Report for 2004OR48B: Hydrogeomorphic Analysis of the Luckiamute Watershed, Central Coast Range, Oregon:

There are no reported publications resulting from this project.

Report Follows

USGS Mini Grants
FY 2005 Annual Technical Report

Start Date: March 1, 2004 **Original End Date:** February 28, 2005
Extended End Date: February 28, 2006 (No Cost Extension)

Title: Hydrogeomorphic Analysis of the Luckiamute Watershed, Central Coast Range, Oregon: Integrating Applied Watershed Science with Undergraduate Research and Community Outreach

Focus Categories: Education, Geomorphological Processes, Hydrology, Sediments, Water Quality

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Congressional District: Oregon 5th

Abstract:

Mountainous watersheds are fundamental landscape elements that form an important setting for local ecological interactions, human occupation, and water resource development. They also represent the foundational components for mass sediment transfer from continental regions to ocean basins. As such, the understanding of hydrogeomorphic variables and related process interactions is critical for designing sustainable water resource and habitat conservation plans. From the perspective of undergraduate training in the Earth Sciences, watersheds represent the ideal natural laboratory for student application of quantitative techniques to multivariate systems with interdependent process-response mechanisms.

This project involves hydrogeomorphic analysis of the Luckiamute River basin (A_d = 815 km^2) of western Oregon. The Luckiamute is being used as a model watershed to integrate select components of applied research into a sequence of surface-process courses at Western Oregon University (WOU). Faculty and undergraduate Earth Science majors are currently engaged with integrated studies in fluvial geomorphology, environmental geology, hydrology, and GIS analysis. Primary research objectives include: (1) characterization of bedrock control on topography and geomorphic processes in the upper Luckiamute, (2) calculation of valley-bottom sediment storage volumes, as related to item 1 above, (3) characterization of channel-bed composition with respect to sediment-transport functions, and (4) collection and analysis of hydrologic data in the context of geologic and anthropogenic variables.

From a training perspective, the watershed-based curriculum (1) incorporates research into the undergraduate Earth Science program at WOU, (2) engages students in socially-relevant watershed-based science, (3) improves quantitative skills via coursework, lab exercises, and applied research, (4) develops problem-solving and scientific skills within a regional watershed setting, and (5) fosters an interconnected perspective of watershed processes across several linked courses. The research model is placed in the context of community outreach via collaboration with a local watershed council. In addition, final results of this project will contribute to the understanding of upland watershed dynamics in the Pacific Northwest.

As originally proposed, the project timeline was planned to extend over 2 summers and 1.5 academic years to develop the related curriculum modules and complete the proposed research. This

time frame is necessary to offset the persistent teaching commitments related to working at a primarily undergraduate institution. As such, a no cost extension was requested and granted in Spring of 2005, with the mini-grant subcontract extended through February 28, 2006. Status reports and relevant projects links are located at http://www.wou.edu/las/physci/taylor/luck/research.htm. Final results from this study will be posted by January 31, 2006.

Problems and Research Objectives:

Sediment-Transport Dynamics

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).

Taylor (2002) conducted GIS-based analyses in the Luckiamute to elucidate associations between lithospatial domain (i.e. Tyee, Siletz, Yamhill-Intrusive, Spencer-Valley Fill) and slope gradients. The study revealed that the Tyee domain is associated with significantly steeper slopes, wider valley bottoms, and higher occurrence of slope failure compared to the other three domains. Previous studies similarly documented the debris-flow-prone nature of Tyee landscapes in the Oregon Coast Range (e.g. Benda and Dunne, 1987; Mills and Ziolko, 2002). Taylor (2002) postulated that the comparatively steep slopes and wide valley bottoms in the Tyee domain are associated with hillslope transport rates greater than the ability of the channel system to export sediment. The model suggests a net deficit of unit stream power along the higher-order portions of the Luckiamute tributary. As slope gradients and valley-width morphology vary according to lithospatial domain, 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. A portion of the work will test this hypothesis via large-scale surficial mapping, channel-reach characterization, and sediment-storage volume estimates.

Water Quality and Hydrogeology

The relationship between land use and water-quality degradation in the Willamette Valley is well documented (Wentz and others; 1998). 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. The greatest potential for water-quality degradation in the lower Luckiamute is from fertilizer-related nitrates, pesticides (herbicides, insecticides, and fungicides), and high concentrations of suspended sediment. Available surface water quality data for the Luckiamute Basin is limited to a few select field parameters (e.g. turbidity, dissolved oxygen, pH, conductivity) that were collected mostly in the late 1960's and early 1970's (Oregon Dept. of Environmental Quality, 2003). The most consistent water data are associated with the Soap Creek tributary near Coffin Butte Landfill, Benton County. Given the relative paucity of data and lack of a systematic sampling distribution, little is known about the effects of anthropogenic activity and regional geology on surface-water quality in the Luckiamute Watershed. In addition, detailed quantitative analyses of Luckiamute aquifer systems are needed to delineate the physical and chemical nature of hydrogeologic processes in the basin. A significant component of the work plan addresses these needs and calls for systematic hydrologic analysis throughout the Luckiamute basin.

Undergraduate Training

Integrating undergraduate research and education in the sciences is recognized as an important model for preparing students to participate in the 21st century workforce (National Science Foundation, 2003). College graduates are increasingly required to understand complex integrated systems by applying multi-disciplinary problem solving skills. As such, there is a general lack of linked science curricula in which students systematically build a set of problem-solving skills that are applied to a real-world problem (Heins and Walker, 1998). Watershed systems represent the interaction of physical and biological processes at spatial and temporal scales that are highly relevant to the community at large (Woltemade and Blewett, 2002). This project will serve as a framework for undergraduate training in applied fluvial geomorphlogy, environmental geology, and watershed science at Western Oregon University.

Project Goals And Objectives

The purpose of this project is to integrate research, undergraduate education, curriculum development, and community outreach with watershed science as a unifying theme. The Luckiamute Watershed is being used as a natural laboratory for integrated studies in fluvial geomorphology, environmental geology, hydrology, and GIS analysis. The scientific objective of this project is to contribute to the understanding of mountainous watershed dynamics in the Pacific Northwest. Primary research objectives include: (1) characterization of bedrock control on topography and geomorphic processes in the upper Luckiamute, (2) calculation of valley-bottom sediment storage volumes, as related to item 1 above, (3) characterization of channel-bed composition with respect to sediment-transport functions, and (4) collection and analysis of water quality data in the context of geologic and anthropogenic variables.

From a training perspective, the proposed watershed-based curriculum will (1) incorporate research into the undergraduate Earth Science program at WOU, (2) engage students in socially-relevant watershed-based science (e.g. Woltemade and Blewett, 2002), (3) improve quantitative skills via coursework, lab exercises, and applied research, (4) develop problem-solving and scientific skills within a regional watershed setting, and (5) foster an interconnected perspective of watershed processes across several linked courses.

Methods, Procedures, and Facilities:

Proposed research activities focus on hydrogeomorphic assessment of the Luckiamute Watershed, explicit action items include:

(1) Design and implementation of undergraduate research modules in a series of Earth Science courses at WOU: G322 Geomorphology, G473 Environmental Geology, G476 Hydrology, and G492 GIS Applications in Earth Science.

(2) Weave select portions of Earth Science course curricula with assessment and monitoring activities associated with the Luckiamute Watershed Council.

(3) Creating linked research modules in the courses listed above, each focusing on different aspects of the Luckiamute Watershed:

   (A) G322 Geomorphology: Assessment of valley-bottom sediment storage volumes, sediment-transport efficiency, and channel bed composition.
      (i) Surficial mapping of Luckiamute valley bottom
      (ii) Channel reach characterization
   (B) G473 Environmental Geology: Assessment of surface water quality and land-use impacts in the Luckiamute basin.
      (i) Baseline water quality monitoring
      (ii) Land use analysis
   (C) G476 Hydrology: Characterization of drainage composition and slope-area relationships in the context of bedrock associations
      (i) Morphometric analyses
   (D) G492 GIS Applications: Compilation of geospatial products.
      (i) Building spatial data bases
      (ii) Assembling web-based GIS products

(4) Cultivate community involvement via advisory panel meetings with Luckiamute stakeholders and students.

(5) Web-based dissemination of research products.

Geomorphic Techniques

Surficial mapping techniques follow those presented by Taylor and others (1996) for mountainous landscapes. Valley-bottom storage compartments (channel, floodplain, terrace, fan) are the focus as they reflect the ability of watersheds to export sediment. Detailed surficial mapping, with measurement of surface heights above channel grade, allow first-order approximation of valley-bottom storage volumes. Channel-reach surveys include: (1) channel classification (after Rosgen, 1994; Kondolf, 1995; Montgomery and Buffington, 1997), (2) clast-size analysis (after Wolman, 1954 and Hack, 1957), (3) measurement of bankful stage, gradient, channel width, total valley width, and (4) spatial distribution of bedrock-alluvium reaches (after Montgomery and others, 1996). Morphometric analyses and slope-area relationships are being analyzed using GIS, as modified from procedures outlined by Hack (1957), Strahler (1957), and Dalla Fontana and Marchi (2003). Volume estimates are examined in tandem with clast-size analysis, bedrock-channel distribution, and slope-area relationships to make inferences regarding controls on long-term sediment-transport efficiency.

Hydrologic Analysis

Surface water quality and aquifer systems are currently being evaluated by extrapolation of existing data from available state and federal databases. Database extrapolation will allow derivation of an initial assessment from which to devise a more extensive, field-based sampling strategy. GIS anayses will be used to identify associations between water quality, land use, and geologic setting.

Data Compilation-Dissemination-Community Outreach

All data and reports completed as part of this project are being compiled and distributed via internet technologies (refer to URL: http://www.wou.edu/las/physci/taylor/luck/research.htm. The project web site is the primary information source for students and watershed stakeholders. Spatial data are being compiled into a GIS and distributed via a dedicated map-server housed at Western Oregon University. Research results and related curriculum products are being disseminated by presentation at national geoscience meetings (e.g. Taylor, 2005).

Principal Findings and Significance:

As stated above, the project is still in progress and is extended through February 2006. However the following provides a status summary of findings achieved thus far:

Lithologic Controls on Watershed Morphology

Studies in the Oregon Coast Range have yielded numerous contributions to the understanding of mountain river systems. Published research topics include sediment budget analysis, sediment transport models, debris flow dynamics, hillslope hydrology, landslide risk modelling, effects of punctuated sediment supply, landscape evolution, and tectonic controls on bedrock erosion rates. While this rich body of work has significantly improved our geomorphic understanding of mountain river systems, most studies have been limited to landscapes underlain by bedrock of the Eocene Tyee Formation. Few studies have been conducted in portions of the Oregon Coast Range underlain by other lithostratigraphic units. Work in other bedrock domains is needed to assess the applicability of existing models to other Coast Range landscapes. This study involves comparative morphometric analysis of HUC 6^{th} field watersheds, using Tyee-based landscapes as a benchmark for comparison with other bedrock types in the central Oregon Coast Range.

The Luckiamute River watershed drains 815 km^2 along the east flank of the Coast Range in west-central Oregon. 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 Spencer-Valley Fill 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 Spencer-Valley Fill 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 Spencer Domain.

Fourth-order subbasins (n = 5-6, avg. Ad = 16 km^2) were selected from each bedrock domain for subsequent terrain analysis of USGS 10-meter DEMs. Averaged quantitative parameters for the Spencer, Siletz, Yamhill, and Tyee domains include, respectively: **(1)** hypsometric integral (0.30, 0.40, 0.48, 0.29), **(2)** basin ruggedness (0.2, 1.2, 1.1, 1.6), **(3)** total drainage density (1.4, 2.3, 2.0, 2.4 km^{-1}), **(4)** Shreve magnitude (14, 49, 31, 55), **(5)** first-order stream density (0.7, 1.2, 1.0, 1.2 km^{-1}), **(6)** channel gradients (0.04, 0.13, 0.18, 0.14), **(7)** stream power index (69, 1909, 2534, 1133), **(8)** hillslope gradients (3.2, 12.7, 11.9, and 14.5 degrees), and **(9)** hillslope profile curvature (0.004, 0.008, 0.007, 0.011 m/deg). The Tyee Domain is more finely dissected by low-order stream channels and associated with more rugged hillslopes compared to the other three 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 higher-order valley widths at 500 m increments shows that trunk drainage across the Tyee Domain covers a much wider swath of valley floor (avg. W_v = 274 m) compared to a similar-sized drainage area in the Yamhill Domain (avg. W_v = 109 m). Stream power parameters suggest that while Tyee drainages are more energetic than the Spencer system, they are less potentially less effective at sediment transport than the other upland domains. These data suggest that bedrock lithology exerts a strong control on hillslope morphology, style of hillslope process, and sediment-transport efficiency 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. The rich body of work from other Tyee-based landscapes in the Oregon Coast Range will serve as the platform from which to extend future research in the Luckiamute to other bedrock domains.

Hydrogeologic Setting

Gannet and Caldwell (1998) and Woodward et al. (1998) delineated the principle hydrostratigraphic units in the Southern Willamette Basin. In ascending order these include: (1) basement confining unit (BCU), (2) Willamette confining unit (WCU), (3) Willamette aquifer (WAq), and (4) Willamette Silt (WS). The lowermost unit is represented by indurated bedrock, while the latter three are comprised of unconsolidated alluvium and valley-fill sediments. Alluvial-fill thickness in the lower Luckiamute and Ash Creek sub-basins ranges up to 30 m (100 ft) with most localities in the 12 to 24 m (40 to 80 ft) range. Luckiamute alluvial-fill thickens to the east towards the center of the Willamette Valley, and thins upstream to a minimum near the communities of Falls City and Pedee (Caldwell, 1993; Gannett and Caldwell, 1998).

The basement confining unit is composed predominantly of Tertiary marine sedimentary rocks and related submarine basalts. This unit is characterized by relatively low permeability lithofacies with intermixed low-yield aquifer horizons and aquitards. In the lower Luckiamute and Ash Creek subbasins, BCU is composed largely of Spencer Formation strata. The Siletz River Volcanics form the basement unit in the southern portion of the watershed, along Soap Creek.

The Willamette confining unit is composed of unconsolidated fine-grained fluvial facies deposited by low-gradient streams during the Pleistocene. Drilling logs commonly refer to this unit as “blue clay”, “silty clay” or “shale", containing laterally discontinous sandy and gravelly interbeds. WCU is characterized by limited ground water production, however coarse-grained interbeds locally serve as aquifers. Regional yields from wells set in this unit range from 2 to 10 gallons per minute. WCU thickness in the study area ranges from a maximum of 18 m (60 ft) at Luckiamute Landing, to less than 6 m (20 ft) upstream of Helmick State Park. The Willamette confining unit is less than 18 m (60 ft) thick in the Ash Creek subbasin.

The Willamette aquifer is composed of coarse-grained facies associated with Pleistocene alluvial fans and deposits of smaller side tributaries. This unit was referred to as the "Linn Gravel" by

Allison (1953). It is characterized by thick-bedded sand and gravel facies with thin interbeds of fine-grained sand, silt and clay. WAq is locally cemented and partially indurated. Regionally, the Willamette aquifer is formed by fluvio-glacial outwash from large drainage systems in the Cascades that debouch westward onto the valley floor. Given lower summit elevations, the Coast Range was not glaciated during the Pleistocene. Thus eastward-draining tributaries to the Willamette, including the Luckiamute, tend to be smaller in area compared to those of the western Cascades, and are not associated with high-volume fluvio-glacial aquifer systems. The lower end of the Luckiamute lies approximately 30 km (18 mi) west of the Stayton and Lebanon fans, deposits of the North and South Santiam Rivers, respectively. Given the distal position of the Luckiamute in relation to large fan deposits, WAq gravels in the watershed are generally less than 6 m (20 ft) thick and are likely composed of sediments derived locally from Coast Range sources.

The Willamette Silt is the uppermost valley-fill unit and is comprised of late Pleistocene Missoula Flood deposits (map unit Qff2 of O'Connor and others, 2001). Fine-grained clay, silty clay, and silt occurs up to an elevation of 120 m (400 ft) in Luckiamute Basin and is less than 6 to 9 m (20 to 30 ft) thick. This unit serves as a semi-confining aquitard for the Willamette aquifer, however it is partly saturated and is commonly associated with water table conditions throughout much of the Willamette Basin.

In addition to the valley ground-water system, a significant portion of the Luckiamute is served by upland bedrock aquifer horizons set in strata of the Siletz River Volcanics, Tyee Formation, Yamhill Formation, and Oligocene Intrusives. Crystalline volcanic and intrusive rocks have inherently low porosity and permeability, but secondary fracture porosity can be significant (Freeze and Cherry, 1979). In the case of the Siletz River basalts, low-grade alteration and secondary zeolitization has likely resulted in significant reduction of hydraulic conductivity. Similary, the fine-grained nature of the Tyee and Yamhill formations makes them of limited value as aquifer material.

Hydrogeologic data were collected from field-located wells as part of the Willamette Regional Aquifer Systems Analysis (RASA) conducted by the U.S. Geological Survey (Woodward and others, 1998; Gannett and Caldwell,1998). Approximately 40% of well heads are located in unconsolidated valley-fill alluvium, with 60% situated in basement-confining or upland bedrock units. Given that maximum alluvial fill in the Luckiamute-Ash Creek basins is generally less than 30 m (100 ft), all of the wells in the inventory have bottom depths situated in the basement-confining or upland bedrock aquifers. Average depth relations reveal that the bedrock wells have greater total depths and lower static water level elevations compared to wells situated on valley fill. Although quantitative hydraulic analyses are lacking in the Luckiamute, Gonthier (1983) documented hydraulic conductivities in the range of 0.2 to 0.3 ft/day for the Dallas-Monmouth Area. Accordingly, the average specific capacity for wells ranges from <1 to 7 gallons per minute per foot of drawdown (Woodward and others, 1998).

The Spencer-Valley Fill domain in the Luckiamute forms part of the regional Willamette aquifer system which is generally associated with unconfined potentiometric conditions. Valley-fill aquifers in the Ash Creek subbasin are hydrogeologically separated from the Luckiamute by a hydraulic divide comprised of low-permeability lithofacies in the Spencer Formation (basement confining unit of Gannett and Caldwell, 1998). The lower Luckiamute valley-fill aquifer system is characterized by eastward ground water flow and hydraulic gradients on the order of 5 ft/mi (Woodward and others, 1998). Unconsolidated valley fill is more prevalent in the Ash Creek subbasin with eastward-directed hydraulic gradients of 20 ft/mi (Caldwell, 1993). Regionally, seepage velocity in the Willamette aquifer ranges from 3 to 30 ft / day, comparable to other coarse-grained aquifers. Iverson and Haggerty (2002) are conducting ongoing research in the Willamette Silt to determine hydraulic and geochemical properties. The results of their preliminary work along the Pudding River suggests that WS serves as a confining unit to the underlying Waq. Horizontal hydraulic conductivities are on the order of 0.004 to 5.53 ft/day, with vertical permeabilities of 0.008 ft/day and porosity of 40%.

Natural ground water quality ranges from good to poor in the Luckiamute-Ash Creek subbasins. Caldwell (1993) documented localized high salinity concentrations in the Monmouth-Independence area. His study utilized trace element analyses to relate bedrock mineralogy to ground water residence times and salinity contamination risk. The results indicate that ground water in the region is associated with chloride-dominant ionic species ($CaCl_2$ and NaCl) and poses a potential water quality hazard. It is interpreted that increased salinity levels are derived from connate brine waters trapped in Tertiary marine sedimentary rocks. This saline water mixes with shallow ground water via upward migration along folds and faults in the basement confining units. Preliminary analyses of water quality data to the south indicate that similar salinity conditions may also be present in Luckiamute aquifers. Detailed quantitative analyses of Luckiamute aquifer systems are needed to delineate the physical and chemical nature of hydrogeologic processes in the basin.

Training and Support:

4 undergraduate students at WOU have been / are being supported by this project as research assistants:

Jeff Budnick, B.S. Earth Science (expected graduation June 2005)
Chandra Drury, B.S. Earth Science (expected graduation December 2005)
Jamie Fisher, B.S. Earth Science (expected graduation December 2005)
Diane Hale, B.S. Physical Geography (August 2004)

The watershed coordinator at the Luckiamute Watershed Council is being trained and supported by this project as a research associate: Eve Montanaro (B.S. Physical Geography, 2002, University of Oregon)

Publications, Reports, Presentations, and Spin-off Grant Proposals:

Taylor, 2005, In Preparation, Lithologic Controls on Watershed Morphology in the Central Oregon Coast Range: to be submitted to *Geomorphology*.

Taylor, S.B., 2005, Lithologic Controls on Watershed Morphology in the Central Oregon Coast Range: Towards Extrapolation of Tyee-Based Models to Other Bedrock Types – Mountain Rivers Session: Association of American Geographers, Abstracts with Programs, Annual Meeting, Denver.

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