To: BLM

FROM: Rich Nawa Siskiyou Project

Sent 1/10/08

1977

D. Best Management Practices (DEIS 1132-1183) must explain how these are changes from existing BMPs, otherwise its impossible to know if the new BMP is more restrictive in preventing resource damage or allows more discretion. Previously each District had its own set of BMPs which seems appropriate, why change to uniform but confusing state-wide BMPS. If current BMPs work, why change them? Unattainable and impractical BMPs for roads (DEIS:1135 first 3 BMPs) to attain desired sediment modeling result (DEIS 1109) is not practical. BLM needs to be truthful about new roads and expected sediment based on previous road building.

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Cumulative Effects of Land Use on Salmon Habitat in Southwest Oregon Coastal Streams

by
Christopher A. Frissell

A THESIS

submitted to

Oregon State University

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the requirements for the
degree of

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APPROVED:

Associate Professor of Fisheries and Wlidlife in charge of major

Head of Department of Fisheries and Wildlife

Dean of Graduate School

Date thesis is presented April 30, 1992

Typed and Formatted by Christopher A. Frissell

AN ABSTRACT OF THE THESIS OF

Christopher A. Frissell for the degree of Doctor of Philosophy in Fisheries Science presented on April 30, 1992.

Title: Cumulative Effects of Land Use on Salmon Habitat in Southwest Oregon Coastal Streams.

Abstract approved: _____

William J. Liss

As part of a hierarchical approach to classifying watersheds and stream habitats based on geomorphic and geologic criteria, we defined ten classes of fluvial and lacustrine habitats at the scale of valley segments. Valley segments are landscape units which encompass surface waters and the adjacent floodplains and hillslopes with which they interact over time frames of thousands of years. They form a large-scale template that constrains the character of aquatic habitat, controls the effects of disturbances in riparian areas, and mediates responses of streams to upland and upstream events. The regional distribution of valley segment types in southwest Oregon reflects bedrock geology and tectonic history of the landscape. Fluvial segment types differ in stream-adjacent landforms, slope erosion processes, floodplain and valley morphology, channel slope, riparian vegetation, streambank texture, gravel bar morphology, and pool-forming features. Studies that do not carefully account for inherent differences between valley segment types could fail to detect critical changes in stream habitat caused by human disturbance. Alluvial valley and alluviated canyon segment types, which have extensive

floodplains, low channel slopes, abundant woody debris, and ample gravel beds, are of greatest direct importance for salmon and other native fishes. Virtually all alluvial valleys in the study area have been heavily disturbed by logging, agriculture, and residential development. Alluviated canyon segments located in the few drainage basins where human activity has been limited probably serve as habitat refugia for the last diverse assemblages and productive populations of salmon in the region. Alluviated canyons in extensively-logged basins exhibit increased abundance of large woody debris, fewer cross-channel debris jams, more extensive bank erosion, reduced pool area and increased riffle area, shallower riffles, and increased surface concentration of fine sediments in pools and other habitats, compared to similar segments in lesser-disturbed basins. These changes in channel morphology and stability appear to be driven by increased sediment load, caused by logging-related landslides and other erosion sources. Field studies in Sixes River basin indicated that abundance and diversity of salmonid fishes declines as maximum stream temperature increases. Changes in summer distribution of juvenile chinook and coho salmon since 1970 are related to changes in water temperature. Although some tributaries have cooled, a decline in rearing distribution in mainstem areas could be caused by long-term loss of channel complexity and associated coolwater refugia. Analysis of fish habitat structures constructed by federal and state agencies indicated that failure rates are high. Recovery of anadromous fish runs in southwest Oregon will require protection of remaining habitat refugia and reduction of sediment yield from disturbed watersheds.

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Many talented people have assisted on this project in the field and in the lab; their contributions have been crucial. Roughly in chronological order I thank Earl Hubbard, Dan Schively, Eric Leitzinger, Shaun Robertson, and Rodney Garland. Kelley Wildman has provided dedicated and talented administrative support and a cheerful presence I value highly. Most of the best-looking figures were drafted by Bill Gilbert. John Bragg provided photography that has been invaluable in public presentations. Other faculty, researchers, fellow graduate students, and miscellaneous personalities have had major, though indirect, influences on this work. In particular I wish to acknowledge Brendan Hicks, Jeff Dambacher, Bruce Sims, Courtney Cloyd, Gordon Reeves, Gordon Grant, Danny Hagans, Mary Ann Madej, Steve Ralph, Dave Bella, Dan Bottom, Hiram Li, John Bragg, Jim Britell, Mike Anderson, David Bayles, Don Boyd, Bill Bakke, and all the folks at Oak Creek Lab. This list is far from complete, but I have to turn this thesis in tomorrow morning. I thank John Bragg, Eric Cain, Steve Jones, Ted Williams, and Dennis Hayward for bringing our project and its implications to the attention of so many.

I especially thank Dale Hannon for her love and perseverence, and my parents for lots of kind encouragement.

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A patriot must always be ready to defend his country against his government.

--Edward Abbey

Those who fail to learn natural history are condemned to be eaten by it.

--bOB gROSS

CONTRIBUTIONS OF COAUTHORS

This thesis consists of four manuscripts summarizing work completed over a six-year period. The research often involved close collaboration among the coauthors, particularly in the planning and accomplishment of field work. The principle author did most of the data analysis, writing, and final editing of the material contained in this thesis, and should be held solely responsible for any errors or exaggerations of fact. The particular contributions of coauthors to papers in this thesis are summarized below.

R.K. Nawa-- Involved in all phases of field work and some aspects of quality control and analysis of data; closely collaborated in developing objectives, field study design and methods, and management implications; reviewed and edited the manuscripts several times.

W.J. Liss-- Principal Investigator of project, handled most aspects of funding and administrative arrangements; participated in setting study objectives and theoretical perspective; reviewed and edited manuscripts.

J.L. Ebersole-- Assisted in field work and development of field methods; reviewed and edited manuscript.

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Cumulative Effects of Land Use on Salmon Habitat in Southwest Oregon Coastal Streams

Chapter 1

Overview

Overview

The primary theme of this dissertation is that drainage basins exert pervasive control of the stream habitats and biota embedded within them. This is a refrain long-developed by Warren (1979) and others before him, but one which unfortunately has been widely neglected in environmental research, planning, and management. It is a confounding assumption from the standpoint of the mechanistic world view, for to the extent that the organization and response of a system is dependent on its context in space and time, no two ecosystems or habitats are alike. The conduct of the rather mechanistic pursuit I will here call "standard resource science" rests on the existence of replicate systems, on the ability of such replicates to exhibit independent responses, and to a large extent upon the principle that natural and cultural process-response systems are fundamentally reversible. In the realm of ecology and resource management, we have much evidence that none of these three notions is reasonable.

The decline of the Pacific salmon during this century is a tragic and resonant illustration of the failure of the European paradigm of resource science and management. The story of the salmon dramatically underscores the inadequacy of the assumptions of the prevailing paradigms of resource management and science. Each population of salmon is unique, in that it homes to and is intricately adapted to the peculiar combination of circumstances in its natal stream and the associated rearing environment. Even if such populations were similar enough that they were functionally

interchangeable, an idea which a century of experience in salmon culture has consummately refuted, they are unique by virtue of their location and the timing of their life history events. In ecological and human terms, the importance and singularity of the salmon is defined by the very habitat it animates.

Finally, there is little evidence that the depletion of the salmon and its ecosystem is reversible, at least under the cultural norms and environmental conditions that have prevailed since the virtual destruction of the aboriginal civilization. Perhaps the best-fit model of the salmon decline is one of unremitting, incremental loss of habitat and biotic diversity for the century or so that European man has been a major force in their environment. Arthur McEvoy has documented this story eloquently (McEvoy 1986), and strikingly recounts how the once-rich cultural diversity of salmon fisheries-- aboriginal and later Eurasian-- has suffered the same fate as the natural system upon which it depends.

We can find hope, however, in small places. A few salmon populations have demonstrated remarkable capacity for either explosive growth or slow and steady rebound if their habitat is intact and artificial impediments to their survival are removed. There is widespread and growing interest in not just the protection of salmon ecosystems, but their restoration. And perhaps even as a consequence of the descent of the wild salmon's importance as simple raw material for the region's economy, its value as a cultural icon and symbol of environmental quality is becoming rediscovered, recognized, and celebrated.

Science is complicit in the loss of the salmon and the environmental destruction it signifies. Scientists have not just tacitly accepted, but actively courted the demands that economic and political forces have thrust upon them: that in questions about the management of ecosystems, the burden of proof lies with those who would ensure their protection, rather than those who would risk them through resource exploitation.

Following in step with the expectations of policymakers, most scientists have proceeded to apply the unrealistic premises of the a highly mechanistic paradigm in their research, and have generally failed to demonstrate that human activities have damaged ecosystems, even as those ecosystems were disappearing beneath them (McEvoy 1986).

In this dissertation I focus on the fate of salmon and their habitat in the watersheds of southwest Oregon. The following chapters examine one approach to understand and articulate the complex network of habitats and cascade of processes that constitute the stream and its watershed. The challenge of such research is to determine how activities occurring over large expanses of land and long spans of time can affect the aquatic habitat downslope and downstream. The approach taken is a hierarchical one, where close attention is paid to scale and the contingent constraints imposed by nested environments. My goal in this thesis is to further a "non-standard" scientific path, one more coherent with what we know to be fundamental principles of ecosystemic and cultural behavior, while avoiding being perceived as wholly bizarre or unrealistic by the guardians of the prevailing paradigm. I am not particularly satisfied with the result. The social challenge of bridging contradictory world views and the scientific and technological subcultures they pervade has been a far more daunting charge than gaining understanding of the natural world. Here is the message that keeps filtering back from the front lines: this work is but a small step where great strides are needed.

Chapter 2

Aquatic Habitat in a Coastal Mountain Landscape: Classification and Ecological Significance of Valley Segments

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ABSTRACT

In the Klamath Mountains of southwest Oregon we describe ten classes of fluvial, lacustrine, and estuarine habitats that differ in fundamental geologic, geomorphic, and ecological properties. Valley segment classes encompass stream channels and the adjacent floodplain and riparian lands with which channels directly interact over time periods of thousands of years. Valley segments form a large-scale template controlling the effects on aquatic habitat of disturbances in riparian areas and mediating the response of streams to upstream and upslope disturbances in their drainage basins. The regional distribution of valley segment types is controlled by lithology and tectonic history. Fluvial segment types differ in stream-adjacent landforms, slope erosion processes, floodplain and valley floor width, channel slope, riparian vegetation, texture of streambank deposits, gravel bar morphology, and pool-forming features. By virtue of their geomorphology and downstream location, alluvial segment types are the most widely impacted and most sensitive to the cumulative effects of basin-wide disturbance. Such low-gradient segments with active floodplains are of greatest ecological importance for salmon and other native fishes, many species of which are in serious decline. This classification provides a systematic methodology for large-scale mapping of stream and riparian habitats, and analysis, prediction, and monitoring of the effects of landscape change on aquatic ecosystems. We believe this kind of approach will be necessary for effective protection and recovery of threatened fishes and other aquatic biota.

1. Introduction

Landscapes along tectonically active continental margins, such as the west coast of North America, are marked by short, very steep gradients from the mountain crest to the sea, and abundant, periodically intense rainfall. These conditions drive extreme rates of transfer of material and energy from upland to lowland areas via colluvial, fluvial, chemical, and biological processes (Hewitt 1972, Muhs et al. 1987). In steep, humid regions, stream systems serve as the primary pathways for this seaward flux. Natural and anthropogenic disturbances originating high in the watershed are rapidly and efficiently transferred, transformed, and sometimes amplified downslope and downstream. Therefore, coastal mountain streams, although biologically productive, offer highly dynamic, physically challenging habitats for aquatic organisms.

The fish fauna of north Pacific coastal streams is generally species-poor. However, abundant populations of Pacific salmon (Oncorhynchus spp.) are widely distributed and culturally and economically valued. The watersheds providing freshwater habitat for these fishes also support a burgeoning array of land uses, including logging, agriculture, mining, urbanization and industrial development. Many species of Pacific salmon have suffered serious decline and local extinction in recent decades, particularly in the southern portion of their ranges (Konkel and McIntyre 1987, Moyle and Williams 1990, Nehlsen et al. 1991). Most of these losses are associated with damage or

destruction of freshwater habitats (Nehlsen et al. 1991, Frissell submitted). However, the complex causal relationships between logging and other human modifications of the landscape and deterioration of aquatic habitats are poorly understood, in part due to inherent variation among watersheds in different geologic and climatic regions (Swanston 1991, Hicks et al. 1991a) and among streams in different geomorphic settings (Chamberlin et al. 1991).

To date, research and management of aquatic ecosystems in the coastal zone have focused on direct, lateral linkages between riparian areas and immediately adjacent aquatic habitats. However, because habitats within aquatic ecosystems are also tightly coupled in the longitudinal or downstream dimension (Vannote et al. 1979), there is clearly a need for landscape-level conceptual and methodological tools to understand and predict the cumulative, downstream-propagating impacts of land use on aquatic habitats within whole drainage basins. This requires a conceptual framework for interpretation of linkages between terrestrial and aquatic environments. It also requires a means of classifying landscape "patches" that both reflects key land-water linkages, and discriminates spatial units at a level of resolution appropriate for mapping and analysis of large drainage basins. In an earlier paper we described a hierarchical conceptual framework for understanding the structure and function of watersheds and stream systems, including general criteria for classification of stream habitats at a range of spatio-temporal scales (Frissell et al. 1986). In this paper we describe a specific classification scheme which resolves watersheds and streams into units at the scale of valley segments.

Valley or stream segments, defined in Frissell et al. (1986), are hundreds of meters to kilometers in length and persist as geomorphic units over time scales of thousands of years. Valley segment types differ geomorphically and ecologically in ways that constrain the potential morphology and dynamics of stream channels and

aquatic habitat at smaller scales (Frissell et al. 1986), and largely determine the suite of physical and biotic processes linking terrestrial and aquatic systems (Hynes 1975, Decamp 1984, Swanson et al. 1988). The variables most useful for such a classification reflect the diverse geomorphic origins of valley segments, and identify long-term constraints on aquatic habitats and their potential response to changes in the watershed (Warren 1979, Frissell et al. 1986). For valley segments these variables include channel slope, bedrock geology, sideslope and floodplain morphology, soil properties, and potential natural vegetation (Frissell et al. 1986).

Various investigators have suggested comparable typological schemes for stream segments or reaches in mountainous areas (e.g., Platts 1979, Rosgen 1985, Marion et al. 1987, Harris 1988, Cupp 1989a, 1989b). Although the potential advantages of such classifications have been frequently acknowledged (Warren 1979, Lotspeich and Platts 1982, Mosley 1987, Hicks et a. 1991, Naiman et al. 1992), so far those who have attempted to evaluate their actual utility in research and management report mixed success (e.g., Platts 1979, Mosley 1987, Bryant et al. 1991, Ralph et al. 1991, MacDonald et al. 1991). Unfortunately few of these reports have appeared in the peer-reviewed literature. Most are limited in geographic scope (as may be appropriate), and none address the particular conditions of the Klamath Mountains region of coastal Oregon and California, where the crisis of collapse and endangerment of fish populations is particularly acute. This paper describes a classification of valley segments designed to assess the geographic distribution and physiography of aquatic habitats, to define their relationship to terrestrial landscape features, and to predict their response to human disturbance of drainage basins in southwest Oregon. Elsewhere we apply the classification in field studies of the effects of logging on channel morphology and aquatic habitat (Frissell et al. 1992b).

2. Methods

2.1 Study Area

The study area (Fig. 1) is broadly defined as the coastal river basins within the Klamath Mountains physiographic province of southwest Oregon (Franklin and Dyrness 1976). The area comprises steep, highly dissected mountains descending to short river valleys and a very narrow, discontinuous coastal plain. The region is largely forested with diverse, patchy stands of conifers and hardwoods. Common tree species include Douglas-fir (Pseudostuga menziesii), Port-Orford-cedar (Chamaecyparis lawsoniana), western hemlock (Tsuga heterophylla), red alder (Alnus rubra), bigleaf maple (Acer macrophyllum), California bay laurel (Umbellularia californica), willow (Salix spp.), tanoak (Lithocarpus densifloras), and Pacific madrone (Arbutus meziesii). Clear-cut logging has been widely practiced since about 1955. The few low-lying areas along the coast have been largely cleared for agricultural and residential development, mostly prior to 1940 (Frissell and Liss 1986). The study area supported large indigenous runs of salmon, steelhead, and trout (Oncorhynchus spp.) that have dramatically declined in recent decades (Nicholas and Hankin 1988, Nehlsen et al. 1991, Frissell submitted).

Steep slopes and river canyons have developed on highly heterogeneous geologic formations in a tectonically active landscape (Kelsey 1990), sometimes referred to as the Klamath Knot (Wallace 1983). These formations include large areas of metamorphosed and faulted and sheared rocks of sedimentary, volcanic, and plutonic origin (Beaulieu and Hughes 1976, Ramp et al. 1977). Very steep slopes on competent rocks are prone to shallow, rapid landsliding, whereas deep soils formed over incompetent rocks are subject to deep-seated slump-earthflows, block slides, rapid soil creep, and gully erosion (Beaulieu and Hughes 1976, Swanston 1979, Sonneville et al.

Figure 1. Location of the study area, the quadrangles where extensive map survey of streams was conducted (stippled), and field study basins (diagonally shaded) in southwest Oregon. Number codes as in Table 1. Symbols indicate basin geology: square for highly sheared, Jurassic age metasedimentary rocks (Otter Point Formation); upward-pointing triangle for massive, Cretaceous-age sandstone and conglomerate (Rocky Point and Humbug Mountain Formations); circle for basins comprised of a complex of Jurassic age schist (Colebrook Schist), Otter Point Formation metasediment and Cretaceous sedimentary rocks; and downward-pointing triangle for massive, Jurassic-age greywacke sandstone (Dothan Formation).

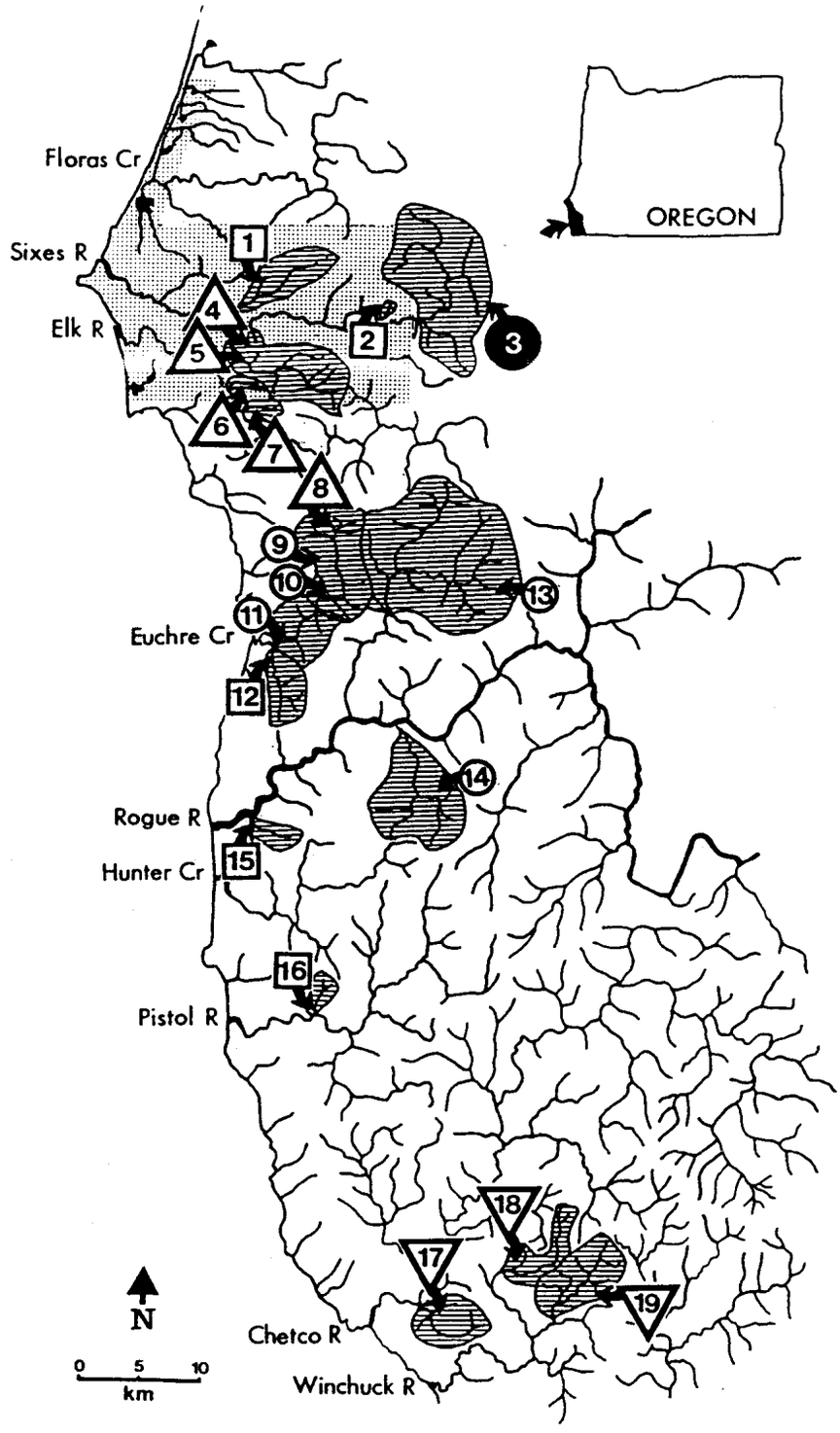
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Figure 1

1987). Logging and road construction increase the rate of erosion by 1-4 orders of magnitude, relative to comparable natural forested slopes (Swanston 1979, Amaranthus 1985, McHugh 1987, Swanston et al. 1988). Streamside landslides and debris flows initiating on streamside "inner gorge" slopes and headwall areas directly impact streams, particularly in extensively logged basins (Kelsey 1980, Pitlick 1982, Kelsey 1988, Frissell and Liss 1986).

Intense winter rainstorms produce flashy, high-magnitude peak flows, followed by extremely low streamflow during the dry period between July and October (Friday and Miller 1984). Accelerated erosion and sedimentation associated with floods and logging have caused widespread aggradation, widening, and destabilization of channels since 1955, disturbing forest vegetation along low-gradient reaches of the many of the region's rivers (Kelsey 1980, Lisle 1981, Frissell and Liss 1986).

2.2 Reconnaissance and Identification of Segment Types

Following review of existing literature and topographic and geologic maps, we conducted field reconnaissance, including mapping of landforms and channel features, reconstruction of vegetation and land use history, and survey of cross sections along selected streams. These observations allowed us to relate patterns on maps and aerial photographs to site-specific field conditions. Based on the apparent role of geologic and geomorphic features in constraining key geomorphic and ecological processes (e.g., erosion, sediment transport, composition and succession of vegetation, and input and retention of boulders and large wood in streams) we subjectively identified major valley segment classes, discernible using topographic maps or field data. For the purposes of mapping and analysis in this paper, we did not discriminate geomorphically

distinct units of less than 100 m in length as valley segments, but rather treated them as inclusions within larger units. The final typology is the outcome of a years-long, iterative process of field description, map and airphoto investigations, development of conceptual hypotheses to explain the causal bases of differences among sites, and sorting, lumping, splitting, or rejection of provisional categories.

2.3 Landscape Associations

Once we defined a satisfactory classification, we used 1:62,000-scale topographic and geologic maps to develop a provisional map of segment types across all the basins of the study area. This analysis was intended as a rapid and approximate assessment at a regional scale of the spatial distribution of valley segment types. In this coarse-resolution mapping we aggregated competent bedrock canyons with colluvial canyons, and alluvial-fan-influenced valleys with alluvial valleys, since more detailed work using larger-scale maps, aerial photographs, or field work is often necessary to adequately distinguish these classes.

To assess the correspondence between geomorphically-defined valley segments and aspects of the drainage basin including position within the drainage network (i.e., stream size), geology, and channel slope, we mapped valley segments in the Sixes River, Euchre Creek, and portions of Elk River and Floras Lake basins in detail. This area is representative of the northern half of the study region. The sample encompassed valley segments of Strahler order four or larger based on U.S. Geological Survey 1:24,000- scale topographic quadrangles (Fig. 1) (Cape Blanco, Sixes, Mt. Butler, Floras Lake, and the western one-third of Langlois quadrangles). In this survey we identified and classified valleys based strictly on topographic criteria, primarily side slope

steepness and form and topographic expression of valley floor surfaces. We then measured the downstream slope of the valley floor from the topographic map and determined bedrock geology from geologic maps (Beaulieu and Hughes 1976, Ramp et al. 1977, DOGAMI 1982). As an index of stream size we determined stream order following Strahler (1952), using contour crenulation on the topographic maps to delineate headwater, ephemeral-flow channels as first-order streams (Gregory 1966). We compared frequency distributions of these factors among segment types, and assessed differences between segment types using linear regression and analysis of variance. Because we gained considerable field experience in this portion of the regional study area, we were able to develop detailed and field-verified maps of valley segments in several basins, two of which are included in this paper.

2.4 Field Surveys

In summer of 1989 we conducted field inventories to assist in validation of map-based valley segment classification and to compare stream habitat conditions among valley segment types. We designed the field study to accommodate four important sources of variation: valley segment type, geology of the drainage basin, land use history of the basin, and basin size (Table 1). These factors interact to affect habitat conditions and response of habitat to natural or human disturbance (Frissell et al. 1986). Based on evidence that low-gradient, alluvial segment classes provided much of the habitat critical for native fishes in the area, and that these habitats were likely the most sensitive to basin-wide disturbance, we selected 19 study streams that included major alluvial valley, alluvial fan, alluviated canyon, or terrace-bound-valley segments (Fig. 1).

Table 1. Characteristics of the field study sites. Site codes refer to Fig. 1. Segment type codes as in Table 2. In parentheses is number of discrete segments surveyed if more than one. Basin Geology is generalized, refers to dominant rock type as follows: Jop = Otter Point Formation, Jurassic metamorphics; Krh = Rocky Peak and Humbug Mountain Formations, Cretaceous sedimentary rocks; Jc/Krh = Complex of Colebrook schist and Otter Point metasedimentary rocks, with Cretaceous sedimentary rocks in headwaters; Jd = Dothan Formation, Jurassic greywacke sandstones. Land Use codes: OG/M = predominantly old-growth and mature forest; SG/CC = predominantly second-growth and clear-cut forest; AG = areas of agricultural land use occur at lower elevations.

Stream			Drainage Basin Data			Study Site Data	
Code Number	Stream Name	Valley Segment Types	Basin Geology	Drainage Area (km2)	Land Use	Elevation (m)	Total m Surveyed
1	Edson Cr	AV(2), BRC	Jop	28.1	SG/CC, AG	10	1895
2	Big Cr	CC(2), AC	Jop	3.9	OG/M	80	537
3	Upper Sixes R	TBV	Ts/Jop	98.6	SG/CC, AG	105	710
4	Little Dry Cr	AC, CC	Krh	3.4	SG/CC	25	1603
5	Dry Cr	AV, AC	Krh	41.7	OG/M, AG	25	2000
6	Rock Cr	AV, AC	Krh	3.4	SG/CC	30	637
7	Anvil Cr	AC, BRC	Krh	7.2	OG/M	40	460
8	Chismore Fk of Euchre Cr	AC	Krh	5.4	SG/CC	245	710
9,10,11	Euchre Cr	AV, AFV (2), AC	Jc/Krh	65.0	SG/CC, AG	10	3720
12	Cedar Cr	AV	Jop	23.4	SG/CC, AG	10	1050
13	Lobster Cr	AV, CC	Jc/Krh	144.8	SG/CC	80	1800
14	Quosatana Cr	AC	Jc/Krh	65.9	OG/M	15	1600
15	Indian Cr	AV	Jop	9.6	SG/CC, AG	10	100
16	Deep Cr	AV, AC	Jop	9.2	SG/CC	35	1406
17	Jack Cr	AV (2)	Jd	22.1	SG/CC, AG	10	1600
18	Wheeler Cr	AC, BRC, CC	Jd	18.0	SG/CC	115	1200
19	E.Fk. Winchuck R	AC, CC	Jd	58.8	OG/M	50	1278

[a]Elevation measured at downstream end of survey section, to nearest 5 m.

The study basins can be grouped into four major geologic associations, adapted from Beaulieu and Hughes (1976): largely incompetent metamorphic rocks of Jurassic age (Otter Point Formation, Jop and Jov); Jurassic age, incompetent schist with competent sedimentary rocks in the headwaters (Colebrook schist and Cretaceous sedimentary rocks, Jc/Krh); largely competent, Dothan Formation sandstone of Jurassic age (Jd); and competent, massive Cretaceous conglomerate and sandstone (Krh).

We surveyed several bedrock canyons and colluvial canyons adjacent to the alluviated segments, but our sample size for these categories is relatively small. In addition, we surveyed just one terrace-bound-valley segment, and two alluvial-fan-influenced valleys (Table 1). We did not conduct field surveys in estuaries or lakes, since they comprise a very small part of the study area, are easily discriminated from other segment types, and would require different sampling techniques.

Field surveys, conducted during summer and fall of 1989, included systematic transect samples at intervals of 50, 100 or 200 m (increasing with increasing stream width), from downstream to upstream. At each transect point, we measured width of the active, unvegetated channel, width of active floodplains (surfaces showing evidence of inundation, scour, or deposition from floods of recent decades), and width of the valley floor, including alluvial fan and terrace surfaces above the active floodplain. Channel slope was measured with a hand-held Abney level. Texture of soils exposed in each streambank was described semiquantitatively by ranking the following size classes in terms of their volumetric abundance in the deposit (median axis length range in parentheses): bedrock (massive), large boulders (>100 cm), small boulders (26-100 cm), cobbles (6-25 cm), gravel (0.8-6 cm), fine gravel (2-8 mm), sand (0.06-2 mm, gritty consistency), silt (0.008-0.06 mm, greasy consistency), and clay (<0.008 mm, sticky consistency). We classified the riparian vegetation structure at the transect as grassland, brush, clear cut plantation (<10 y old), second-growth forest (>10 y old),

mature forest (trees 75-200 y old with few snags or downed logs), and old growth forest (some trees >200 y old, with numerous snags and downed logs). Riparian tree species were ranked by their relative contribution to canopy over and adjacent to the channel at the transect site. We visually estimated total canopy cover in terms of percent of the low-flow channel shaded by vegetation.

Channel pattern of the 50-m reach centered on the transect was classified based on Richards (1982) as straight, sinuous, meandering, anabranching (multiple channels with vegetated islands), or braided (multiple sub-channel threads across a continuous, unvegetated channel surface). This classification indicates increasing sinuosity, lateral complexity, and width of channels.

Between transect points, we recorded the occurrence of erosion sources, tributaries, debris jams, and stream-adjacent landforms within each reach. Following Varnes (1958) and Swanston (1979), we classified erosion sources as debris avalanches, streamside debris slides, debris flows from tributary sources, slump-earthflows, or gullies. We recorded only the erosion sources that, based on vegetation growth, had occurred or been active during the five years prior to the survey. The minimum volume of sediment delivered to the channel was roughly estimated by measuring the size of the evacuated erosion scar, or in the case of debris flow deposits, estimating the volume of the depositional fan or lobe. Our objective was to roughly estimate the quantity of material transferred from hillslope or tributary to valley floor locations by various processes.

At each debris jam, erosion feature, tributary, and transect site we identified the right- and left-bank landforms adjacent to the active channel. We classified landforms or geomorphic surfaces, adapted from Balster and Parsons (1966) and Parsons (1978), as follows: steep, competent hillslopes (>60% even, unbroken slope, shallow rocky or skeletal soils, or rock cliff face), moderate competent slopes (15-59% even slope,

moderate to deep, fine-textured soils), colluvial complex slopes (variable hummocky or broken slope, unstable, deep, heterogeneous soils), rock-floored strath terraces (alluvium veneer over exposed bedrock, silty or sandy soils), alluvial terraces (high, flat or very gently sloping surface entirely of alluvial origin, silty or sandy soils), floodplain (lower, flat surface of alluvial origin; silty, sandy, or gravelly deposits), and alluvial-colluvial fans (gently sloping, cone-shaped, heterogeneous deposits at tributary mouths).

Between transects we also counted gravel bars and classified them as transverse, mid-channel, side, point, or diagonal in form, following Richards (1982). Bar form reflects sediment size, transport processes, and sorting of bed materials, and the relative abundance of different kinds of gravel bars is correlated with channel pattern and bed stability (Richards 1982).

2.5 Biological Information

We used information on spawning and juvenile rearing distribution of anadromous fish in Sixes River and Elk River (Reimers 1971; Stein et al. 1972; Reimers and Concannon 1977; Burck and Reimers 1978; Gordon Reeves, U.S. Forest Service, Pacific Northwest Research Station, Corvallis, Oregon, unpublished data; Oregon Department of Fish and Wildlife, unpublished data), coupled with data from our own field studies in Sixes River and Euchre Creek (Frissell et al. 1992c; Nawa and Frissell, unpublished data) to qualitatively assess how key native fishes use segment types during their freshwater life history.

3. Results

3.1 Valley Segment Types and Landscape Distribution

We identified six classes of fluvial valleys, three lacustrine valley types, and one estuarine type (Fig. 2, Table 2). These categories can be readily recognized in the field, and most of these types can be discriminated using topographic maps of 1:62,500 or larger scale. Accuracy can be improved if field data or detailed maps of surface geology or soils are available. Table 3 indicates that strong associations exist between geologic map units and segment types.

The study area can be broadly divided into subregions having different spatial associations of valley segments (Fig. 3). Certain segment types, primarily alluvial valleys, terrace-bound-valleys, and the three types of lakes, are highly clustered within the study area. This distribution relates closely to geology and tectonic history. Most of the region is dominated by a mosaic of narrow, canyon segment types interspersed with slightly wider alluviated canyons.

Colluvial canyons are associated with sheared or faulted schist, siltstones, ultramafic rocks, or faulted sandstones vulnerable to deep-seated creep, slumps, and earthflows (Kelsey 1988). Competent bedrock canyons are incised in thickly bedded, unsheared sandstones; highly metamorphosed, indurated siltstones of the Galice Formation; and hard, metavolcanic or intrusive, granitic rock masses (Fig. 4, Table 3). Bedrock canyons also occur locally within other, less competent rock formations, commonly corresponding with unmapped intrusions or isolated, massive blocks within otherwise highly sheared formations. Chi-square analyses of the data in Table 3 indicate that colluvial canyons occur more frequently and bedrock canyons less frequently than would be expected by chance ($P < 0.0001$) within the highly sheared Otter Point

Figure 2. Ten valley segment types identified in southwest Oregon. For each type, figure shows a generalized oblique view, and paired topographic and geomorphic surface maps for a type locality, for which a legal description is provided. Type localities were selected for representativeness, availability of field data, and ease of public access. Scale varies as indicated on topographic maps, contour interval is 12.2 m (40 ft). For fluvial segment types we provide typical cross sections from field surveys indicating vegetation, soil morphology, and location and width of active channels, and floodplains ofapproximate 5-10-year and 100-year inundation frequency. Legends for geomorphic maps and cross-sections are inset. Table 2 provides verbal description and criteria for identification.

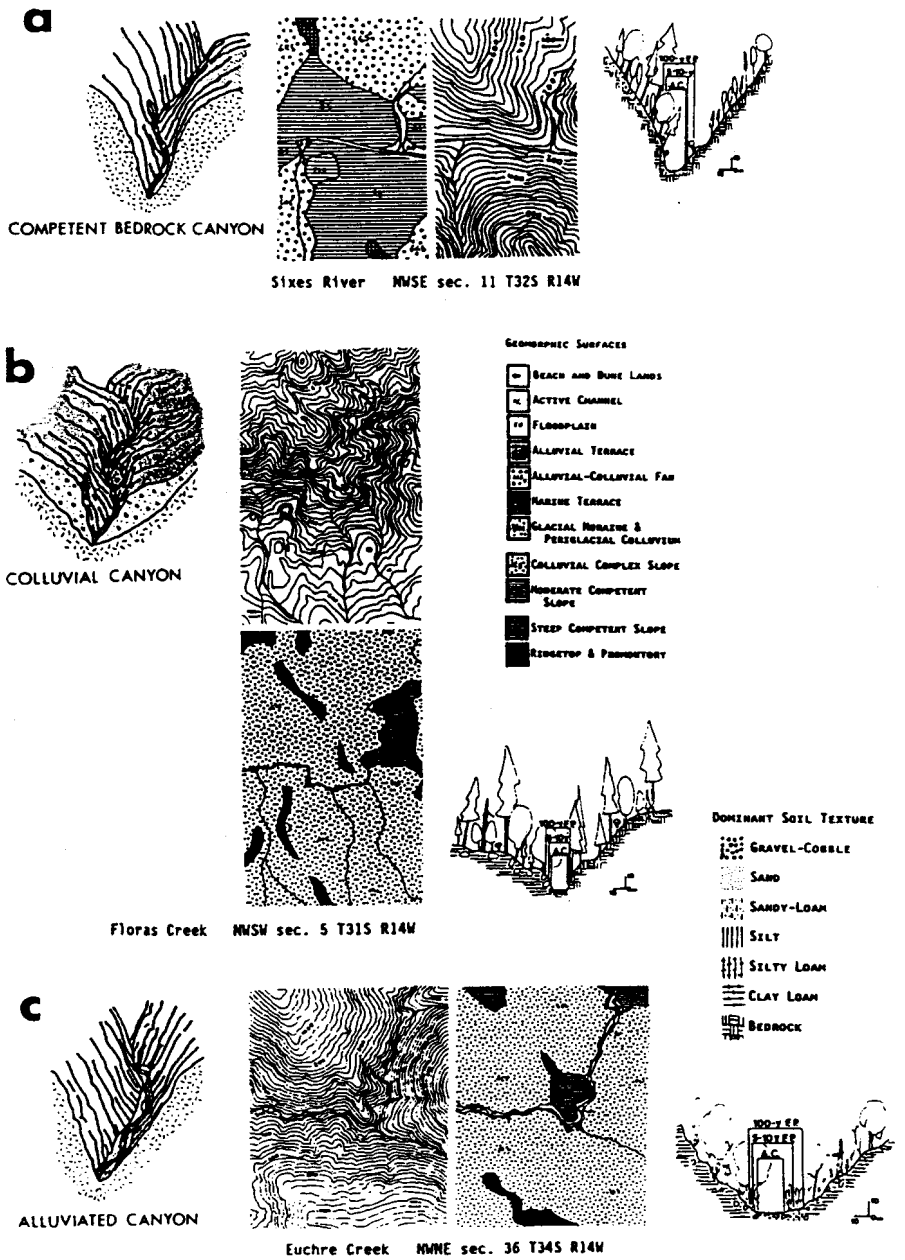
a
COMPETENT BEDROCK CANYON
Sixes River NWSE sec. 11 T32S R14W
b
COLLUVIAL CANYON
Floras Creek NWSW sec. 5 T31S R14W
Geomorphic Surfaces
Beach and Dune Lands
Active Channel
Floodplain
Alluvial Terrace
Alluvial-Colluvial Fan
Marine Terrace
Glacial Moraine & Periglacial Colluvium
Colluvial Complex Slope
Moderate Competent Slope
Steep Competent Slope
Ridgetop & Promontory
Dominant Soil Texture
Gravel-Cobble
Sand
Sandy-Loam
Silt
Silty Loam
Clay Loam
Bedrock
c
ALLUVIATED CANYON
Euchre Creek NWNE sec. 36 T34S R14W

Figure 2

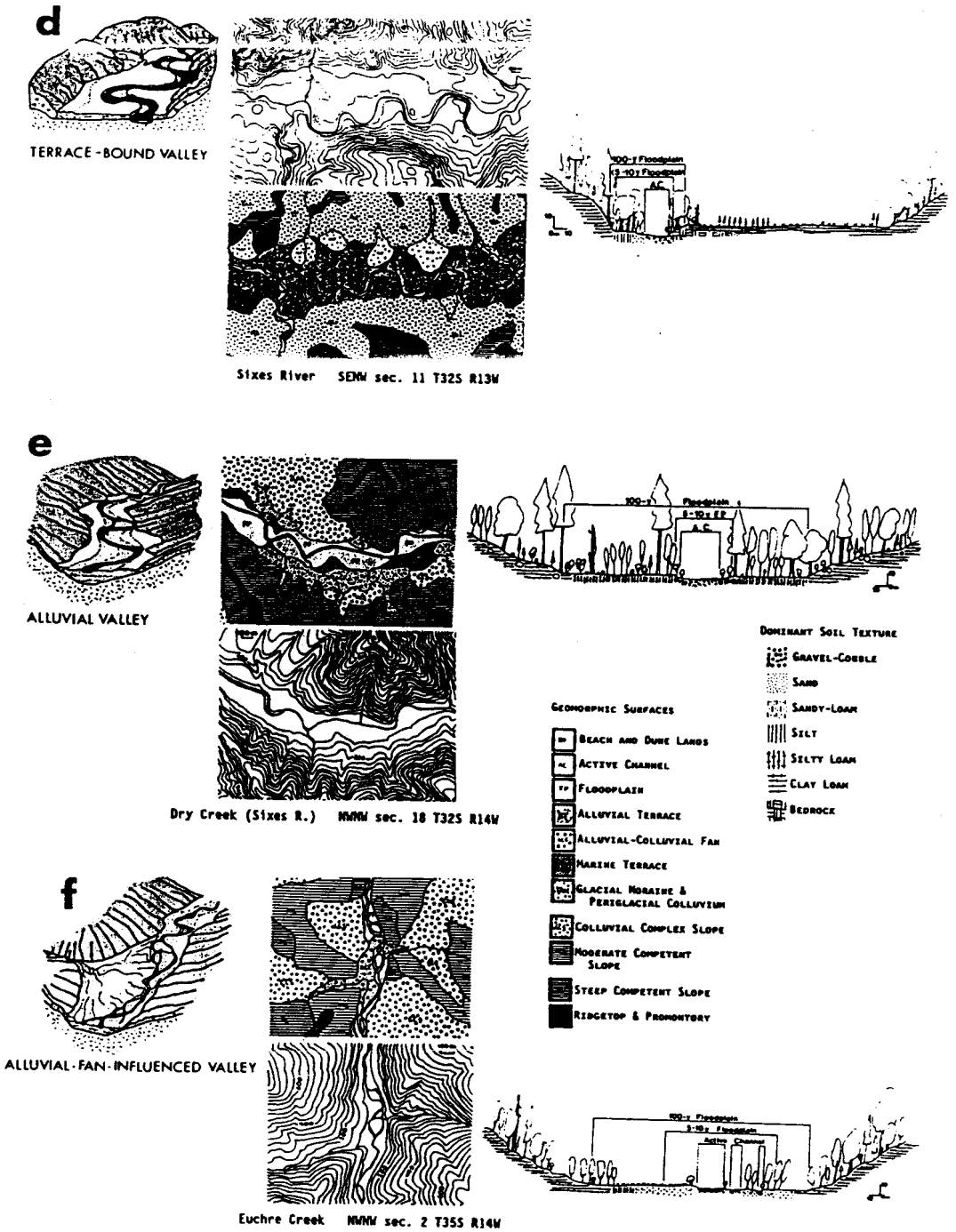
d
TERRACE-BOUND VALLEY
Sixes River SENW sec. 11 T32S R13W
e
ALLUVIAL VALLEY
Dry Creek (Sixes R.) NWNW sec. 18 T32S R14W
Dominant Soil Texture
Gravel-Cobble
Sand
Sandy-Loam
Silt
Silty Loam
Clay Loam
Bedrock
Geomorphic Surfaces
Beach and Dune Lands
Active Channel
Floodplain
Alluvial Terrace
Alluvial-Colluvial Fan
Marine Terrace
Glacial Moraine & Periglacial Colluvium
Colluvial Complex Slope
Moderate Competent Slope
Steep Competent Slope
Ridgetop & Promontory
f
ALLUVIAL-FAN-INFLUENCED VALLEY
Euchre Creek NWNW sec. 2 T35S R14W

Figure 2

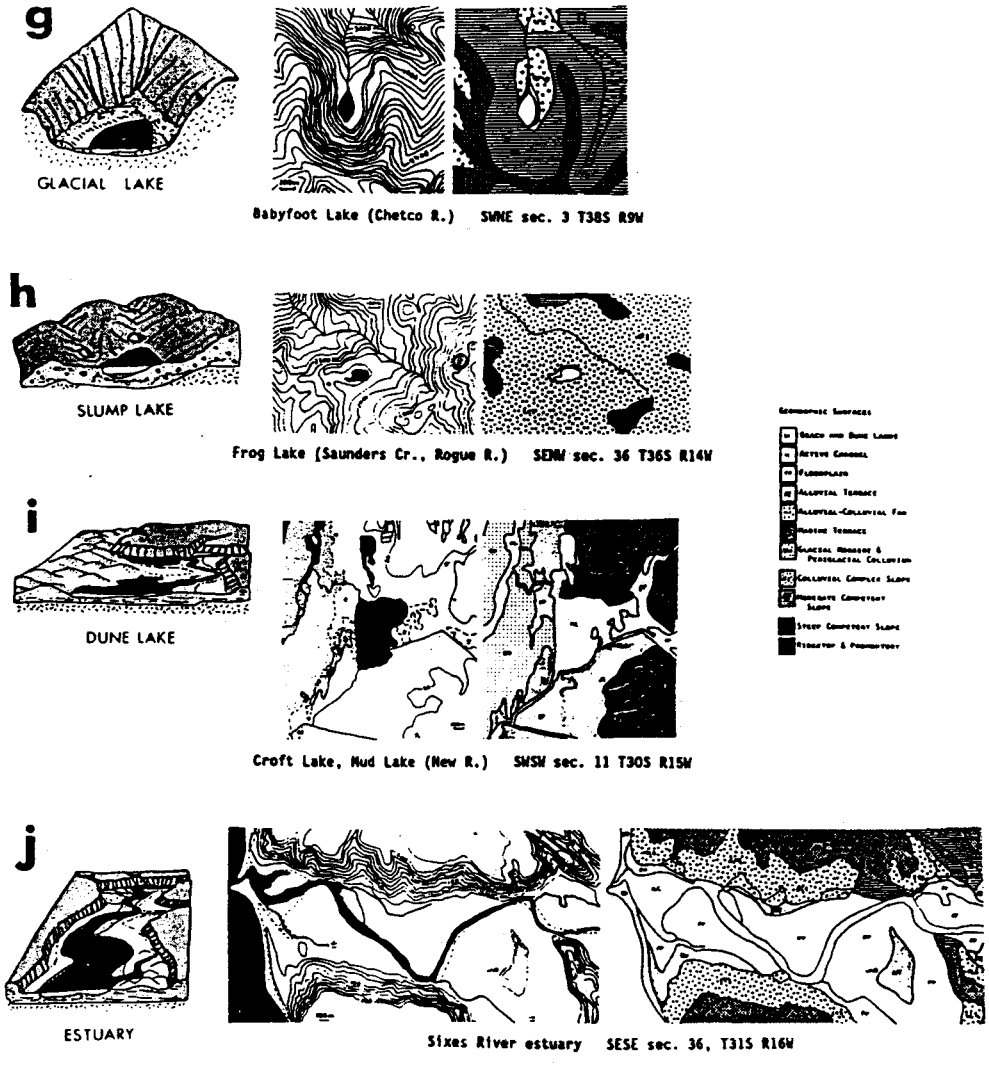
g
GLACIAL LAKE
Babyfoot Lake (Chetco R.) SWNE sec. 3 T38S R9W
h
SLUMP LAKE
Frog Lake (Saunders Cr., Rogue R.) SENW sec. 36 T36S R14W
i
DUNE LAKE
Croft Lake, Mud Lake (New R.) SWSW sec. 11 T30S R15W
j
ESTUARY
Sixes River estuary SESE sec. 36, T31S R16W

Figure 2

Table 2. Key characteristics of ten valley segment classes in southwest Oregon.

Valley segment type	Valley slope	Floodplain width[a]	Valley width[a,b]	Channel pattern	Landscape position	Geomorphic surfaces and soils	Dominant Geology
Alluvial valley (AV)	<3%, mean 1%	>2X ACW	>2X ACW	Meandering or sinuous	Mostly near coast, some in tectonic or landslide-dammed basins in headwaters; 10-100 m elevation	Broad, continuous floodplains, local alluvial or marine terraces, local contact with marginal hillslopes	Quaternary alluvium
Alluvial-fan-influenced valley (AFV)	<2%, mean 0.7%	>3X ACW	>3X ACW	Anastomosed, relatively unstable	Where tributary depositional fans encroach on alluvial valley mainstem, <50 m elevation	Heterogenous alluvial fan deposits, gravel, sand, and silt; complex floodplain surfaces, relict channels and wetlands	Quaternary alluvium
Terrace-bound valley (TBV)	<2%, mean 1%	<2X ACW	>2X ACW	Meandering or sinuous, stable	Uplifted, flat valleys floored by competent sandstone strata, 10-100m elevation	Uplifted, bedrock-floored strath terraces, local hillslope contact; channel floor and banks are bedrock or consolidated alluvium	Quaternary fluvial terraces, Tertiary sedimentary rocks, Dothan formation metasediments
Alluviated canyon (AC)	<7%, mean 1%	1.2-2X ACW	1.2-2X ACW	Sinuous or straight	Transition zone between steep, headwater canyons and alluvial valleys, or as isolated flats within mountain canyons, 10-500 m elevation	Narrow, discontinuous floodplains, bounded by colluvial complex or competent hillslopes	All formations, especially at faults, shear zones, contacts, paleolandslides
Colluvial canyon (CC)	1-20%, mean 5%	=ACW	=ACW	Straight	Steep, narrow canyons in headwater and mid-basin areas, 10-800 m elevation	Angular boulders, cobbles in deep, fine-textured matrix of colluvium; at least one side slope shows paleolandslide, creep-earthflow, slump, blockslide, debris slide features (colluvial complex)	Incompetent rocks in fault or shear zones, paleolandslides, or where colluvial deposits occur along toeslopes
Competent bedrock canyon (BRC)	0.5-20% mean 2%	=ACW	=ACW	Straight	Steep, narrow canyons in headwater and mid-basin areas, 10-800 m elevation	Bounded both sides by steep, competent hillslopes with shallow skeletal or sandy soils, locally talus	Competent rocks, various formations

Table 2. Continued.

Valley segment type	Valley slope	Floodplain width[a]	Valley width[a,b]	Channel pattern	Landscape position	Geomorphic surfaces and soils	Dominant Geology
Glacial lake (GL)	Level	--	--	Ponded	Glaciated cirque basins and troughs, ridgelines and peaks >750 m elevation	Glacial moraines, periglacial colluvium, talus, and steep, glacially scoured competent hillslopes	Quaternary glacial deposits within various rock formations of high Klamath peaks
Slump lake (SL)	Level	--	--	Ponded	Small basins or saddles in headwaters, 300-800 m elevation	Colluvial complex slopes predominantly large slump-earthflow features	In shear zones of Jurassic age metasediments and serpentine masses; or where Tertiary sediments overlie sheared older rocks
Dune lake and wetland complex (DL)	Level	--	--	Ponded	Coastal margins with active or stabilized dunes, <10 m elevation	Sandy beach, dune, and marine terrace deposits, with silt and sand alluvial and lacustrine deposits on extensive floodplains and alluvial terraces	Quaternary alluvium, beach and dune deposits, Quaternary marine and fluvial terraces
Estuary and estuarine wetlands (EST)	Tidally variable	--	--	Ponded, or braided at low tide	Mouths of rivers and major streams, at sea level	Sandy beach and dune lands, silty and sandy floodplains, sandy alluvial and marine terraces adjacent	Active beach and dune lands, Quaternary alluvium, fluvial and marine terraces

[a] Includes width of active channel; ACW = mean active channel width of segment; for fluvial segments only.
[b] Includes width of active channel, floodplain, and alluvial fans and terraces forming valley fill.

Figure 3. Broad-scale distribution of valley segment types of lakes and fourth-order or larger streams across the study area. In this map alluvial fan-influenced valleys are not differentiated from alluvial valleys, and colluvial canyons are not discriminated from competent bedrock canyons, due to limitations of map interpretation and field verification at this scale. Some short (<200 m) alluviated canyon segments also do not appear. Letter codes indicate geomorphic subregions defined by their diversity of valley segment types. a: Klamath Uplands, the regional matrix of dissected, mountainous terrain composed of narrow canyons and isolated alluviated canyons. b: Langlois Plain, coastal lowlands with dune-formed lakes and wetlands. c: Cape Blanco Shelf, uplifted coastal plain with alluvial valleys and estuaries dissecting marine terraces. d: Powers Valley, interior basin with terrace-bound valleys incised in Tertiary-age sedimentary rocks. e: Agness shear zone, slump-formed lakes on highly sheared and faulted metasedimentary rocks. f: Ophir-Pistol shelf, narrow coastal benches with alluvial valleys and estuaries, local marine terraces and small dunes. g: Klamath-Siskiyou peaks, high-elevation uplands with glacially-formed lake basins. h: Franciscan terraces, terrace-bound-valleys incised in uplifted strath terraces of Dothan or Franciscan sandstones. i: Del Norte shelf, northern end of a series of subsident coastal benches extending south into California, associated with broad alluvial valleys and sand-formed estuaries or large lagoons.

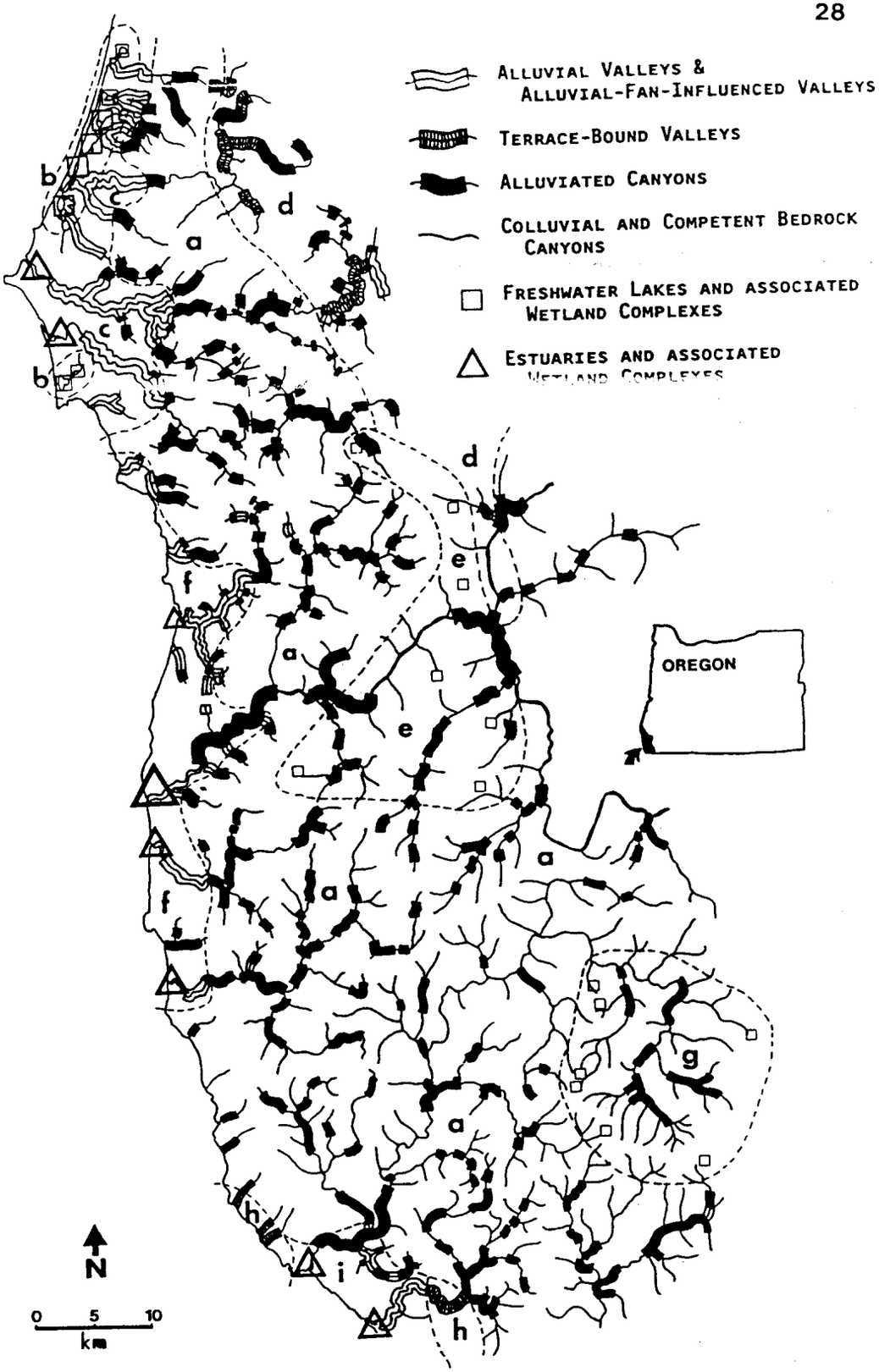
Alluvial Valleys &
Alluvial-Fan-Influenced Valleys
Terrace-Bound Valleys
Alluviated Canyons
Colluvial and Competent Bedrock
Canyons
Freshwater Lakes and associated
Wetland Complexes
Estuaries and associated
Wetland Complexes
OREGON
N
0 5 10
km

Figure 3

Table 3. Percent of each valley segment type located primarily within indicated geologic map unit[a]

Valley segment type[b]	Quaternary		Tertiary	Cretaceous	Jurassic				
	Alluvium and fluvial terraces	Marine terraces	Sandstones and Siltstones	Conglomerate, sandstone, and siltstone	Otter Point meta-sedimentary	Serpentine and peridotite	Colebrook schist	Galice shales	Otter Point meta-volcanics
Alluvial valleys (17)	76.5	5.9	0	0	0	0	0	0	0
Alluvial-fan-influenced valleys (1)	100.0	0	0	0	0	0	0	0	0
Terrace-bound valleys (1)	100.0	0	0	0	0	0	0	0	0
Alluviated canyons (33)	0	0	6.1	51.5	33.3	0	3.0	6.1	0
Colluvial canyons (178)	0	0	7.9	32.6	47.8	0.5	5.0	3.4	2.8
Competent bedrock canyons (55)	0	0	7.3	87.3	1.8	0	1.8	1.8	0
Dune lakes (4)	25.0	75.0	0	0	0	0	0	0	0
Estuaries (6)	66.7	33.3	0	0	0	0	0	0	0
All segment types combined	6.5	2.7	6.8	41.8	33.3	0.3	3.7	3.1	1.7

[a] Sample from selected portions of northwest quarter of study area (see text).
[b] In parentheses is number of segments sampled in category.

Figure 4. Maps of valley segments in Sixes River (a) and Euchre Creek (b) basins. Bedrock geology (sources cited in text) is indicated to show relationships between geology and valley geomorphology. Fourth-order and larger streams and lakes are shown. Segment classification in these basins is about 90 percent field verified.

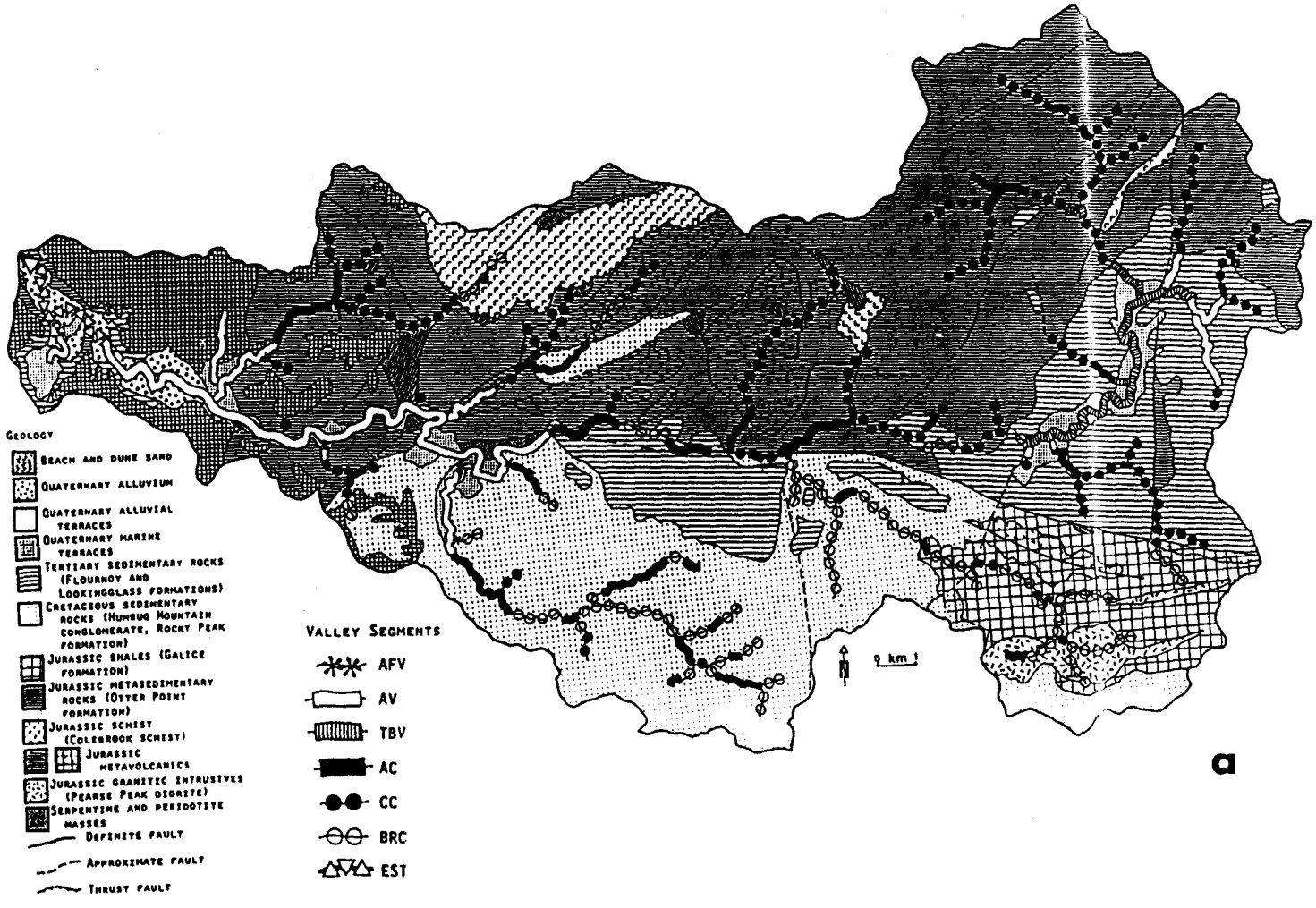
Geology
Beach and dune sand
Quaternary alluvium
Quaternary alluvial terraces
Quaternary marine terraces
Tertiary sedimentary rocks (Flournoy and Lookinglass formations)
Cretaceous sedimentary rocks (Humbug Mountain conglomerate, Rocky Peak formation)
Jurassic shales (Galice formation)
Jurassic metasedimentary rocks (Otter Point formation)
Jurassic schist (Colebrook schist)
Jurassic metavolcanics
Jurassic granitic intrusives (Pearse Peak diorite)
Serpentine and peridotite masses
Definite fault
Approximate fault
Thrust fault
Valley Segments
AFV
AV
TBV
AC
CC
BRC
EST
N
0 km 1
a

Figure 4

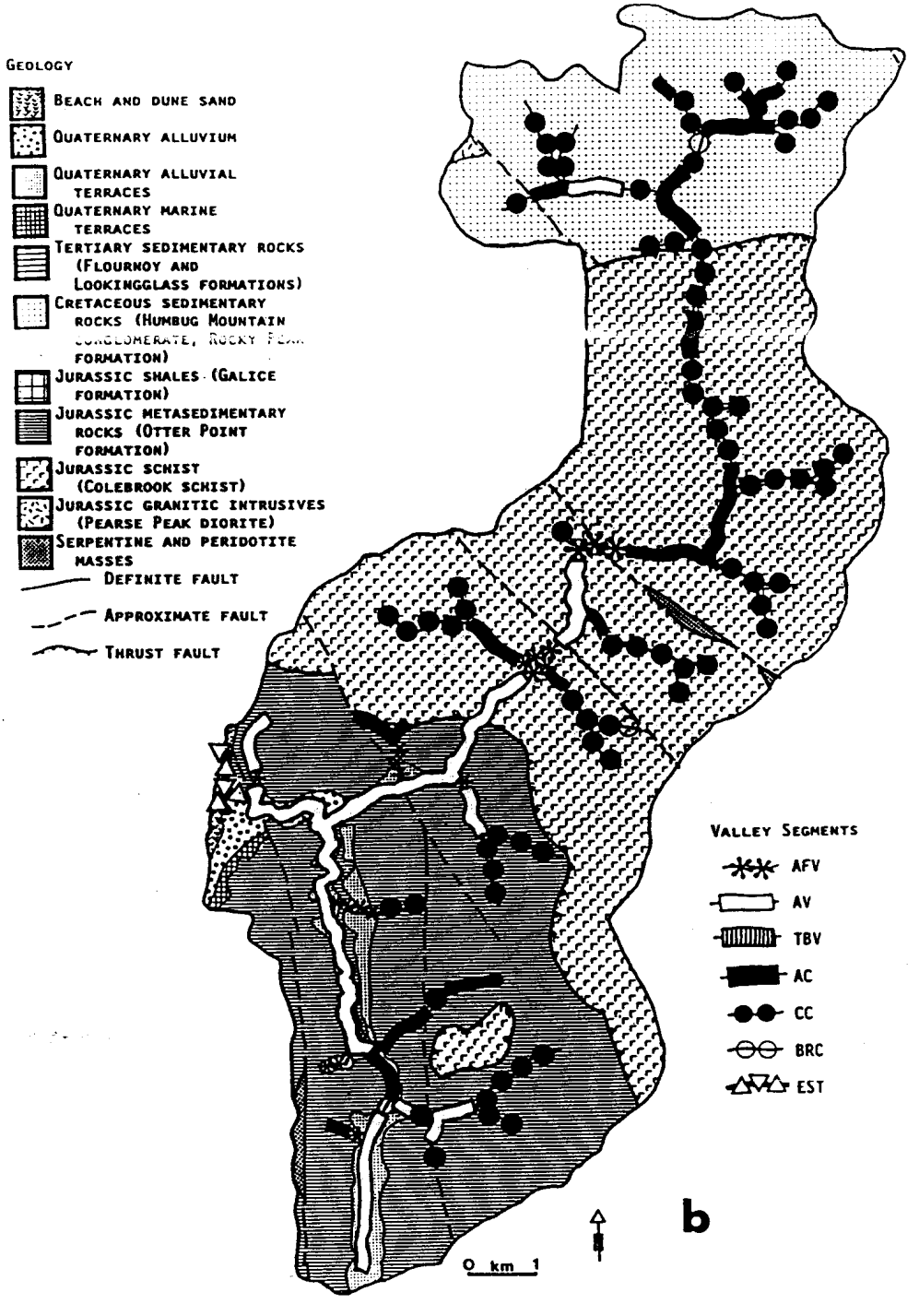
Geology
Beach and dune sand
Quaternary alluvium
Quaternary alluvial terraces
Quaternary marine terraces
Tertiary sedimentary rocks (Flournoy and Lookingglass formations)
Cretaceous sedimentary rocks (Humbug Mountain
formation)
Jurassic shales (Galice formation)
Jurassic metasedimentary rocks (Otter Point formation)
Jurassic schist (Colebrook schist)
Jurassic granitic intrusives (Pearse Peak diorite)
Serpentine and peridotite masses
Definite fault
Approximate fault
Thrust fault
Valley Segments
AFV
AV
TBV
AC
CC
BRC
EST
b
0 km 1

Figure 4

metasedimentary rock formation. Conversely, bedrock canyons are more frequent and colluvial canyons less frequent within areas of the more competent Cretaceous sedimentary rocks (Chi-square test, $P < 0.0001$). Hillslopes in both types of canyon typically assume the convex form of an inner gorge, indicating a tectonically rejuvenated landscape (Kelsey 1988).

Alluviated canyons have developed where faulted or sheared, incompetent hillslopes have allowed limited valley floor widening and landslide-caused constrictions or tectonic deformation have encouraged fluvial deposition (McHugh 1987, Kelsey 1988, Swanson et al. 1990). Alluviated canyons are not strongly associated with any particular geologic map unit (Table 3). Alluviated canyons are distinguished in the field and on detailed topographic maps by narrow, often discontinuous floodplains of Recent alluvium, but due to their small size these deposits are rarely delineated on geologic maps. Since Table 2 is derived from geologic maps, the geologic aspects of alluviated canyons and colluvial canyons appear very similar. It seems likely that colluvial and alluviated canyons are closely associated in geomorphic origin, and perhaps evolutionary transitions between them are common over a time frame of tens or hundreds of thousands of years: large-scale slope failure occurs, the debris is subsequently excavated by fluvial processes, and another cycle of failure is initiated. Fault movement or other tectonically-driven landscape deformation may be the initial trigger for many of these large landslide features.

Alluvial valleys primarily encompass coastal plains and river mouths where river canyons have been filled with Quaternary alluvium (Fig. 3, Fig. 4), probably during interglacial periods of high sea level (Beaulieau and Hughes 1976) or as a result of local tectonic subsidence (Kelsey 1988). Most of the alluvial valleys include extensive high terraces, as well as active floodplains, and are commonly bordered by colluvial complex slopes. These slopes contain relict landslide features that were probably extensively

active prior to valley filling (Late Pleistocene or early Holocene?), but today fail primarily where they are undercut by the outside edge of a stream meander.

We have identified only a few alluvial-fan-influenced valleys in the study area. They occur where tributaries draining highly unstable colluvial hillslopes join a mainstem channel on a broad valley floor. The formation over centuries of a large fan of alluvial and debris flow deposits at the tributary mouth creates highly unstable, complex channel and groundwater networks in the tributary, and sometimes also in the main stream adjacent to and upstream from the fan.

Terrace-bound-valleys are common in two areas, one in the northeastern portion of the study area in association with Tertiary-age sedimentary deposits (Fig. 3, Fig. 4a), and a second along the southern coastal margin (extending south into northwestern California) in association with fluvial terraces overlying Dothan or Franciscan formation sandstones (Fig. 3). Terrace-bound valleys have sinuous or meandering channels incised into broad, bedrock-floored strath terraces. These gently-sloping, entrenched channels may have formed partly as a result of the unusual susceptibility of certain bedded sandstones to fluvial corrasion of the channel floor (Ashley et al. 1988), but likely have developed in response to late Pleistocene or Holocene uplift of pre-existing alluvial valleys (Muhs et al. 1987, Kelsey 1988).

Lacustrine segment types are highly clustered in space (Fig. 3), and the pattern reflects their diverse geomorphic origins. Dune-formed lakes and associated wetland complexes occur at sea level on the widest coastal plain, near Cape Blanco. They are associated with Holocene beach sands and dunes, uplifted marine terraces of Pleistocene age (Kelsey 1990), and alluvial deposits at river mouths. A second group of small lakes and bogs-- sag ponds formed in depressions within slump and earthflow landforms-- is scattered in uplands on sheared sedimentary, metasedimentary, and ultramafic rocks of the central portion of the study area. The third lacustrine type

encompasses of high-altitude, glacial-origin lakes near ridgetops in the Kalmiopsis Wilderness. Small, sand-bedded, interannually unstable estuaries occur at the mouths of larger basins in the study area, formed by the interaction of seasonally transported beach sands, fluvial deposits, and associated dune sets (Clifton et al. 1973).

Table 3 provides some indication of the relative extent of different valley segment types in the region as a whole. About 60 percent of the valley segments surveyed in this portion of the study area were colluvial canyons, about 20 percent were competent bedrock canyons, and 11 percent were alluviated canyons. Alluvial valleys, alluvial-fan-influenced valleys, and lakes and estuaries comprised the remaining 9 percent. In general, low-gradient, alluviated canyons or alluvial segment types rich in floodplains, which harbor much of the region's fish diversity, encompass less than 20 percent of its stream valleys.

3.2 Valley Slope, Rock Type, and Landscape Development

Valley floor slope, as measured on topographic maps, varies by valley segment type. In general, valley slopes were lowest in alluvial valleys, slightly greater in alluviated canyons, much greater in bedrock canyons, and greatest in colluvial canyons. These differences are partly a function of whether segments tend to be located high or low in the drainage network. More importantly, downstream changes in valley slope differed among segment types (Fig. 5), and irregularities in downstream profiles were associated with the sequence of valley segment types present. We speculate these differences reflect different geomorphic processes controlling the evolution of river valleys.

For a given stream order, valley slope declined more rapidly downstream in competent bedrock canyons than in colluvial canyons and other segment types (Fig. 5,

Figure 5. Valley slope as a function of Strahler stream order for third-order and larger channels in four fluvial segment types. Note that y-axis scale varies. Curves are predicted means based on regression of $\log_e$ slope on order. Data derived from 1:24,000-scale topographic maps.

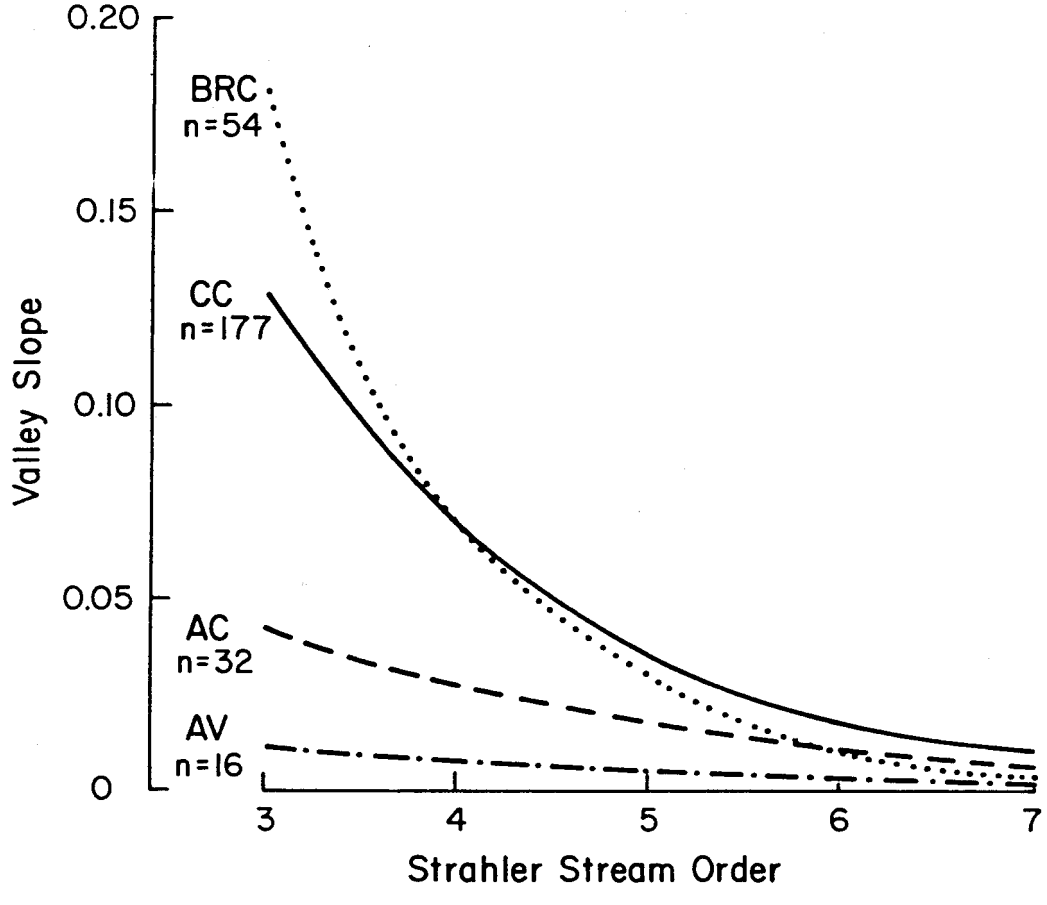
0.20
0.15
0.10
0.05
0
Valley Slope
BRC
n=54
CC
n=177
AC
n=32
AV
n=16
3
4
5
6
7
Strahler Stream Order

Figure 5

Table 4. Regression parameters and their 95 percent confidence intervals for the regression of $\log_e$ valley slope on Strahler stream order, in four valley segment types.

			Slope			y-intercept		
				95% C.I.			95% C.I.	
Segment Type	R^2	P-value	Predicted	Min.	Max.	Predicted	Min.	Max.
Alluvial Valleys	0.345	0.013	-0.47	-0.82	-0.11	-3.11	-4.99	0.29
Alluviated Canyons	0.505	0.000	-0.46	-0.63	-0.29	-1.80	-2.63	-0.98
Colluvial Canyons	0.433	0.000	-0.62	-0.73	-0.52	-0.15	-0.51	0.25
Competent Bedrock Canyons	0.707	0.000	-0.88	-1.09	-0.73	0.93	0.32	1.55

Table 4); in other words, competent bedrock canyons were relatively steeper than other segment types in low-order, headwater streams, but relatively low in gradient among higher-order, mainstem rivers. This could reflect an ability of larger streams to carve graded profiles through competent rocks where deep gorges can develop without collapsing, while small, headwater streams lack the power to incise into hard rock and thus are only slightly less steep than adjacent competent hillslopes. By contrast, colluvial canyons are frequently re-loaded with coarse sediment as oversteepened hillslopes fall into the channel, preventing even higher-order streams with high stream power from reaching a graded state. As watersheds develop over periods of thousands of years, colluvial canyons can be viewed as the primary zones of rapid erosion, bedrock canyons primarily function as stable transport zones, and alluvial valleys serve as zones of deposition and storage of alluvium.

Geology and valley slope are correlated with the valley shape variables we used to classify segments in this analysis, and segment type accounted for most of the variation among streams in valley slope. However, we wanted to determine the extent to which bedrock geology influences variation in valley and channel slope within segment types. For example, bedrock geology could affect the long-term development and present-day state of competent bedrock canyons and colluvial canyons in much different ways, because the geomorphic processes linking hillslopes to stream channels differ dramatically between the two canyon types. By regressing the log-transformed slope against stream order, then performing one-way ANOVA on the residuals classified by channel-adjacent bedrock type, we could assess whether for a given segment type there were any consistent deviations from the mean channel slope/stream order relationship that could be explained by differences in bedrock geology of side-slopes. Only for colluvial canyons did we detect significant variation among residuals associated with geology ($P<0.001$). Among colluvial canyons, streams passing through Colebrook

schist had the lowest slopes, those in Cretaceous sediments and Otter Point metamorphic rocks had intermediate slopes, and streams in Galice formation shales and Tertiary sedimentary rocks were steepest.

Colluvial canyons, therefore, appear to be more sensitive to variation in bedrock geology than are other valley segment types. We speculate that in colluvial canyons, where over a time frame of centuries channels are frequently loaded from hillslope failures, valley slope is a function of particle size and resistance of the material delivered (Hack 1957, Milne 1982). Valley slopes are therefore lowest for rock types delivering primarily small rock fragments (Cretaceous sediments) or clasts that are rapidly broken down in the fluvial environment (e.g., Colebrook schist). Valley slopes are steeper in less friable, less sheared (e.g., Tertiary sediments), or more highly metamorphosed (e.g., Galice formation) rocks where large, hard clasts are delivered. Geology and clast size makes less difference in other segment types, where delivery rates of hillslope material are low relative to transport capacity (competent bedrock canyons) or channel form is largely determined by deposition and reworking of alluvium (alluvial valleys, alluviated canyons).

Alternatively, one could hypothesize a tectonic explanation for differences in valley slope among colluvial canyons in this actively uplifting landscape (Kelsey 1988, Kelsey 1990). Within the sample area, for example, the rate of uplift in the area dominated by Tertiary sediments and Galice shales could, by coincidence, have exceeded that in the area with other rock types, steepening stream channels there. However, the close intermingling of Tertiary sediments and Galice shales (having steep-floored colluvial canyons) with Cretaceous sedimentary rocks (with relatively gently-sloping canyon floors) in the precipituous, dramatically uplifted southern portion of the sample area (Fig. 4) argues against a purely tectonic explanation for the differences in valley slope seen among different rock types. Over time periods of millenia, differential

uplift undoubtedly has influenced valley form and channel profiles in the study area, but any such effects appear to be mediated or overwhelmed by large-scale hillslope processes partly determined by pre-existing valley and channel floor geology. The secondary geomorphic processes of landscape development, triggered by faulting, shearing, and failure of valley slopes, may obscure the direct effects of tectonic deformation on stream networks.

Because geologic mappers use geomorphic cues to interpret boundaries of their map units, and lithology and tectonic history exert strong control over the geomorphic processes and the development of landforms, geomorphic and geologic data derived from maps should not be considered strictly independent. Our interpretations of causal mechanisms, therefore, are not conclusive. However, the analysis does confirm that in the study area, as elsewhere in mountainous regions (e.g., Hack 1957, Keller and Tally 1979, Kelsey 1988), valley structure largely reflects the underlying geology.

3.3 Floodplain and Valley Width

A longitudinal view of three valley segments in Edson Creek illustrates covariation among valley and floodplain width, geology, geomorphic surfaces, and pool-forming channel features in the channel (Fig. 6). Floodplains widen as the stream passes through less competent rock formations, emerging from a narrow bedrock canyon into a transitional, rather narrow alluvial valley, then finally a wide alluvial valley. The influence of hillslope landforms decreases downstream, and pool-forming roughness elements shift from bedrock and boulders in the bedrock canyon to large wood, tree roots, and eroding cutbanks in the alluvial valley.

Field data verified and clarified the differences in valley floor slope and floodplain

Figure 6. Downstream gradient in channel, floodplain, and valley width, and geologic and geomorphic conditions in three valley segments of Edson Creek, tributary to Sixes River. Floodplain width includes active channel, and valley width includes width of floodplain and active channel. AV1 is a wide alluvial valley with extensive terraces and a meandering channel pattern. AV2 is a narrower alluvial valley, lacking high terraces and having a sinuous channel pattern. BRC is a bedrock-walled canyon, with very sparse, discontinuous floodplains and a straight channel pattern. Valley structure reflects geologic properties of the watershed, as indicated. Inset bar chart depicts relative frequency of geomorphic surfaces along the channel margin; SS = steep competent hillslopes, CC = colluvial complex slopes, ST = strath terraces, AF = alluvial fans, FP = floodplains. Pie diagrams show relative frequency of pool-forming features; BR = bedrock, B = boulders, LWD = large woody debris, TRC = tree roots and eroding cutbanks.

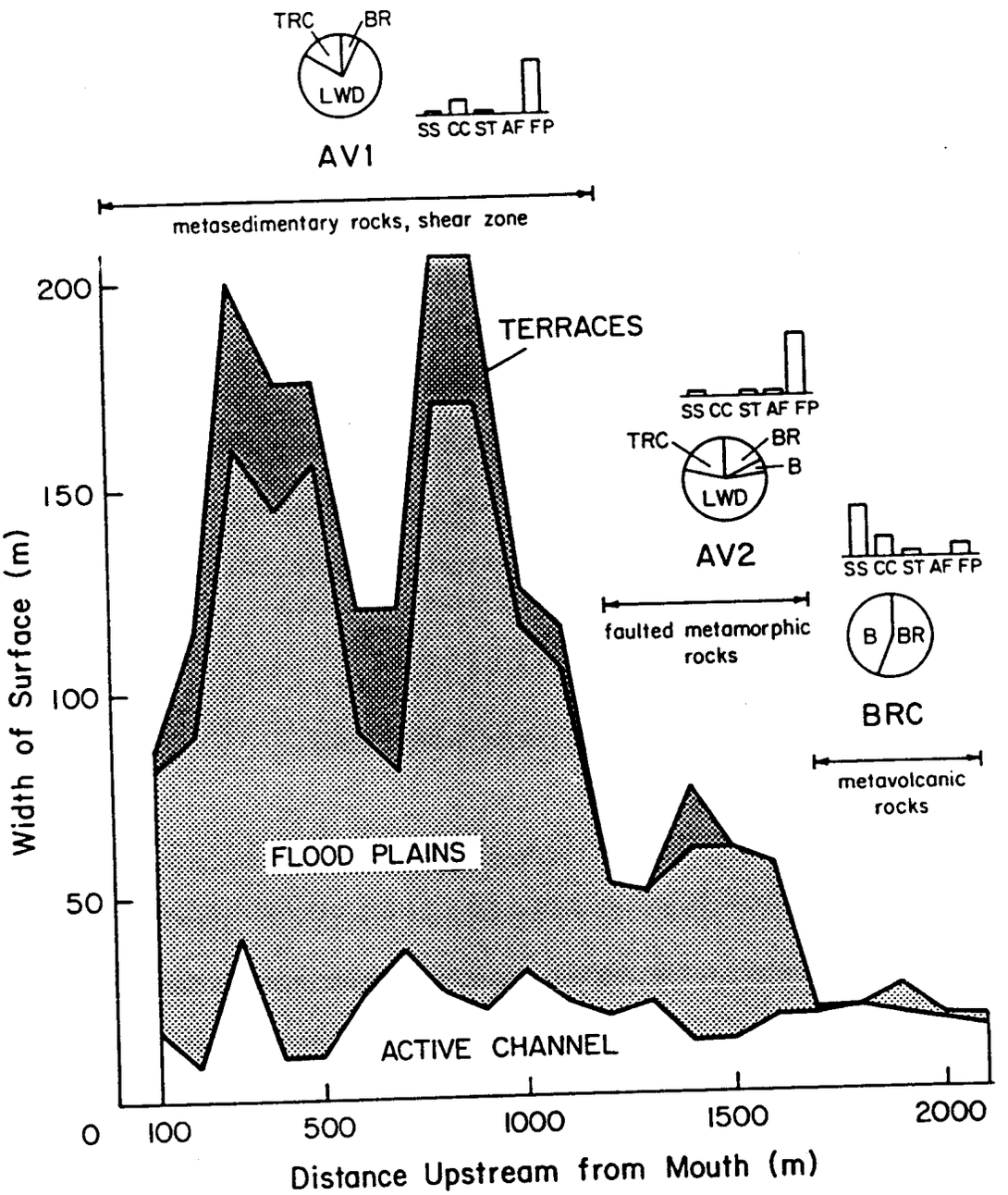
TRC
BR
LWD
SS CC ST AF FP
AV1
metasedimentary rocks, shear zone
TERRACES
SS CC ST AF FP
TRC
BR
B
LWD
AV2
faulted metamorphic rocks
SS CC ST AF FP
B
BR
BRC
metavolcanic rocks
FLOOD PLAINS
ACTIVE CHANNEL
Width of Surface (m)
200
150
100
50
0
100
500
1000
1500
2000
Distance Upstream from Mouth (m)

Figure 6

width that we used to classify valley segments from topographic maps. A bivariate plot of field measurements of the ratio of active channel width to floodplain width (a scaling factor for stream size) against channel slope provides a simple ordination in which segment types can be seen as rough clusters (Fig. 7). Valley width and valley slope are in general inversely correlated (Richards 1982, Harris 1988, Kelsey 1988), and field measurements of valley or channel slope closely approximated valley slope measured from topographic maps. Canyon types are not easily differentiated from each other on this plot, because they are discriminated largely based on the stability of stream-adjacent hillslopes, rather than morphometric variables. It is likely that with the addition of more observations, overlap would increase between segment types in this ordination space, but it is unlikely that the centroids of the clusters would change much. Field data on this plot cover much of the range of geologic conditions in the study region.

3.4 Streamside Geomorphic Surfaces and Processes

Field data confirmed that frequency distributions of stream-adjacent geomorphic surfaces differed significantly among segment types (Fig. 8). Steep slopes dominated bedrock canyons, where they were about three times more abundant than in all other segment types (one-way ANOVA, $P<0.001$). Stable slopes of moderate steepness were rare in the study area; we recorded them only in two alluviated canyon segments. Predictably, colluvial complex slopes dominated colluvial canyon segments, where they were 2-3 times more abundant than in any other segment type (ANOVA, $P<0.001$). Colluvial complex slopes are surfaces with deep regolith having poorly developed soil profiles, including active or metastable slump-earthflows and blockslides, creep-prone

Figure 7. Simple ordination of valley segments by field measurements of ratio of active channel width to floodplain width and mean channel slope. Dashed lines define clusters by segment type.

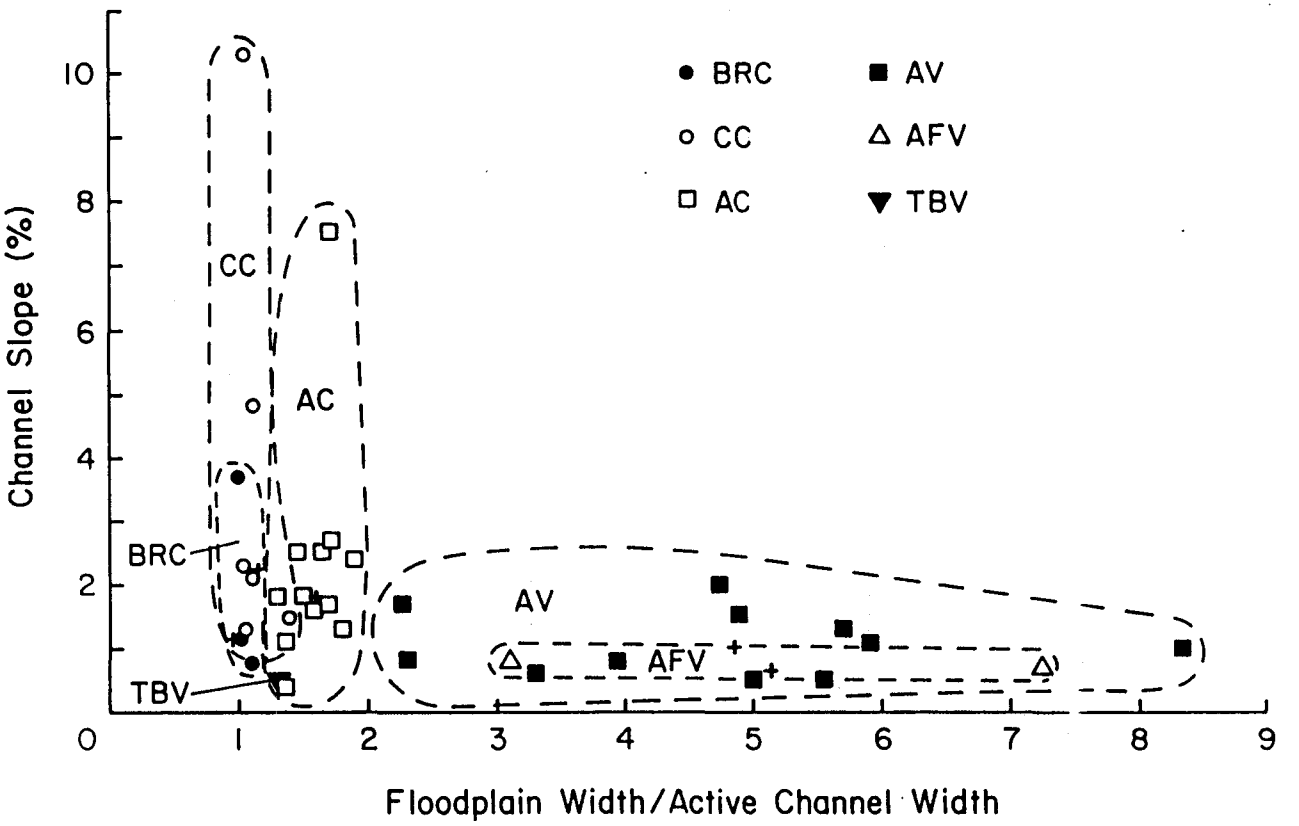
BRC
CC
AC
AV
AFV
TBV
Channel Slope (%)
Floodplain Width/Active Channel Width
0
1
2
3
4
5
6
7
8
9
10

Figure 7

Figure 8. Mean frequency distribution of channel-adjacent geomorphic surfaces in field surveys. Data for upper and lower Big Creek colluvial canyons are aggregated to compensate for small sample size. In parentheses is number of segments in sample.

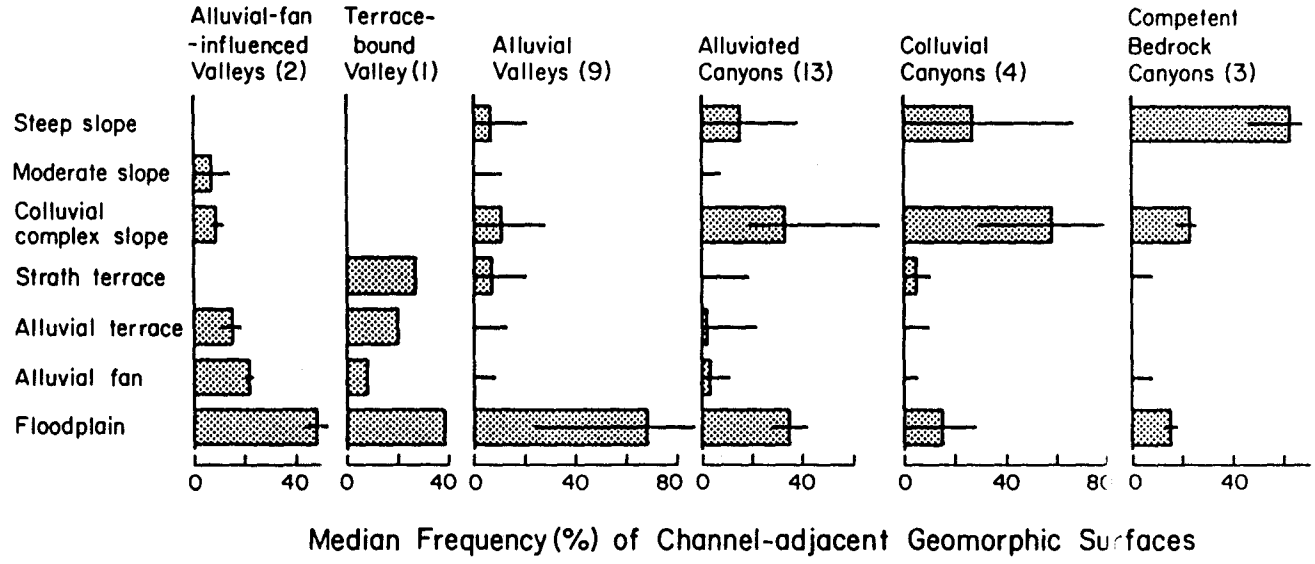
Alluvial-fan -influenced Valleys (2)
Terrace-bound Valley (1)
Alluvial Valleys (9)
Alluviated Canyons (13)
Colluvial Canyons (4)
Competent Bedrock Canyons (3)
Steep slope
Moderate slope
Colluvial complex slope
Strath terrace
Alluvial terrace
Alluvial fan
Floodplain
0
40
80
Median Frequency (%) of Channel-adjacent Geomorphic Surfaces

Figure 8

hillslopes with remnant landslide morphology, or toeslope accumulations of colluvium derived from numerous, smaller up-slope failures. Bedrock-floored strath terraces and terraces of unconsolidated alluvium occurred as scattered, remnant surfaces.

Of the streams where we conducted field surveys, terraces occurred as continuous features only along the terrace-bound valley segment. Likewise, small depositional fans of colluvial and alluvial origin occurred at low frequency in nearly all segment types, being widespread only in the alluvial-fan-influenced valley of Euchre Creek. Floodplains were about twice as frequent in alluvial valleys as in alluviated canyons (ANOVA, $P<0.001$), and were occasionally present but infrequent in bedrock and colluvial canyons. Floodplains in alluvial valleys and alluvial-fan-influenced valleys were broad and continuous, whereas those in alluviated canyons and the terrace-bound valley were narrow and often disjunct. In narrow canyons floodplains occurred as very small, isolated features associated with large boulders, bedrock outcrops, or woody debris jams.

Processes of slope erosion differed substantially among segment types (Fig. 9). Most slope erosion adjacent to the study reaches occurred as mass failure, with occasional instances of gully erosion of tributaries and valley floor surfaces. Alluvial valleys and the terrace-bound valley had relatively low incidence of slope erosion, as might be expected given their infrequent contact with hillslope surfaces. Slope failures were very frequent, however, along alluviated canyons, where large, translational, streamside debris slides were common along colluvial complex slopes.

Alluviated canyons appear to be especially vulnerable to secondary effects triggered by aggradation and widening of stream channels following increased sediment delivery from upstream sources. Aggradation reduces channel stability and forces the stream laterally against unstable toeslopes, triggering streamside slides (Hagans et al. 1986). The frequency and persistence of streamside landslides in alluviated canyons

Figure 9. Mean linear frequency (left) and estimated volume (right) of sediment contributed to streams from riparian hillslopes, based on field surveys. Number below vertical axis is total distance surveyed.

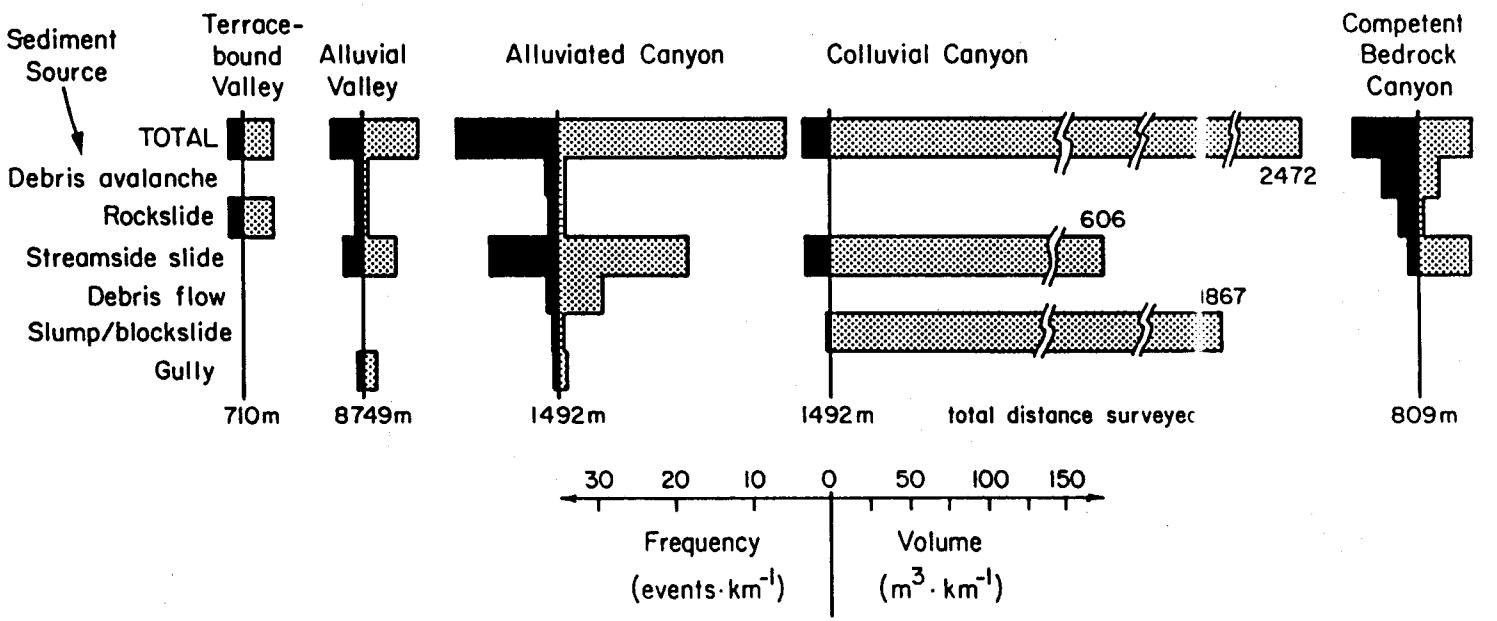
Sediment Source
Terrace-bound Valley
Alluvial Valley
Alluviated Canyon
Colluvial Canyon
Competent Bedrock Canyon
TOTAL
Debris avalanche
Rockslide
Streamside slide
Debris flow
Slump/blockslide
Gully
2472
606
1867
710m
8749m
1492m
1492m
total distance surveyed
809m
30 20 10 0 50 100 150
Frequency (events·km⁻¹)
Volume (m³·km⁻¹)

Figure 9

may be further increased by the direct effects of roads or logging, for example, by loss of root strength following vegetation removal. Deforestation and increased groundwater can accelerate creep of colluvial complex slopes (Swanston 1979, Swanston et al. 1988), resulting in progressive slope deformation that triggers landslides in stream-adjacent, steepened toeslope areas of colluvial canyons and alluviated canyons. Streamside debris slides were the most frequent erosion source in both alluviated and colluvial canyons, but they delivered far greater volume in colluvial canyons (Fig. 10). For example, a single very large slump-blockslide, activated along the toe of a Forest Service clear cut in 1986, delivered more than 50,000 m^3 of sediment to the surveyed section of Wheeler Creek, dwarfing all other sediment sources. We have observed several other very large, active slump-earthflows and blockslides along streams in southwest Oregon, and indeed such failures are the primary process shaping inner gorge topography in colluvial canyons (Kelsey 1988). By contrast, slope failures in competent bedrock canyons are more frequent but much smaller. They are dominated by rockslides and shallow debris avalanches, rather than the deep-seated failures prevalent in colluvial canyons and along the colluvial complex slopes adjacent to alluviated canyons.

It is clear that improved understanding of the causes and effects of landslides will be critical for predicting the cumulative effects of human activities in this landscape. The valley segment types we describe markedly differ in slope-channel linkages, so this classification should prove useful in this task. The frequency of debris avalanches, debris slides, and other relatively shallow erosion processes in the Klamath Mountains is clearly increased by roads and logging of steep slopes (Amaranthus et al. 1985, Hagans et al. 1986, McHugh 1987). Very large landslides such as the Wheeler Creek feature remain problematic, for despite apparent spatial and temporal associations between logging and their movement, the causal mechanisms of failure are poorly understood.