Field Guide to the 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 in 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 (Figure 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 comprises a portion of the Willamette Basin in west-central Oregon (Figure 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 (Figure 2). 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 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 proper to the south (Kings Valley) (Figure 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).

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). 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 (Figure 2). 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 1×10^{-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.

The Willamette Valley proper represents a forearc basin situated between the accretionary Coast Range and Cascade Volcanic Arc. The northern Coast Range forms a broad, north-plunging anticlinorium, with pre-Miocene strata dipping eastward across 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. 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; 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 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.

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.

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.

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 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 (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 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).

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).

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 portions of the Luckiamute Watershed. These maps were derived from slope analysis of 30-meter digital elevation models. Preliminary evaluation of the ODF hazard maps indicate that hillslopes underlain by the Tyee Formation are most prone to debris flow (Table 1). 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-Ti	193	24.6	2
Siletz River	151	30.2	3
Spencer-Valley Fill	229	0.7	4

Soil Associations

Geographic Information System (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 comprised 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 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 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 Figures 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 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 m^3/sec, whereas summer months are typified by less than 3 m^3/sec. The two peak discharges of record were observed at 700 and 620 m^3/sec during December 1964 and February 1996, respectively. The 100-yr flood event at the Suver Station is marked by a discharge of 760 m^3/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 1.23×10^9 m^3. 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.

A large portion of the upper Luckiamute is owned by private timber companies and 67% of the watershed is classified as forest. In contrast, the eastern valley section is comprised of 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 OSU CH2M Hill Alumni Center to 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 portion 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 (Figures 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^{o} NW, and is associated with 11 to 13 km of crustal shortening (Yeats and others, 1996). The net result is westward juxtaposition of 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 the 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 (Figures 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 (Figure 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 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)
25.4 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 (Figure 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 (Figure 2).

The falls represent a knickpoint or hydraulic step in the longitudinal profile of the Little Luckiamute. Total knickpoint relief is approximately 6 m (Figure 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 a 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).

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

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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

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.

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 process. The route through this area follows the Luckiamute drainage divide and provides views of Laurel Mountain to the north of the watershed (Figures 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, 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.
49.5 **Stop 4**, road aggregate quarry.

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

Stop 4. Road aggregate quarry

Stop 4 is at a road aggregate quarry set in the Yamhill-Intrusive Domain (Figure 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 forms 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 (Figure 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 situ* 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 situ* chemical alteration, limited transport, and surface stability. Mills and Allison (1995) used clast weathering rinds as a relative dating tool for surficial deposits and 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 (Figure 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, meolachlor, 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 (Figure 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, 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 facility, 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 EPA (Environmental Protection Agency) 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 (Figures 1 and 2). The unnamed tributary and associated wetlands drain eastward towards 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 (Figure 3). Basalt lithofacies are overlain by 10 to 20 m of Pleistocene terrace gravel (Figure 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.
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 foot bridge and pull out on left.

Stop 8. Sulphur Springs (Baker Creek)

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

Sulphur Spring is a low-discharge spring located on the north bank of Soap Creek, directly upstream from the confluence with Baker Creek. The Sulphur Spring locality was a popular recreation area in the late 1800s and early 1900s. Today the site comprises 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 (Figure 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 Spring was compared to that of Soap Creek using a basic set of field parameters, the results of which are shown in Table 4.

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

Field Parameter	Sulphur Spring	Soap Creek
Conductivity (µS)	371	104
pH (S.U.)	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

Field data suggest that water emanating from Sulphur Spring 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 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 site is 0.5 km south of the confluence between Baker Creek and Soap Creek (Figure 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 (Figure 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 (Figure 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. Opening of the forest canopy by geomorphic disturbance results in extensive development of understory vegetation and multi-layered forests (Swanson, 1980). 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 zone during a high-magnitude rainfall event. Increased pore pressure and 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 riparian hydrology. Beaver ponds dramatically decreased average daily discharge of Baker Creek, altering sedimentation patterns, channel geometry, and displacing 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 in western Oregon. The Baker Creek Landslide site represents one of thousands of similar localities in western Oregon and provides a model for 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 Universtiy, 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 Reser Stadium Parking Lot.

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.

ACKNOWLEDGEMENTS

The 2001 Environmental Science Institute (ESI) at Western Oregon University was sponsored by the College of Liberal Arts and Sciences, Division of Extended Programs, and the Oregon Collaborative for the Excellence in Preparation of Teachers (OCEPT). OCEPT is a science-education grant initiative in the state of Oregon hosted by Portland State University and sponsored by the National Science Foundation. Additional funding for field equipment was provided by the PT3 Project (Preparing Tomorrow's Teachers to Use Technology) at Western Oregon University, a campus-wide enterprise supported by the U.S. Department of Education. The M.J. Murdock Trust Partners in Science Program funded a portion of Taylor's work. Jeff Myers is acknowledged for his contributions to the Environmental Science Institute program and development of the paleoclimatology course module. Jeff Templeton, George Moore, and Ellen Moore graciously reviewed draft versions of the manuscript.

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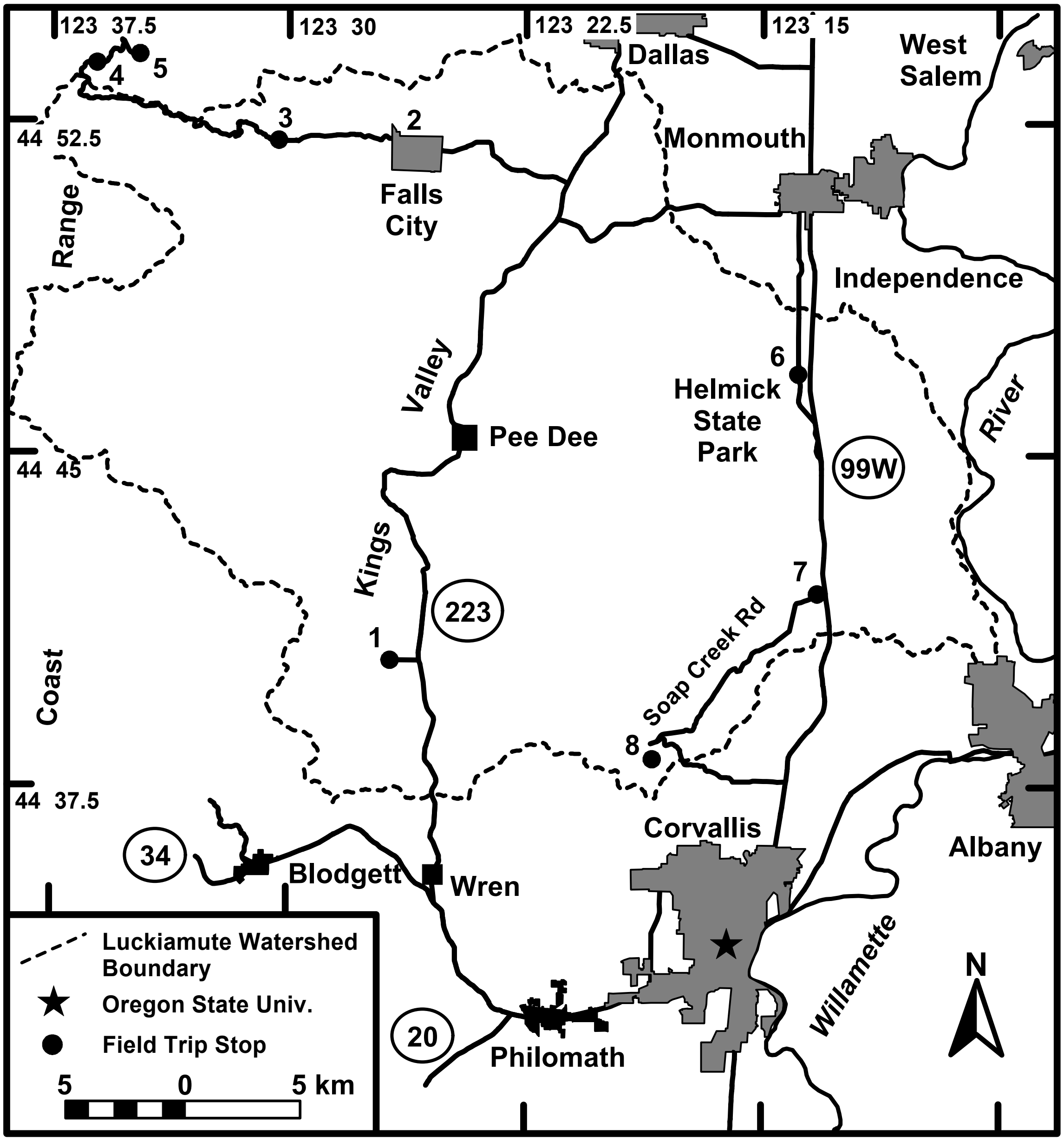

Figure 1. Location map and field trip route for the Luckiamute watershed.

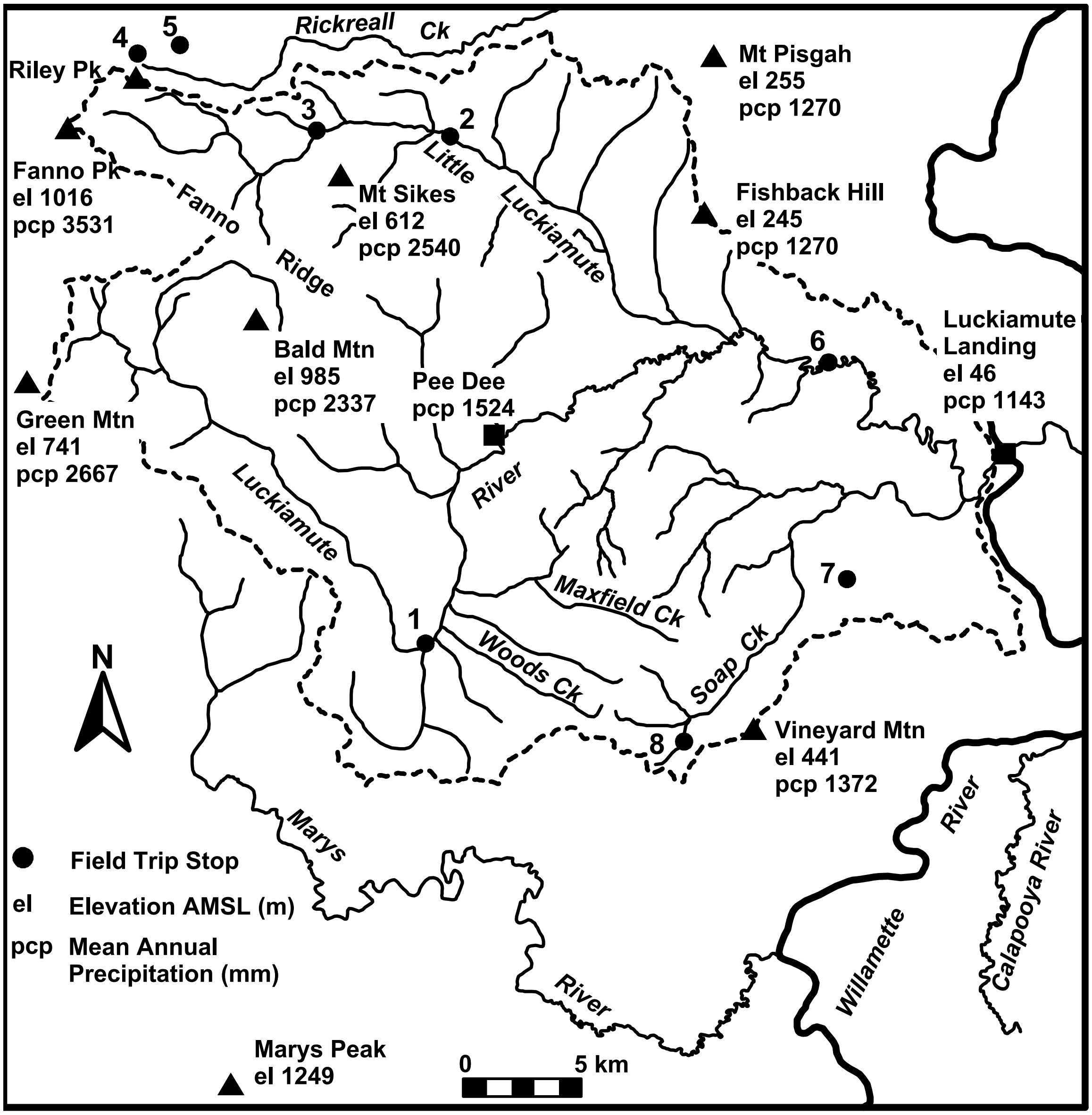

Figure 2. Physiographic map and spot annual precipitation for the Luckiamute Watershed.

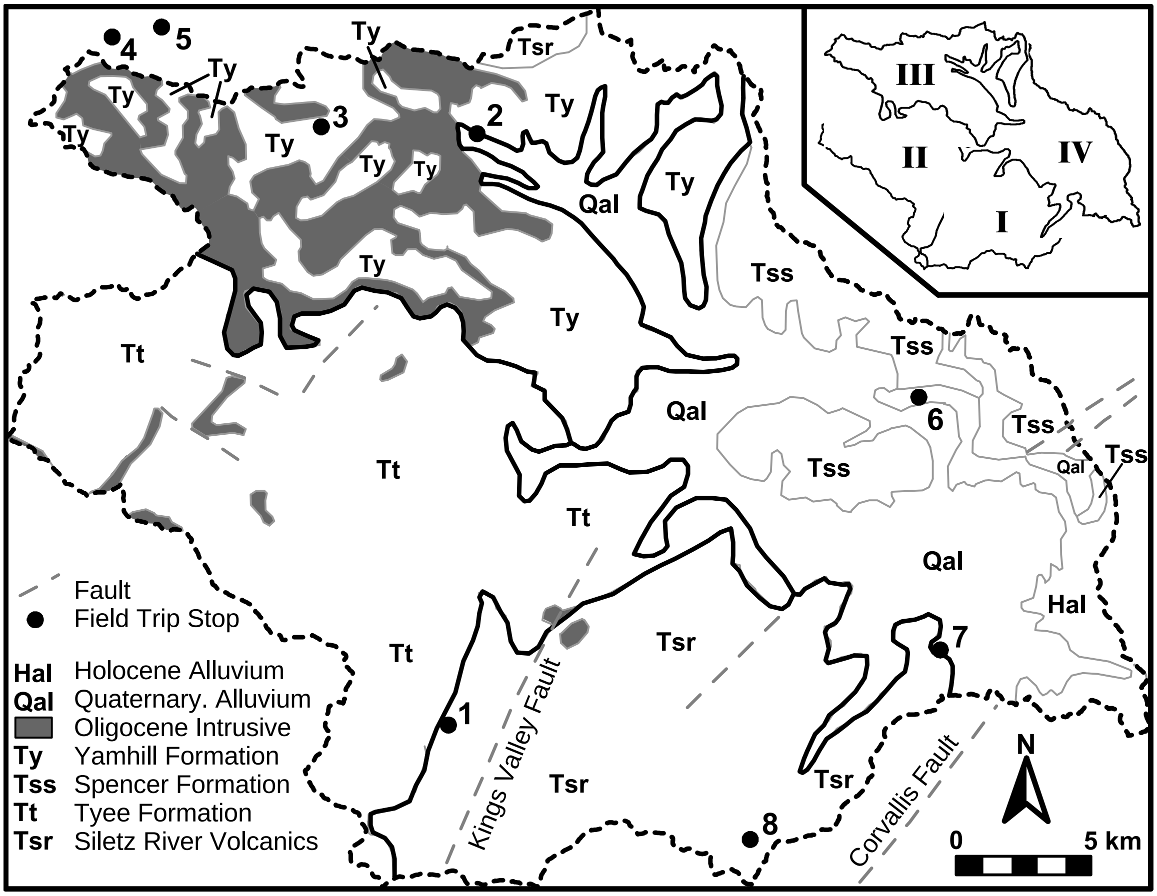

Figure 3. Bedrock geology of the Luckiamute Watershed (after Walker and MacLeod, 1991). Inset map shows grouping of recognized lithospatial domains: I = Siletz River Domain, II = Tyee Domain, III = Yamihill-Ti (Tertiary Intrusive) Domain, IV = Spencer-Valley Fill Domain.

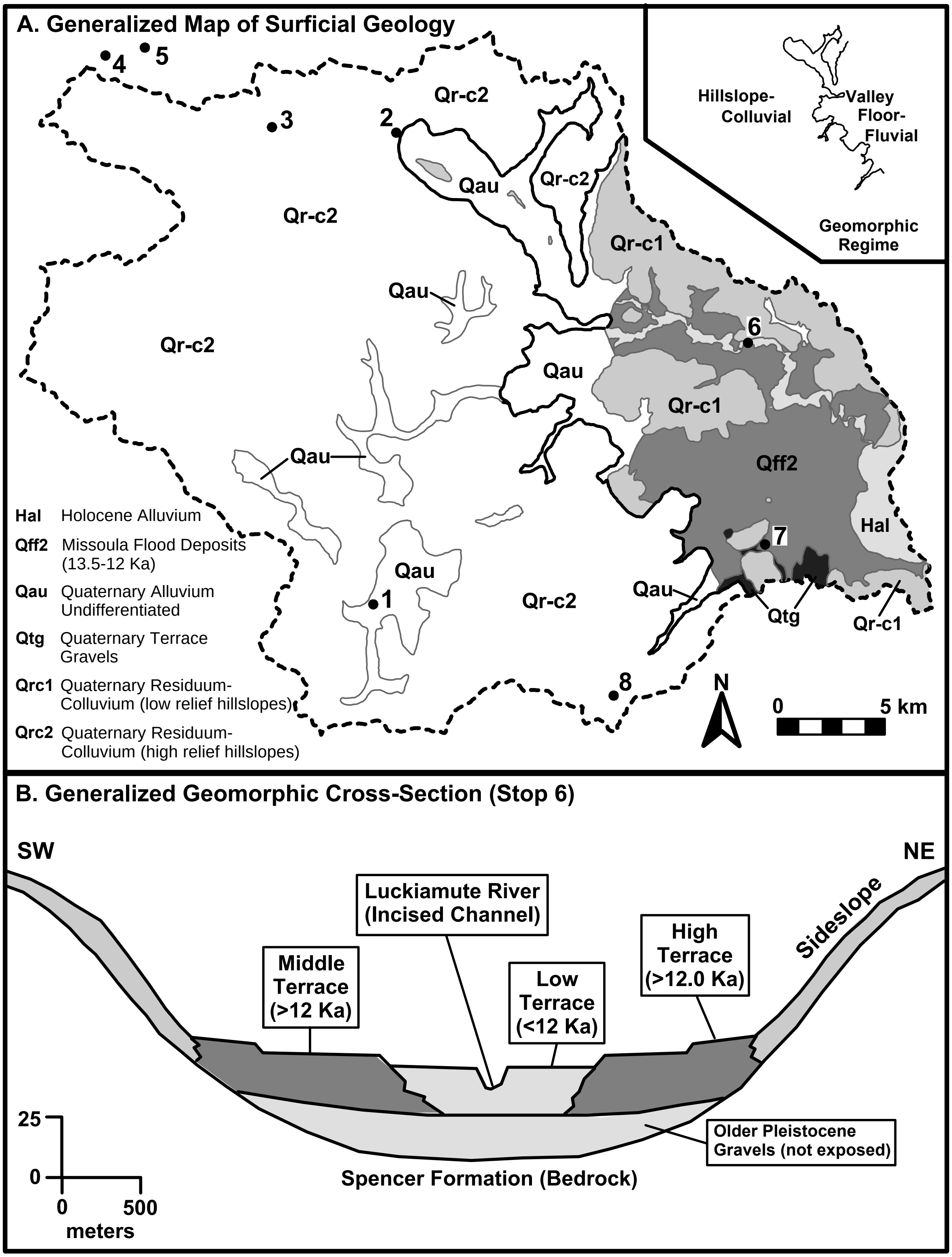

Figure 4. Surficial geology and geomorphology of the Luckiamute River Basin. Surficial map units are modified from O'Connor and others (2001), after Taylor and others (1996). Cross section shown in frame B represents generalized landform elements at Helmick State Park (Stop 6).

Figure 5. Photo of Falls City knickpoint along the Little Luckiamute River, stop 2).

Figure 6. Photo showing overview of Coast Range watersheds and mid-Willamette Valley (view to east from stop 5).

Figure 7. Fresh landslide scar and deposits at Stop 8 along Baker Creek. Note constriction of valley bottom and ponding of drainage.