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

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## 1. ABSTRACT

The Luckiamute River watershed drains 815 km$^2$ 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.

## 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).

### 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 $km^2$ 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 $1.23 \times 10^9$ $m^3$. 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.

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 $1 \times 10^{-8}$ 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; 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.

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

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 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).

### 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 (a = 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.

## 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 Luckiamute (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.

## 8. 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.

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 silstone 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.

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

| Lithospatial Domain | Domain Area (km$^2$) | 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 Luckiamute 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 |

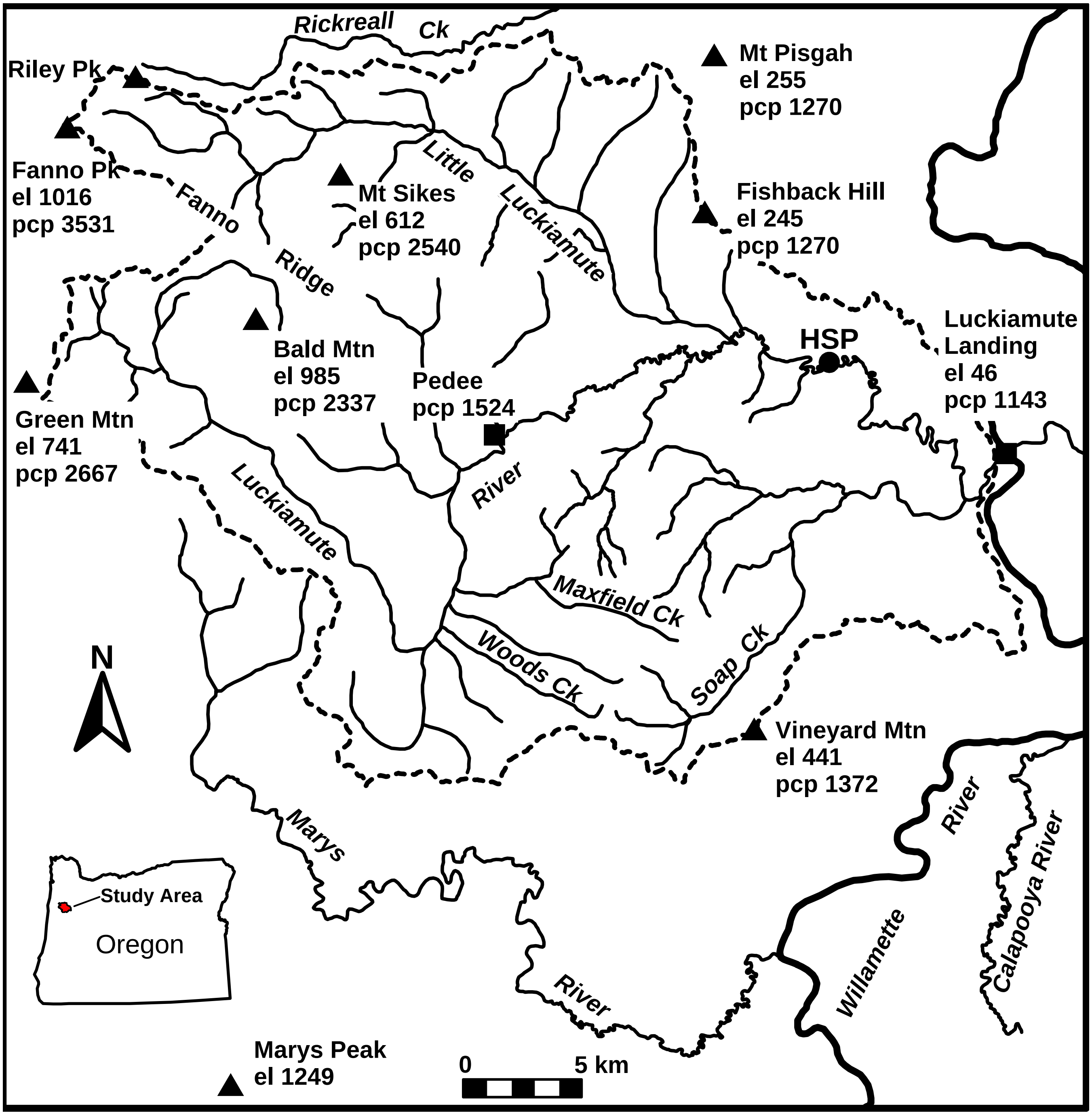

Figure 1. Physiographic map and spot annual precipitation for the Luckiamute Watershed. Abbreviations include el = spot elevation (m), pcp = average annual precipitation (mm), HSP = Helmick State Park (USGS Suver Station 14190500).

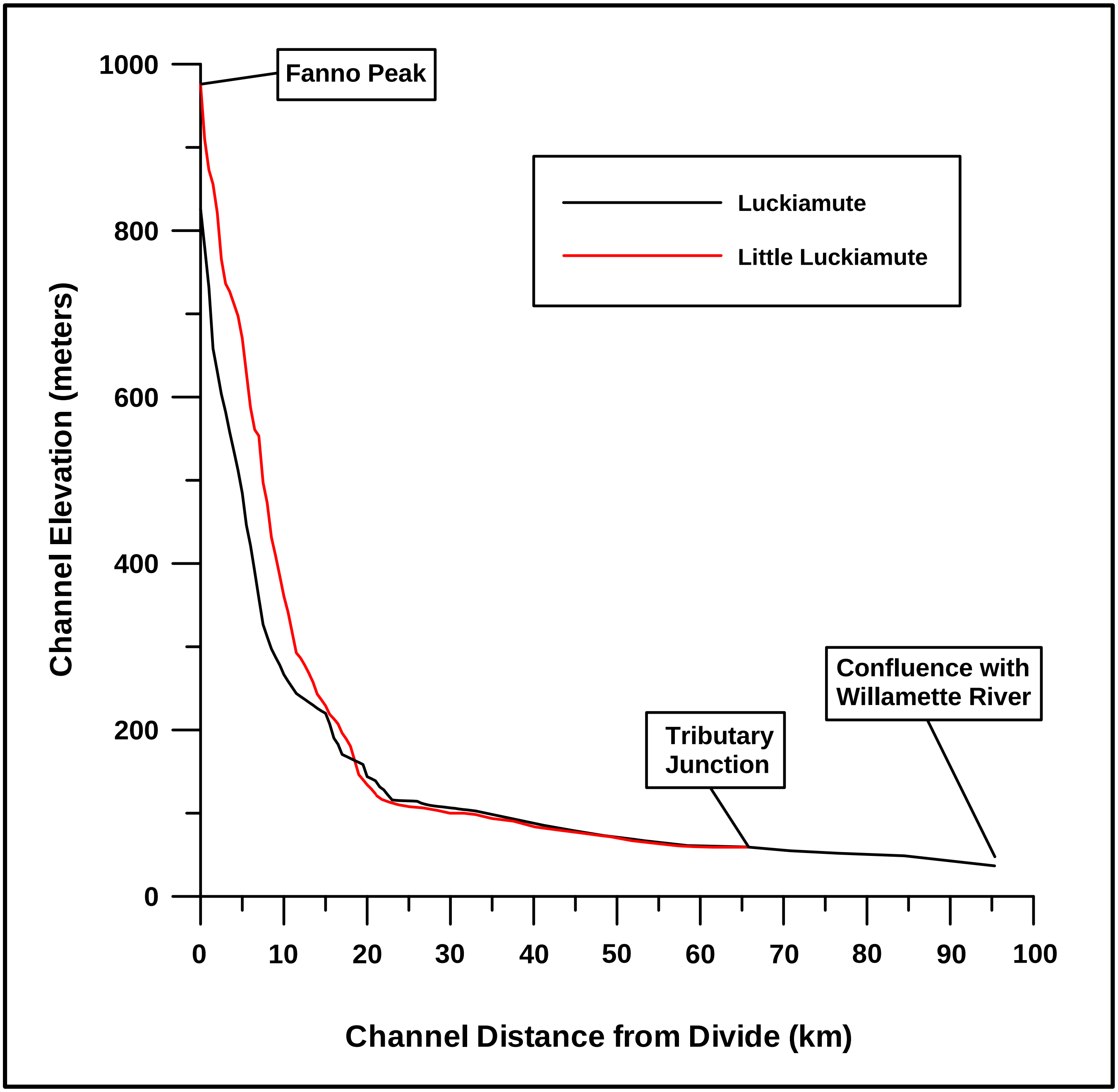

Figure 2. Longitudinal profile and channel gradients of the Luckiamute and Little Luckiamute tributaries.

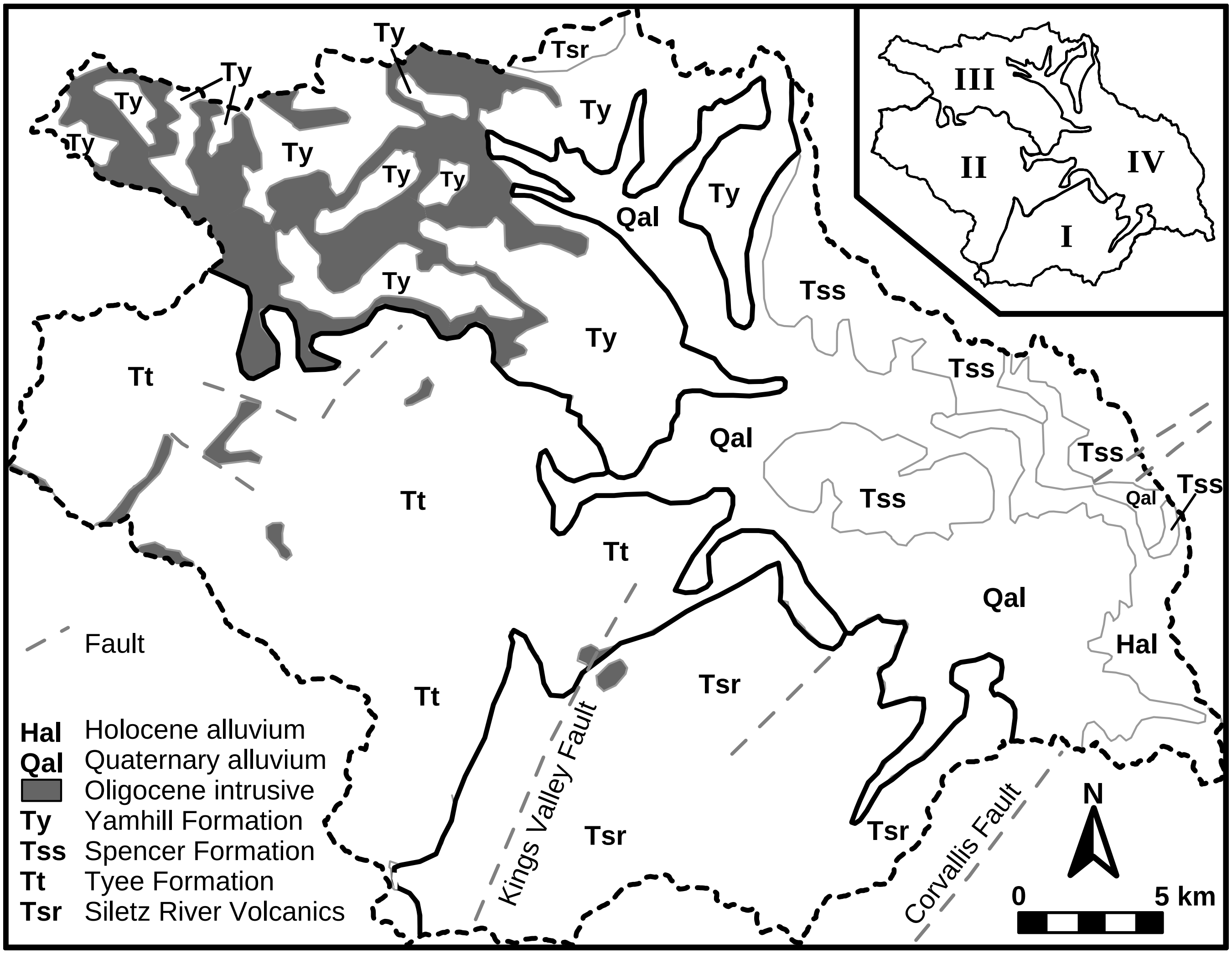

Figure 3. Bedrock geology of the Luckiamute Watershed (after Walker and MacLeod, 1991). Inset map shows grouping of recognized lithospatial domains: I = Siletz River Domain, II = Tyee Domain, III = Yamihill-Ti (Tertiary Intrusive) Domain, IV = Spencer-Valley Fill Domain. See text for discussion.

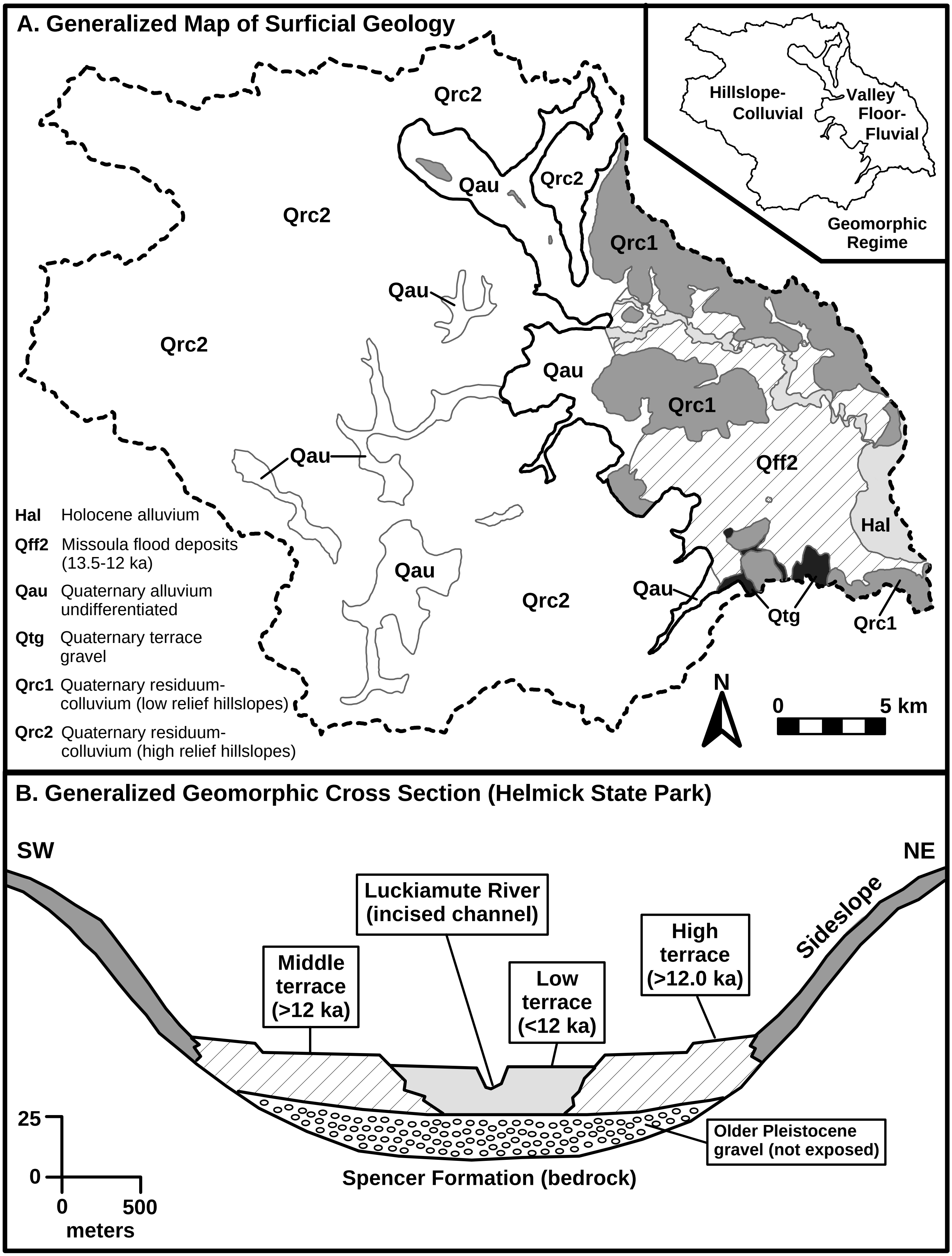

Figure 4. Surficial geology and geomorphology of the Luckiamute River Basin. Surficial map units are modified from O'Connor and others (2001), after Taylor and others (1996). Cross section shown in frame B represents generalized landform elements at Helmick State Park (Location “HSP” on Figure 1).

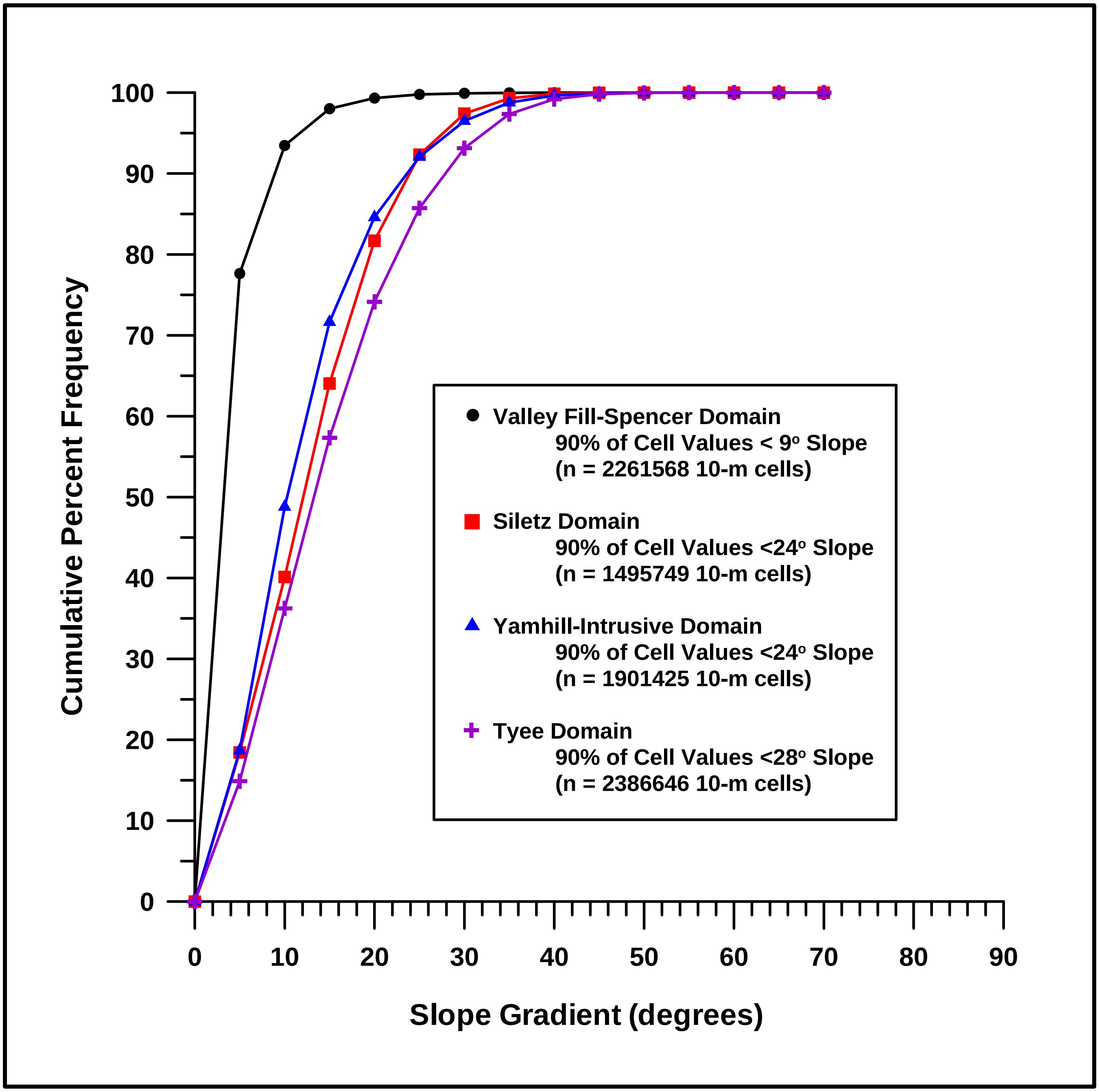

Figure 5. Cumulative percent frequency of slope gradient for the Luckiamute Basin. Data are organized according to lithospatial domain. Systematic t-test analyses (a = 0.01) document that slopes in the Tyee Domain are significantly steeper than those of the other three.

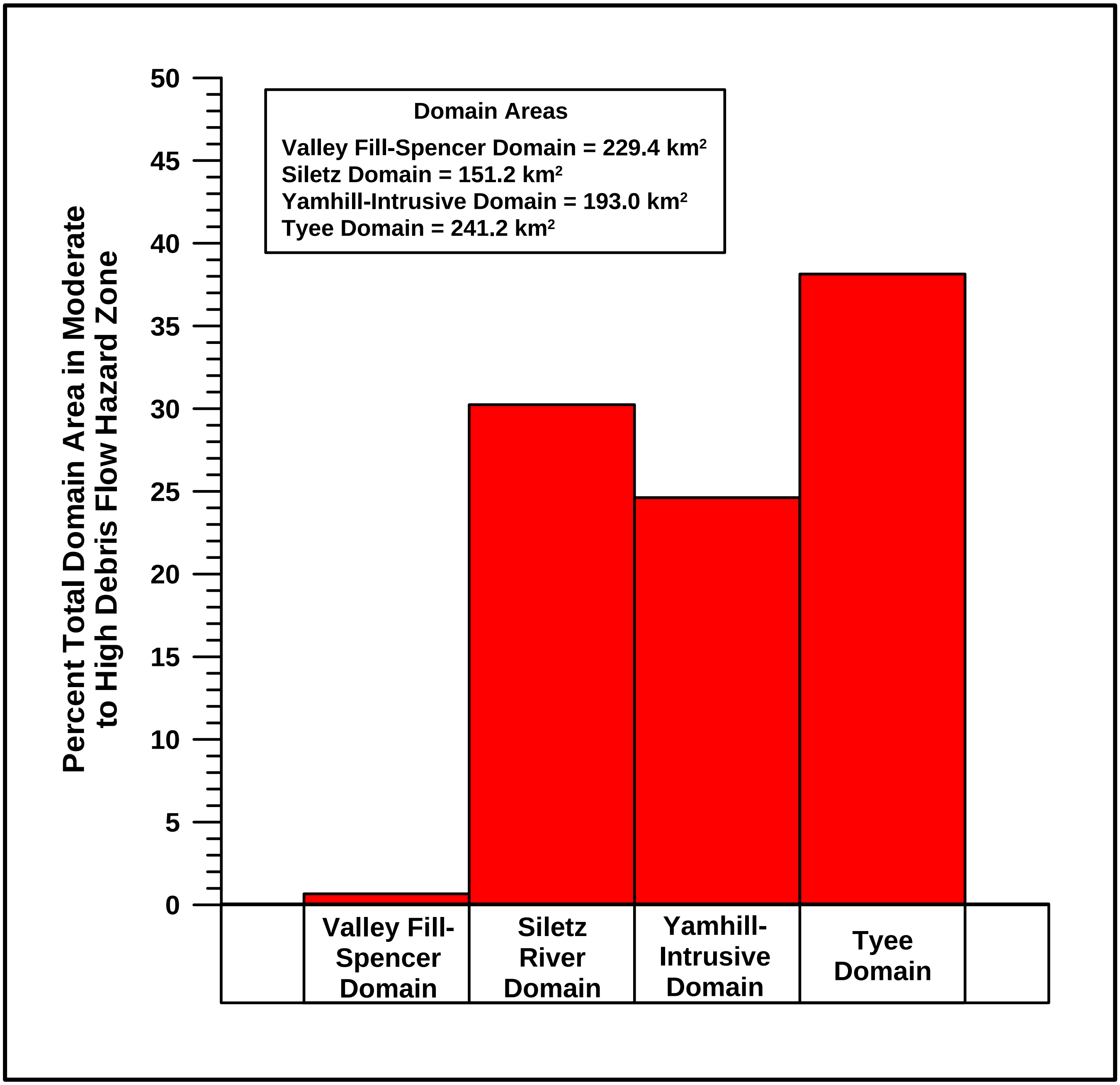

Figure 6. Histogram showing percent of Luckiamute lithospatial domains in the moderate to high debris-flow hazard zones as classified by the Oregon Department of Forestry (ODF, 2000).

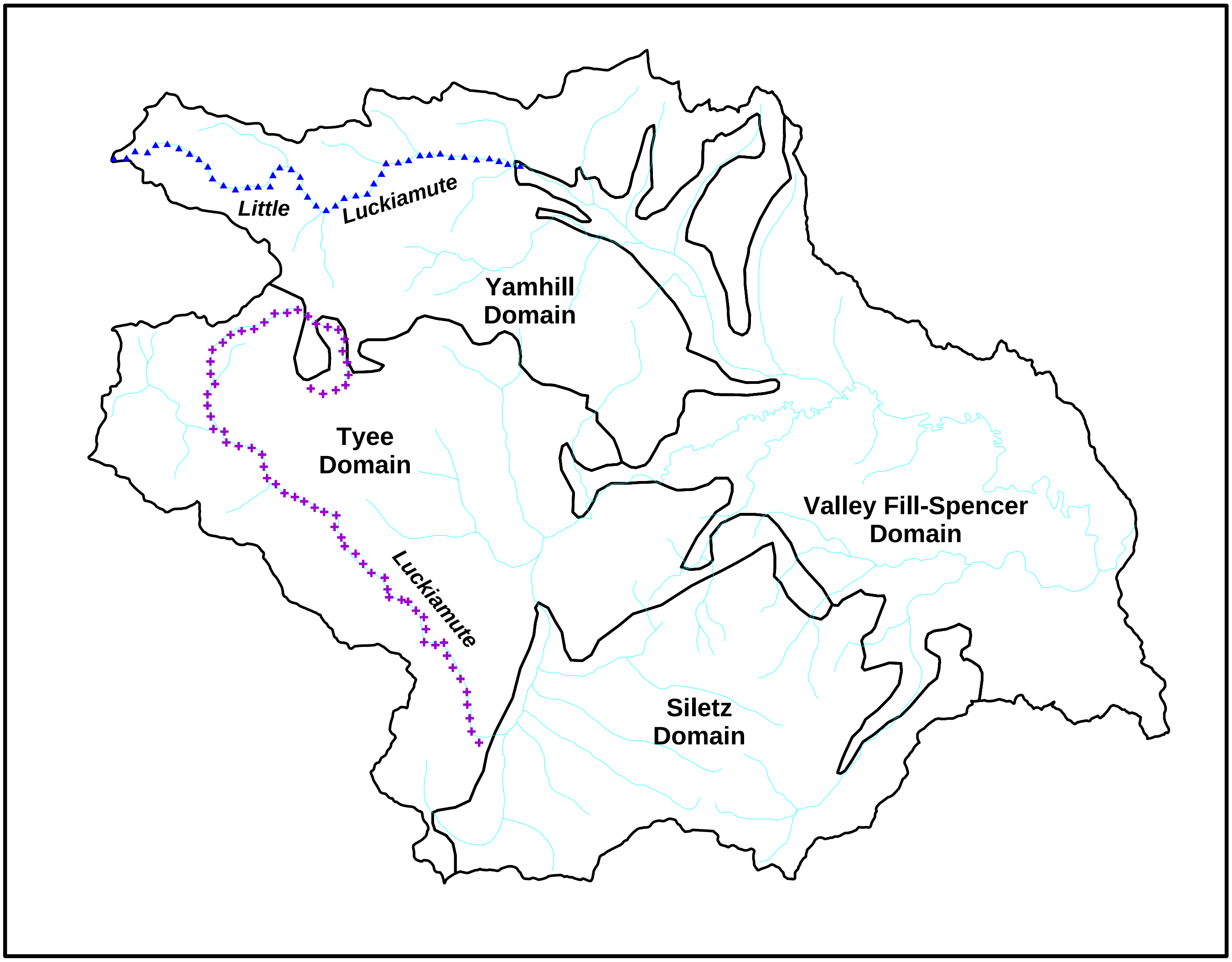

Figure 7A. Map showing sampling distribution (500-m increments) for Luckiamute and Little Luckiamute valley-width data plotted on Figure 7B.

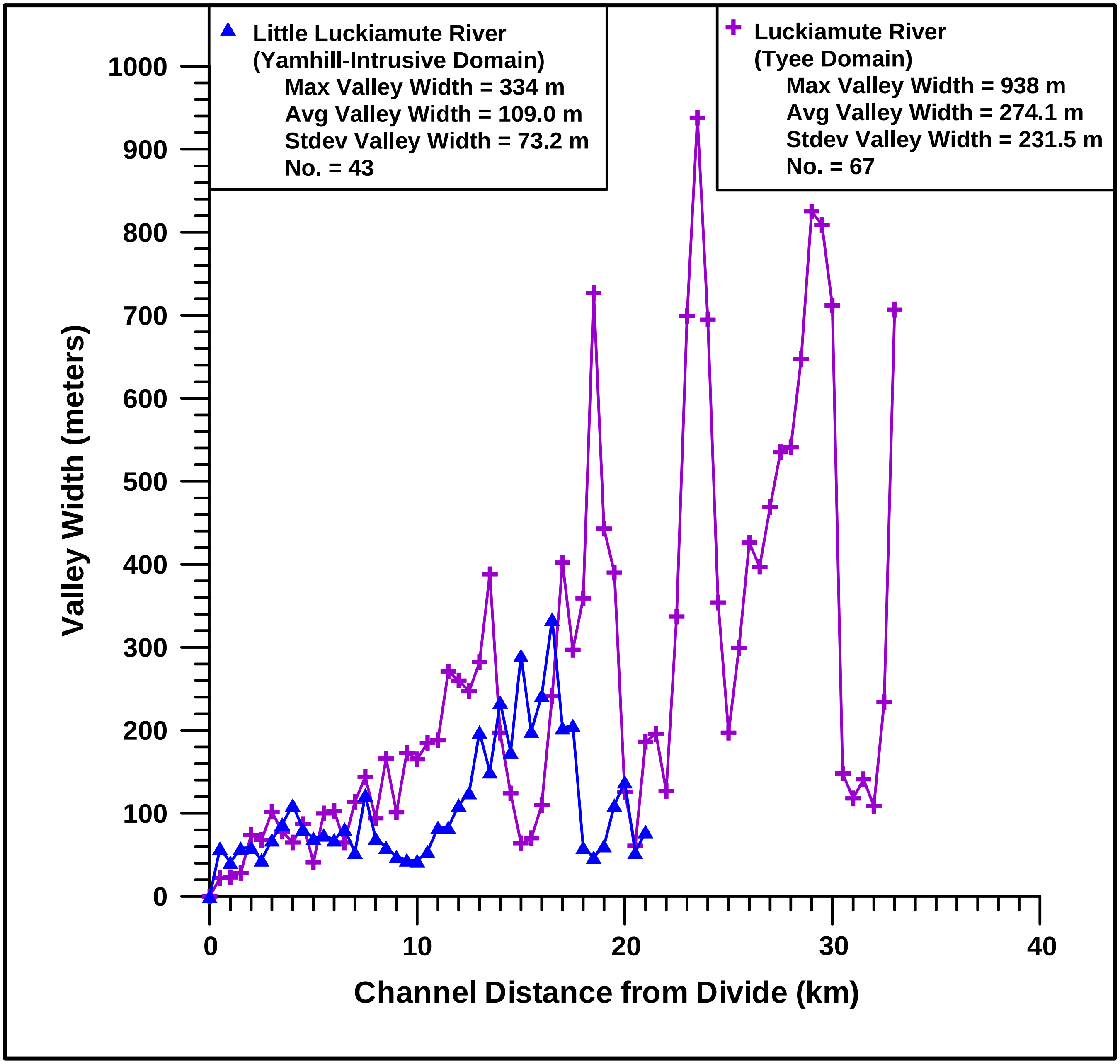

Figure 7B. Plot of valley width (m) vs. channel distance from drainage divide (km) for the Luckiamute and Little Luckiamute tributaries, Tyee and Yamhill lithospatial domains, respectively.