Geomorphology and Hydrology of the H.J. Andrews Experimental Forest, Blue River, Oregon

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INTRODUCTION

The H.J. Andrews Experimental Forest is the Lookout Creek watershed (6400 ha) draining westward from the western Cascade Range about 80 km east of Eugene, Oregon. The experimental forest has been the site of applied forestry research since its establishment in 1948. During the 1970s , research on forest and stream ecosystems flourished as the Andrews Forest served as one of the Coniferous Forest Biome sites within the International Biological Program (IBP). In 1980 the forest became one of the first Long-Term Ecological Research (LTER) sites funded by the National Science Foundation. The central question of the LTER program has been: How do land use (principally roads, forest cutting, and regrowth), natural disturbances (principally wildfires and floods), and climate variability affect key ecosystem properties, mainly carbon dynamics, hydrology, and elements of biologic diversity?

Research at the forest spans many disciplines, including forest and stream ecology, entomology, social science, and many aspects of the earth sciences. Much of the work is focused within the confines of a disciplinary view of the world, yet synthesis and interaction occurs among the disciplines. Consideration of ecosystem structure and function in the context of long-term change imposed by land use, natural disturbances, and recovery processes such as biotic succession, has been an important medium for interdisciplinary thinking (Swanson et al., 1997).

Andrews Forest has been a base of hydrology, geomorphology, and biogeochemical cycling research since the 1960s. The initial stage for these studies was set in 1953 with establishment of experimental watersheds 1, 2, and 3 (Table 1, Fig. 1) and the gauging of Lookout Creek and Blue River, which began in 1949. Over time, work on these topics intensified within the small watersheds and also shifted to finer scale plot experiments and broader scale whole-forest and regional watersheds. The present resurgence of interest in small, experimental watershed studies at the forest is accelerating and is modernizing work on each of these themes.

Hydrology research in the early years at the forest focused on quantifying components of the hydrologic system and assessing initial effects of roads and forest cutting on runoff (Rothacher, 1963, 1970). This work intensified during the IBP with modeling (Waring and Running, 1976), tree physiology (Waring et al., 1977), hillslope hydrology (Harr, 1977), and several other research topics. Recent work on long-term trends of peak flows in response to roads and forest cutting and regrowth (Jones and Grant, 1996; Jones, 2000) has stimulated study of road hydrology (Wemple et al., 1996). Two additional components of hydrology research concern the perennial topic of stream water temperature (Levno and Rothacher, 1969; Johnson and Jones, 2000) and the newer theme of floodplain groundwater systems—the hyporheic zone (Wondzell and Swanson, 1996a, b, 1999).

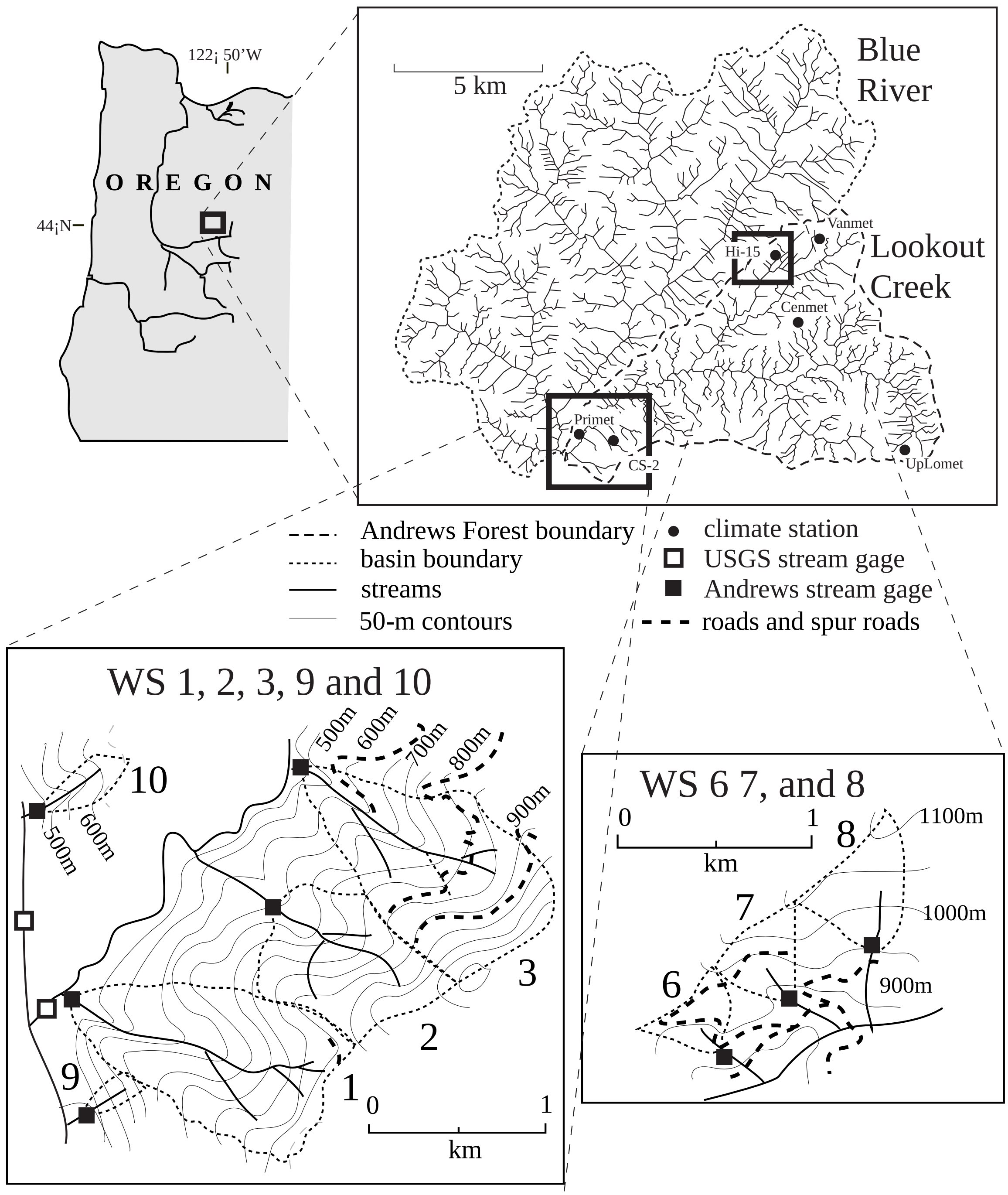

Figure 1. Andrews Forest and upper Blue River watershed stream network and experimental watersheds (noted WS). Primet, Vanmet, Cenmet, and UpLomet are locations of meteorological stations.

Table 1. Experimental watersheds in the H.J. Andrews Experimental Forest. Prior to treatments, forests were 400 to 500 year old Douglas-fir/western hemlock stands in watersheds 1, 2, 3, 9 and 10, and 130-yr old Douglas-fir stands in watersheds 6, 7, and 8.

Basin no.	Area (ha)	Elev (m) Min	Max	Management history	Water, stream chemistry, and sediment records, start date[1] W[2]	C[3]	S	B
1	96	460	990	100% clearcut, 1962-66; prescribed burned 1967	1953	–	1957	1957
2	60	530	1070	control	1953	1981	1957	1957
3	101	490	1070	1.5 km (6%) roads, 1959; 25% clearcut in 3 patches, 1963	1953	–	1957	1957
6	13	880	1010	100% clearcut, 1974	1964	1972	1972	–
7	15	910	1020	50% selective canopy removal, 1974; remaining canopy removed 1984	1964	1972	1972	–
8	21	960	1130	control	1964	1972	1972	–
9	9	425	700	control	1967	1969	1969	1973
10	10	425	700	100% clearcut, 1975	1967	1969	1969	1973

1 W = continuous stream discharge; C and S = composited 3-weekly samples of streamwater collected with proportional sampler and analyzed for chemistry (C): N, P, Ca, Mg, K, Na, alkalinity, conductivity, pH, particulate N, and particulate P; and suspended sediment (S); B = bedload sampling in ponding basin.

2 Streamflow records are continuous up to the present, except for Watersheds 6 and 7, where streamflow was not measured from 1987 to 1994. Records are based on water year, October 1 to September 30.

3 Long-term records with 3-weekly sampling interval began on this date.

Geomorphology studies began with examination of sediment yield from experimental watersheds (Fredriksen, 1970; Grant and Wolff, 1991) and mass movement associated with the 1964-1965 floods (Dyrness, 1967; Fredriksen, 1970). In the IBP sedimentation studies moved to a sediment-budgets and routing perspective (Swanson et al., 1982a, b) to parallel the ecologists' work on water and nutrient cycling. Another example of work at the ecology-geomorphology interface is the continuing study of woody debris in streams, which took off in 1975. A series of studies has addressed channel form-process relations over a hierarchy of scales of channel and valley-floor landforms (Grant et al., 1990; Grant and Swanson, 1995; Grant, 1997). The February 1996 flood catalyzed study of an integrated response of the hydrology, geomorphology, and ecology of a watershed to a major flood (Swanson et al., 1998; Wondzell and Swanson, 1999; Johnson et al., 2000; Nakamura et al., 2000; Wemple et al., 2001). Long-term monitoring activities are underway, including streamflow, sediment yield from experimental watersheds (Grant and Wolff, 1991), movement of the Lookout Creek Earthflow (Wong, 1991), and channel dynamics observed with repeat surveys of cross sections (Faustini, 2000).

Nutrient cycling and cation export studies have pursued the theme of coupling of geophysical and biological processes in forest-stream ecosystems. Studies in the early IBP period emphasized quality of water from control and treated watersheds (Fredriksen, 1971). Subsequent work in the IBP era focused on nutrient budgets, particularly nitrogen, in soil, forests, streams, and small watersheds (Sollins et al., 1980; Triska et al., 1984). Work in the early years on the Andrews LTER site examined precipitation and stream chemistry of undisturbed basins, and contrasted the chemistry of control basins with that of harvested basins (Martin and Harr, 1988, 1989). Recent studies have examined long-term trends of nitrogen budgets for small watersheds (Vanderbilt, 2000).

A close partnership between Andrews Forest scientists and land managers of the Willamette National Forest influences the science and ultimately the management and policy. This work occurs locally in the contexts of the Cascade Center for Ecosystem Management and the Central Cascades Adaptive Management Area, which is designated under the Northwest Forest Plan with the charge to develop innovative approaches to landscape management. A great deal of applied research, development, application, and management demonstration takes place at the interface of research and management. For example, research results are used in modification of roads for purposes of watershed restoration, in assessment of effectiveness of in-stream habitat structures, and in landscape management plans that recognize various types of landslide terrain in terms of hazards as well as their sediment and wood delivery functions. The engagement of land management provides media for synthesis (landscape management plans) and opportunity to conduct large-scale experiments, such as stream-habitat manipulations.

This guide supplements and updates guidebooks for the 1980 GSA Cordilleran Section meeting in Corvallis (Swanson et al., 1980) and an expanded version of that guide used for the 1987 International Symposium on Erosion and Sedimentation in the Pacific Rim held in Corvallis (Swanson et al., 1987). Those guides provide information on the following themes and field stops, which are not covered in this guide: geomorphology of lower Lookout Creek and Blue River reservoir area, Watershed 10 sediment budget, Lookout Creek earthflow, revegetation of debris slide and debris flow sites, dynamics of wood in Mack Creek, and channel and valley floor morphology of Lookout Creek. The 1987 guide also contains a road log from Corvallis to Andrews Forest. See also the Andrews Forest webpages for further information on a variety of topics of interest to scientists (http://fsl.orst.edu/lter) and land managers (http://fsl.orst.edu/ccem). A journalistic account of Andrews Forest science is offered by Jon Luoma (1999).

GENERAL CHARACTERSITICS OF THE ANDREWS FOREST LANDSCAPE

The Lookout Creek watershed, equal to the Andrews Forest, ranges in elevation from 420-1615 m. Bedrock below about 850 m is composed of hydrothermally altered volcaniclastic rocks of late Oligocene to early Miocene age (Swanson and James, 1975). Middle elevations are underlain by ash flows and basaltic andesite lava flows of Miocene age. Upper elevation areas are underlain by andesite lava flows with K-Ar ages in the range of 3-6 million yr. Soils have loamy surface horizons, have aggregate structure bound by organic matter, and have porosity of 60-70%, over half of which is macropore space (Ranken, 1974). Subsoil porosity is also high (50-60%) of which about 20% is macropores. This accounts for the predominance of subsurface flow over streams (Harr, 1977), because infiltration capacity greatly exceeds precipitation intensity. The ability of these soils to retain 30-40 cm of water in the upper 120 cm of soil (Dyrness, 1969) helps sustain the massive forest vegetation through the dry summer (Waring and Franklin, 1979).

The Lookout Creek watershed has been sculpted over perhaps 3 million yr by glacial, mass movement, fluvial, geochemical, and other processes. Glacial landforms dominate the southeastern quadrant of the area with U-shaped valleys along upper Lookout Creek and Mack Creek. These and other north-flowing drainages bounded to the south by ridges over about 1200 m have well-developed cirque forms at their heads. The western part of the watershed is dominated by steep (approximately 30-35°), straight slopes and narrow ridge crests and valley floors produced by stream erosion and shallow, rapid debris slides and flows. Several areas exhibit irregular terrain of moderate slope (5-10°) resulting from deep-seated (> 5m thickness), slow-moving (generally <1 m/yr) landslides, locally referred to as earthflows (Swanson and Swanston, 1977; Pyles et al., 1987). Stream environments range from steep, narrow, bedrock chutes along small streams recently scoured by debris flows to wide alluvial reaches, which have accumulated behind constrictions of the valley floor. Much of the stream network is a boulder-dominated, stepped sequence of pools and steep channel units (Grant et al., 1990).

The area receives approximately 2300 mm of precipitation at low elevations, mainly as rain, and a greater amount in upper elevations, mainly as snow. Approximately 80% of precipitation falls between October and April during long-duration, low-intensity frontal storms. Snow packs are common at low elevations, but rarely persist longer than 2 weeks. A seasonal snow pack develops at elevations about 1000-1200 m. Major floods typically result from rain augmented by snowmelt (Harr, 1981). Evapotranspiration accounts for about 45% of precipitation. Based on analysis of long-term streamflow records from experimental watersheds (Table 1), 100% clearcutting and burning resulted in 40% increase in annual flows and 20-100% increase in moderate and small peak flows in the first 5 yr after treatment (Jones and Grant, 1996; Jones, 2000).

Studies of long-term trends of cation and nitrogen budgets for small watersheds indicate that nutrient cycling is tight within these forest ecosystems and increases in export following disturbance are suppressed within a few years (Martin and Harr, 1989; Vanderbilt, 2000). Net cation export derived from bedrock weathering accounts for about 3 t/yr of annual export or about 30% of long-term export from forested watershed conditions in lower elevation soil and rocktypes (Swanson et al., 1982). Contributions to cation export are $SiO_2 \gg Ca > Na > Mg > K$ (Martin and Harr, 1989).

Before forest removal, the vegetation of these basins consisted of mature to old-growth conifer forest with leaf area indices exceeding 8 (Marshall and Waring, 1986). Forests are dominated by Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*) with some mountain hemlock (*Tsuga mertsiana*) and Pacific silver fir (*Abies amabilis*) at higher elevations. Post-treatment vegetation consists of shrub and deciduous tree species (for example, *Ceanothus spp*., *Acer spp.*, *Alnus rubra*) and planted Douglas fir (Dyrness, 1973; Halpern, 1989; Halpern and Spies, 1995). Forestry treatments were imposed from 1962-1975 and ranged from 25% patch cutting to 100% clearcutting, with various amounts of road construction (Table 1). All treated basins had some roads, but densities varied.

Natural disturbances also have formed the forests at Andrews. Native forest at low and middle elevations of the area is dominantly old-growth (400-500 yr) Douglas fir with heights exceeding 70 m along with other conifer species. Middle and upper elevations experienced wildfire in the mid-1800s and parts of the ridge line burned in the 1880-1910s, in a period coincident with sheep grazing activities in meadows along these ridges. Wildfire was the dominant native disturbance agent in these forests, but windthrow, insects (such as, bark beetles), pathogens (such as, root rots), landslides, and other processes also kill forests.

The cold, clear, fast-flowing streams contain rich aquatic life, including nine species of fish, and complex ecological processes, which respond strongly to geomorphology and adjacent forest cover. Woody debris in streams is a dramatic example of interactions among forest and stream ecosystems with a strong mediating influence of landforms and geomorphic processes.

INVITATION FOR USE OF ANDREWS FOREST DATA AND FIELD OPPORTUNITIES

The Andrews Forest is managed as a national and international research resource. You are cordially invited to make use of the landscape and long-term data sets for research and education. Please contact an Andrews Forest scientist or data manager to make arrangements. Our website is http://www.fsl.orst.edu/lter.