Gulch where it is exposed in the cutbank of Woods Creek is only about three feet higher than the immediately adjacent modern channel of Woods Creek. Present gravel bars are at the same elevation as the base of the fan. Charcoal taken from the exposure in the cutbank at the base of the Deerslayer Gulch fan gave a maximum age for the fan (Balster and Parsons, 1966) of 9570±510 years B.P. (before present). As the fan was deposited on the valley bottom of Woods Creek, there has been no significant downcutting of Woods Creek channel since that time. From the standpoint of net valley deepening accomplished,

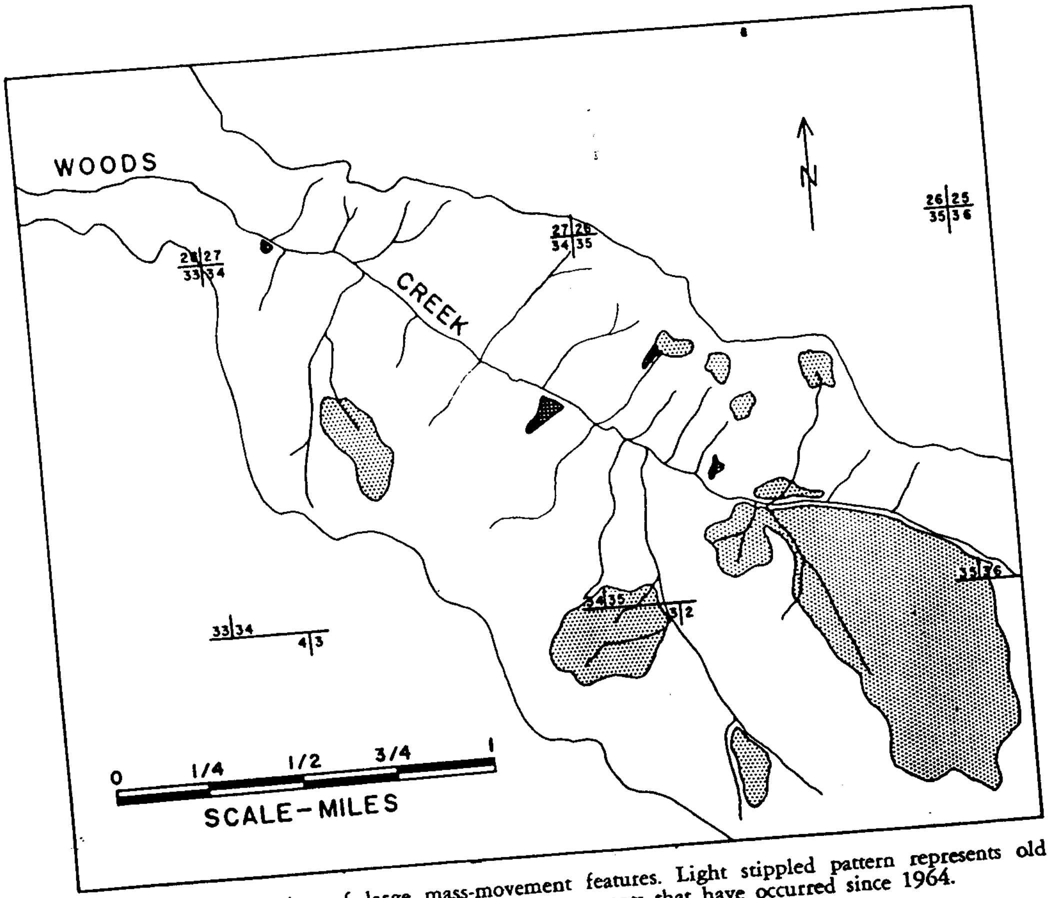

Figure 4. Distribution of large mass-movement features. Light stippled pattern represents old features. Heavy pattern represents movements that have occurred since 1964.

may slightly predate those of Deerslayer and Oakpark gulches. The surfaces of this latter age group are mantled by thin, slightly developed, stony soil. However, soil on the sideslopes of Woods Creek contains more aggregates (peds) than soil along Deerslayer and Oakpark gulches and probably reflects greater time for soil formation.

Air dry samples weighing about 25 pounds each were collected from the upper foot of the sola along transects as shown on the map (Figure 5). The samples were sieved, immediately after collection, through a ¼-inch mesh screen. The coarse material was then divided into two grades: fragments greater than and less than one inch. Each of these three size grades was weighed to the nearest ounce and the weight recorded.

Within the area of the map (Figure 5), the steep valley sideslopes are essentially planar except for a very small toeslope and a similar small shoulder. The slope gradients (in per cent) shown on the map were measured with an Abney[5] level to determine if obvious differences in size of material were related to variation of declivities. No relationship is apparent.

Processes of mass wasting, such as creeping and slumping, tend to produce materials

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[5] Trade names and company names are incuded for the benefit of the reader and do not imply any endorsement by the U.S. Department of Agriculture.

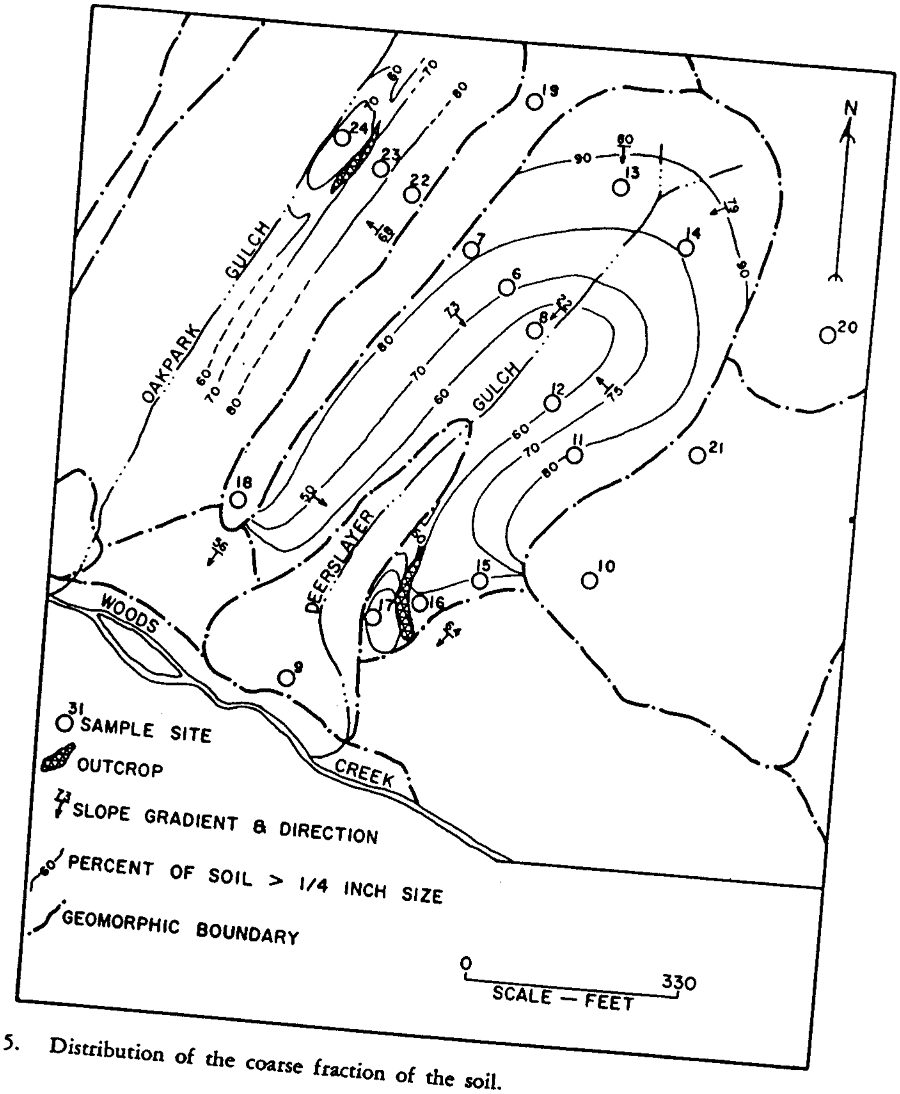

Figure 5. Distribution of the coarse fraction of the soil.

with an assortment of size grades. Transportation by water tends to produce materials with size sorting. The downslope decrease in size of material (Figure 5) seems to be most adequately explained by a combination of transportation of fine particles down the valley walls by water and comminution of fragments by weathering. As should be expected, the areas immediately downslope from outcrops show exceptionally high proportions of coarse material.

Accumulation of assorted material behind logs and stumps is indicative of the mass wasting along these steep valley sideslopes. The predominant process is probably rockfall. "Terraces" on the uphill side and depressions on the downhill side of stumps are much like those described by LaMarche (1964). The rate of downslope movement in the Deerslayer Gulch area is almost certainly increased by activities of sheep and deer in the area.

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Table 3-5. Summary of Surficial Map Criteria for the Central Appalachians (after Kite, 1994).

E:TABLES:SRFMPTBL.DOC

A. Type I Criteria: Age, Origin, Landform, Material.

1. **Age of Surficial Material**
    - H = Holocene (< 10,000 years old)
    - W = Wisconsin (ca. 89 to 10 ka)
    - I = Illinoian
    - P = Pleistocene Undifferentiated
    - EP = Early Pleistocene
    - MPI= Middle Pleistocene
    - LP = Late Pleistocene
    - Q = Quaternary Undifferentiated
    - CZ = Cenozoic Undifferentiated
    - Q-CZ(?) = Quaternary to Cenozoic?
    - MZ = Mesozoic (applied to bedrock)
    - PZ = Paleozoic (applied to bedrock)

2. **Origin / Surficial Process**
    - A. Hillslope
        - r = residuum (in situ regolith)
        - c = colluvium (mass wasting)
        - ds = debris slide
        - rf = rock fall or topple
    - B. Valley Bottom
        - a = stream alluvium (normal flow)
        - hcf = hyperconcentrated flow
        - df = debris flow
        - sw = slackwater deposition
    - C. Lacustrine
        - l = lacustrine deposit, undiff.
        - lb = lake-bottom deposit
        - ld = lacustrine deltaic
        - ls = lakeshore deposit (incl. beaches)
    - D. Other
        - g = glaciofluvial, undifferentiated
        - go = glacial outwash
        - e = eolian
        - co = collapse (solution)
        - cr = cryoturbation
        - x = anthropogenic disturbance
        - f = artificial fill
        - rk = bedrock (continuous outcrop)

3. **Landform Units**
    - A. Hillslope
        - n = nose
        - sl = side slope
        - h = hollow
        - veneer = < 2m of regolith
        - blanket = > 2 m of regolith
        - bf = boulder field
        - bs = boulder stream
        - pg = patterned ground
        - tls = talus deposits
    - B. Valley Bottom
        - ch = channel
        - fp = floodplain (RI </= 2-3 yr)
        - t = terrace (t1, t2 ...tn; height AMRL)
        - f = fan
        - f-t = fan terrace (f1, f2 ...fn; height AMRL)
        - a = apron (footslope deposit)
        - lo = lobe
        - lv = levee
        - ox = oxbow, abandoned channel
    - C. Other
        - ft = flow track (debris flows)
        - hm = hummocky topography
        - rb = rock-block slide deposits
        - x = excavated, fill, disturbed ground
        - d = delta
        - du = dune
        - bedrock = exposed bedrock

4. **Material (Composition and Texture)**
    - b = boulders (>256 mm; clast supported)
    - c = cobbles (64-256 mm; clast supported)
    - p = pebbles (4-64 mm; clast supported)
    - g = gravel (>2 mm; clast supported)
    - sg = mixed sand and gravel
    - s = sand (0.05-2.0 mm)
    - st = silt (0.002-0.05 mm)
    - cy = clay (<0.002 mm)
    - l = loam (mix of sand, silt, clay)
    - d = diamicton undifferentiated
    - bbd = very bouldery diamicton
    - bd = bouldery diamicton
    - cd = cobbly diamicton
    - pd = pebbly diamicton
    - ds = sandy matrix diamicton
    - dt = silty matrix diamicton
    - dy = clayey-matrix diamicton
    - rk = bedrock (modify with lithology)
    - rs = rotten stone, saprolite
    - tr = travertine
    - tu = tufa
    - ma = marl
    - og = organic-rich sediment
    - w = water
    - u = unkown

Table 5-3. Example Application of Surficial Map Criteria at the Little River Basin, Augusta County, VA.

Map Unit Label	Map Unit Description	Age	Origin (Process)	Landform	Material (Texture)	Four-Fold Identifier	Comments
Qr	Quaternary Residuum	Quaternary (Undiff.)	Residuum	Ridge-Veneer	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,r,r-v,c-bdt-l)	Predominantly associated with ridge crests supported by the Pocono Formation.
Qc1	Quaternary Colluvium (Side Slopes)	Quaternary (Undiff.)	Colluvium	Nose-Side Slope Veneer	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,c1,n/s-v,c-bdtl)	Predominantly associated with side slopes underlain by the Hampshire Formation. Includes the Hazleton and Hazleton-Lehew soils series (Hockman and others, 1979).
Qc2	Quaternary Colluvium (Hollows)	Quaternary (Undiff.)	Colluvium	Hollow Veneer	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,c2,h-v,c-bdt-l)	Predominantly associated with zero- to first-order hollows underlain by the Hampshire Formation.
Qbf	Quaternary Boulder Field	Quaternary (Undiff.)	Colluvium (periglacial?)	Boulder Field	Cobbles and Boulders	(Q,c,bf,c-b)	Equant to irregularly shaped side slopes covered by greater than 80% cobbles and boulders. Commonly interpreted as the product of Pleistocene periglacial slope processes.
Qbs	Quaternary Boulder Stream	Quaternary (Undiff.)	Colluvium (periglacial?)	Boulder Stream	Cobbles and Boulders	(Q,c,bs,c-b)	Elongate valley-bottom areas covered by greater than 80% cobbles and boulders. Commonly interpreted as the product of Pleistocene periglacial slope processes.
Hch	Holocene Channel Alluvium	Holocene	Alluvium	Channel and Narrow Floodplain	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(H,a,ch,c-b-pl)	Fluvial channel deposits associated with first- to sixth-order streams. Unit includes channel alluvium and portions of adjacent floodplain too small to map at the given scale.
Hfp1	Holocene Floodplain Alluvium (0.5 to 1.0 m surface)	Holocene	Alluvium	Floodplain	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(H,a,fp1,c-b-pl)	Floodplain alluvium associated with second- to sixth order streams. Unit includes low-lying surfaces 0.5 to 1.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years.
Hfp2	Holocene Floodplain Alluvium (1.0 to 2.0 m surface)	Holocene	Alluvium	Floodplain	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(H,a,fp2,c-b-pl)	Floodplain alluvium associated with second- to sixth order streams. Unit includes low-lying surfaces 1.0 to 2.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years.
Hfp2A	Holocene Floodplain Alluvium (1.0 to 2.0 m surface)	Holocene	Alluvium	Floodplain	Sandy Loam	(H,a,fp2A,s-l)	Sandy slack-water deposits upstream from Hearthstone Lake. Unit includes low-lying surfaces 1.0-2.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years. Buried root flares common.

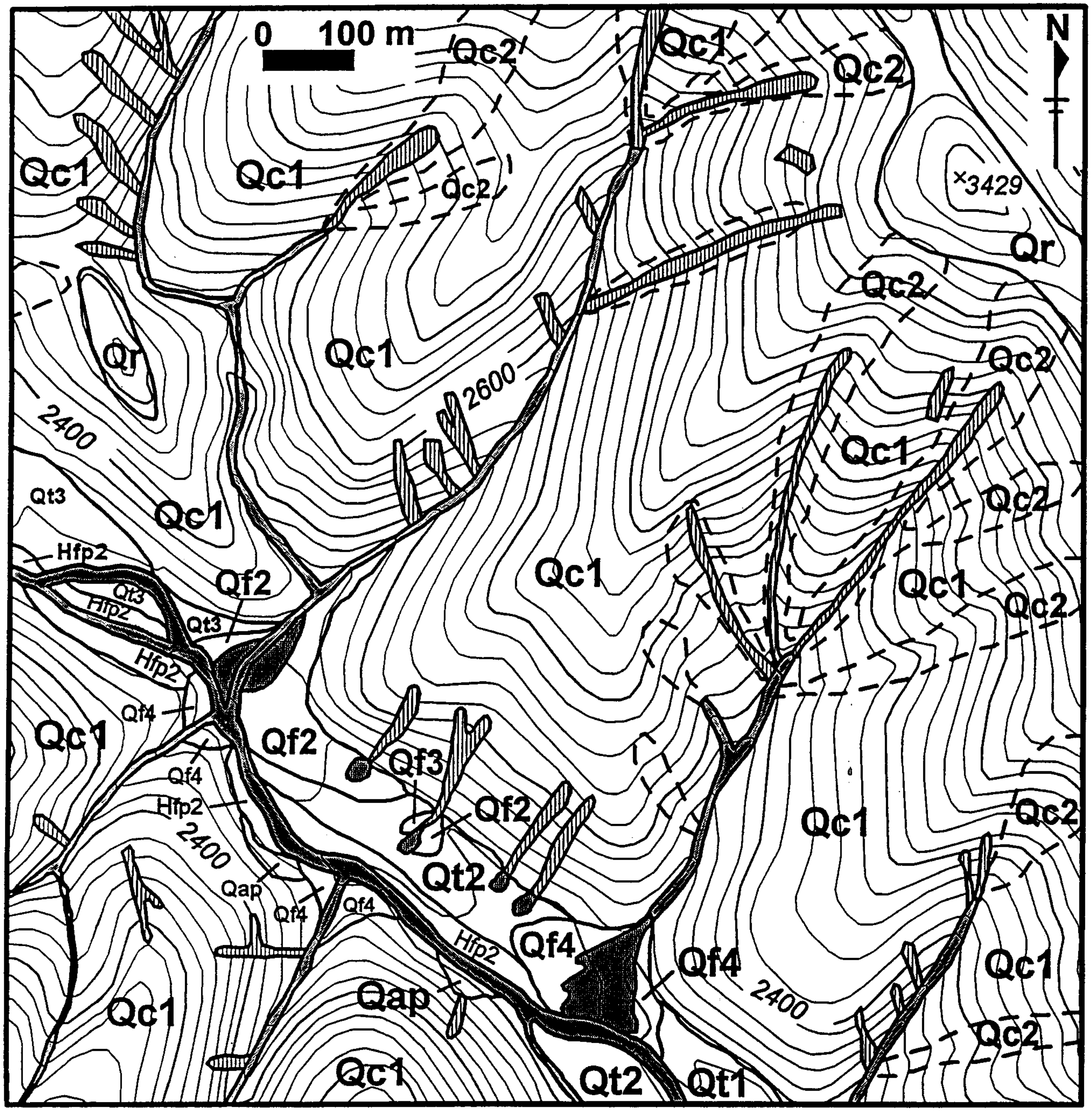
Table 5-3. Example Application of Surficial Map Criteria at the Little River Basin, Augusta County, VA.

Map Unit Label	Map Unit Description	Age	Origin (Process)	Landform	Material (Texture)	Four-Fold Identifier	Comments
Hfp2B	Holocene Floodplain Alluvium (1.0 to 2.0 m surface)	Holocene	Alluvium	Floodplain	Clayey Loam	(H,a,fp2B,cy-l)	Clayey slack-water deposits immediately upstream from Hearthstone Lake. Unit includes low-lying surfaces 1.0-2.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years. Mud cracks and buried root flares common.
Hd	Holocene (Historic) Delta Deposits	Holocene (Historic)	Lacustrine Delta	Delta	Sandy Loam	(H,ld,d,s-l)	Historic lacustrine delta deposits associated with the flood-control reservoir at Hearthstone Lake.
Qt1	Quaternary Low-Terrace Alluvium (2.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace (Floodplain?)	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t1,c-b-pl)	Low-terrace deposits associated with second- to sixth-order streams. Unit includes low terrace surfaces 1.0 to 2.0 m above present channel grade with a flood recurrence interval greater than 5 years.
Qt2	Quaternary Terrace Alluvium (2.0 to 4.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t2,c-b-pl)	Terrace deposits associated with third- to sixth-order streams. Unit includes terrace surfaces 2.0 to 4.0 m above present channel grade.
Qt3	Quaternary Terrace Alluvium (4.0 to 6.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t3,c-b-pl)	Terrace deposits associated with third- to sixth-order streams. Unit includes terrace surfaces 4.0 to 6.0 m above present channel grade.
Qt4	Quaternary Terrace Alluvium (6.0 to 8.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t4,c-b-pl)	Terrace deposits associated with third- to sixth-order streams. Unit includes terrace surfaces 4.0 to 6.0 m above present channel grade.
Hf	Holocene (Historic) Fan Deposits (undissected)	Holocene	Alluvium - Debris Flow(?)	Fan	Cobbles and Boulders, Gravel Diamicton	(H,a-df?,f,c-bdt-l)	Historic fan deposits commonly associated with first to second-order hollows at stream-tributary junctions. Identified by fresh deposits, disturbed and buried vegetation. Primarily the result of June 1949 flood event.
Qf	Quaternary Fan Deposits (undissected)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f,c-bdt-l)	Fan deposits commonly associated with first-order hollows at stream-tributary junctions. Identified by older tree stands and lack of fresh appearance.
Qf1	Quaternary Fan-Terrace Deposits (2.0 to 4.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f1,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.

Table 5-3. Example Application of Surficial Map Criteria at the Little River Basin, Augusta County, VA.

Map Unit Label	Map Unit Description	Age	Origin (Process)	Landform	Material (Texture)	Four-Fold Identifier	Comments
Qf2	Quaternary Fan-Terrace Deposits (4.0 to 6.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f2,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qf3	Quaternary Fan-Terrace Deposits (6.0 to 8.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f3,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qf4	Quaternary Fan-Terrace Deposits (8.0 to 10.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f4,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qf5	Quaternary Fan-Terrace Deposits (>10.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f5,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qap	Quaternary Apron Deposits	Quaternary (Undiff.)	Colluvium	Apron	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,c,ap,c-bdt-l)	Footslope deposits > 2.0 m in thickness. Commonly located at break in gradient between steeper side slopes and valley-bottoms.
Hds	Holocene (Historic) Debris Slide / Flow Scar	Holocene (Historic)	Debris Slide / Debris Flow	Scar	Commonly Scoured to Bedrock	(H,ds/df,sc,rk)	Slide scars associated with the June 1949 flood event. Debris slides transformed into debris flows with attendant erosion of surficial materials to bedrock. Identified by youthful and disturbed vegetation. Bedrock surfaces may be scratched and striated.

Example Surficial Map Product



Surficial Map Units

Qr - Residuum
Qc1 - Colluvium (Side Slopes)
Qc2 - Colluvium (Hollows)
Qt - Terrace Alluvium
Qf - Fan Deposits
Qap - Apron Deposits
Hch - Channel Alluvium
Hf - Historic Fan Deposits
Hfp - Floodplain Alluvium
Hds - Historic Slide Scar

Hillslope Map Units (after Hack and Goodlett, 1960)