AN ABSTRACT OF THE THESIS OF

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Title: Historical Change in Channel Form and Riparian Vegetation of the McKenzie River, Oregon

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This study examined channel structure and position and riparian vegetation and land use on the upper 70 km of the McKenzie River, Oregon in the 1940s, compared the 1940s conditions to present conditions, and explored the processes driving change in this system and the implications for aquatic habitat. The hydrologic record was analyzed, and field surveys were conducted and compared to historical habitat surveys. Riparian characteristics and channel features were digitized from aerial photographs from 1945/49 and 1986 and imported into ArcInfo GIS for analysis. Types of data digitized from the aerial photos included locations and length or area of wetted channel, active channel, tributaries, side channels, large woody debris, exposed gravel bars, roads, and dominant vegetation or land use within 200 m of the active channel.

Construction of dams on the mainstem McKenzie River and two major tributaries, Blue River and South Fork, in the 1960s has altered the flow regime and sediment supply to the mainstem McKenzie, decreasing the frequency, mean and variation of peak flows, reducing the competence of flows to move existing bedload, and cutting off sediment from over half of the drainage area. Mean peak flows decreased 44% and competence of peak flows with a 2-yr recurrence interval declined approximately 29% after dams were constructed

upriver. Adjustments to reduced sediment supply and flow alteration by dams in this system included 57% decrease in exposed gravel bars, 40% decrease in side channel length, and possible substrate coarsening (as compared to historical estimates).

Channel straightening occurred in each of three instances of channel change during the study period, and sinuosity decreased one half of the amount needed to produce a straight channel in the most susceptible, unconstrained reach. Human actions prior to high flow events played a role in the direction of channel change in each case. Over the entire study area, 7% of the main channel changed position by 30 m or more and little or no change in channel position was noted in reaches constrained by valley floors. Additional channel constraint has been produced by road construction near the channel and riprapping for roads, bridges, and residences.

Less large woody debris was observed in the 1986 channel than in the 1949 channel, indicating a reduction in pool-forming agents and channel roughness elements. Frequency of large pools ($\geq$2 m depth and >40 m^2 area) decreased 19% over the study area. The greatest loss in pools (73%) was noted in the unconstrained reach that exhibited two areas of channel change and an increase in exposed gravel bars.

Increased human use of the riparian area for roads and residential purposes has led to an increased fragmentation of the riparian landscape. Density of residential or developed patches within the riparian area has increased 215% as more and smaller areas are converted from natural vegetation to human use. Riparian area devoted to roads and residential uses has nearly doubled since the 1940s. Mean vegetation or land-use patch size has decreased from 2.2 ha to 1.6 ha as larger patches have been sub-divided, and patch and edge densities have increased. Agriculture and clearcuts for timber removal have decreased within the riparian area while continuing upslope. Riparian area in mature conifers has decreased 44% from levels in the 1940s while hardwoods have increased 45% in the riparian area. Future wood loading to the channel is reduced by a decline in mature riparian vegetation, especially mature conifers.

Channel and riparian changes noted in this study have implications for fish populations. Channel straightening, reduction in side channels, and loss of pool-forming agents reduce habitat heterogeneity and off-channel refugia.

Ecosystem management of watersheds requires evaluation of conditions across scales of time and space. The use of GIS in this study made it possible to detect changes in channel form and riparian conditions during four decades, along a 70-m channel and 90-m riparian area and to analyze the large data sets relevant to understanding functions and change in channels and riparian areas.

Historical Change in Channel Form and Riparian Vegetation of the McKenzie River, Oregon

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Historical Change in Channel Form and Riparian Vegetation of the McKenzie River, Oregon

Introduction

Fisheries scientists have expanded the scale of their concern from populations to ecosystems with the growing awareness that habitat quality in an entire river basin has an important bearing on local fish populations and sustainability of anadromous runs. Assessment of salmon stocks at risk (Nehlsen et al. 1991), combined with recent efforts to develop management options based on scientific understanding of forested ecosystems and their dependent species, including salmon, have led to an attempt to implement ecosystem management at a landscape scale (Johnson et al. 1991; FEMAT 1993).

Ecosystem components in large river basins are linked through important ecological processes acting at different scales (Johnson 1990). Application of ecosystem management to large river basins requires ecologically relevant data upon which management decisions can be based because scientists and managers must be able to separate reaction to anthropogenic disturbance from natural variation (Gore et al. 1990). Approaches are needed to clarify spatial and temporal variation inherent to a large watershed, determine extent and timing of channel and riparian changes, assess cumulative effects, analyze trends, and ascertain impact of these changes on aquatic habitat.

Channel Geomorphology

River channel morphology is determined by geology and climate over long periods of time (i.e., centuries to thousands of years), in concert with processes that influence the channel hydraulics and operate over shorter periods of time (i.e., years to decades)(Schumm 1965). At longer time scales, vulcanism, earthquakes, and climate determine the shape of the land, set drainage patterns and influence the evolution and character of biotic communities. River gradient, underlying geology, natural flow regime, location and size of tributaries, relative width of floodplains in relation to active channels, and degree of valley constraint on channels influence geomorphic processes that form channels and river valleys.

Over decades to centuries, channels adjust to the characteristic flow and sediment regime of the system (Petts and Foster 1985). When controlling variables change (e.g., discharge, input sediment load, bed and bank sediment size or slope) there are several degrees of freedom within which the channel can adjust: 1) cross-sectional form, including wetted perimeter, hydraulic radius, and maximum depth; 2) channel slope; 3) planform, including sinuosity and meander wavelength; 4) velocity; and 5) bedform, including dune wavelength and height (Hey 1978). These components mutually adjust to absorb change and to attain a dynamic equilibrium within constraints of stream size and boundary resistance (Knighton 1984).

Channel geometry (i.e., 3-dimensional shape of the channel, including bed roughness elements) is influenced by the interaction of a range of discharges and their temporal sequence (Knighton 1984). Wolman and Miller (1960) suggest that the majority of total sediment load is carried by flows with a recurrence interval of one year or less and channel geometry is associated with flows at or near bankfull stage. In coarse-bedded rivers relative particle protrusion into the flow helps to offset differences in particle weight such that a majority of sizes of bed material are entrained within a narrow range of discharge with particles as large as the median diameter moved by discharge somewhat less than bankfull (Andrews 1983). In Cumberland Basin streams the most effective discharge for bedload transport was associated with small flows having return periods of 1.15–1.40 years (Pickup and Warner 1976). These small flows transport most of the bedload, and large flows determine channel capacity by scouring the channel bed, eroding banks, removing vegetation, and sculpting the floodplain.

Formation and Maintenance of Aquatic Habitat

Channel-forming processes shape aquatic habitat of river ecosystems. Heterogeneity of bedforms, a high degree of sinuosity, and roughness elements (e.g., boulders and large wood) can create hydraulic complexity, which in turn provides a greater variety of aquatic habitats. Habitats with a greater hydraulic complexity have more diverse fish assemblages than habitats with less variation in flow (Bisson et al. 1992). Hydrologic conditions are a critical component in the life of lotic organisms because they affect energy expended by the organism, movement, access to nutrients (Statzner et al. 1988), and availibility of refuge from disturbance (Sedell et al. 1990). Sediment delivery to the basin is critical to maintain adequate habitat for lotic organisms, including salmonids, which need substrate small enough to construct redds but large enough to prevent smothering of the developing eggs.

Structure of riparian areas can also influence channel form and habitat. Riparian vegetation provides shading, stabilization, input of allochthonous materials, uptake of nutrients, retention of particulate organic matter during high flows, and input of large woody debris (Gregory et al. 1991). Large rivers entrain wood from riparian areas by bank cutting and commonly have scattered pieces and aggregations of large woody debris on the upstream ends of islands and on river bends (Lienkaemper and Swanson 1987). Once in the channel large wood promotes lateral channel migration and annual capture and release of sediment (Nakamura and Swanson 1993).

The Natural Disturbance Regime

Large floods construct floodplain surfaces (Leopold et al 1964), maintain channel units and habitat complexity, and influence patterns of biotic succession (Poff and Ward 1989). Connectivity with the floodplain during high flow events allows the interaction of the river with the land, permitting lateral exchange of materials, nutrient recycling and increased production within the floodplain (Junk 1989). Major channel changes caused by floods include channel straightening and widening, but impacts and recovery at numerous locations vary depending upon climate, vegetation, substrate, basin size, relative magnitude of flood flow, and ability of subsequent flows to reconstruct a modified channel (Knighton 1984). Response to a major flood may vary from negligible to catastrophic (Gupta and Fox 1974; Gardner 1977; Gupta 1983; Hickin and Sichingabula 1987). Extreme floods may leave an effective imprint upon the landscape for decades because they transport coarse sediment and debris that subsequent smaller flows are unable to modify (Gupta 1983).

The natural disturbance regime in the watershed is determined by the frequency, magnitude, and duration of flood events compounded by mass failures and debris flows, and the occurrence of fires, windstorms, drought, diseases and pests. Catastrophic fires can affect the channel by decreasing riparian vegetation and increasing sediment supply to streams. Reaction of a particular channel and riparian area to a disturbance depends upon inherent geomorphic characteristics, links to hillslope processes, and prior condition of the system (Newson 1980; Nolan and Marron 1985; Kochel 1988; Miller 1990).

Anthropogenic Disturbances

Growth in human population increases demands on natural resources and subjects ecosystems to more intense human manipulation. Dam-building, channelization, clearcutting, road building, salvage of large woody debris from channels, and conversion of riparian vegetation within a watershed can affect geomorphic processes, channel form, landscape patterns, ecological function and biotic interactions. Human-induced changes can alter thresholds in watersheds, sometimes causing a change in geomorphic processes from which the system may not recover to its previous state. These human disturbances may uncouple the important ecological processes that link ecosystem components within the watershed (Stanford and Ward 1992).

Importance of Historical Context

Often people do not notice gradual changes in their environment. This short-term thinking may be a product of human evolution for which modern humans must consciously compensate before their actions irreparably damage natural ecosystems (Ornstein and Ehrlich 1989). One way to visualize the magnitude and direction of change over time is to create before and after "snapshots" of conditions over longer time scales than individual daily perceptions allow.

A watershed analysis can benefit greatly by reconstructing just such a picture of conditions in the watershed as far back as reliable data are available and comparing the historical picture to present conditions. Historical comparisons of channel and riparian conditions are important for interpreting trends within a watershed. Data from historical aerial photos can be combined with available field data in a Geographic Information System (GIS) to compare and visualize past and present conditions, integrate many variables across scales, analyze interactions between variables, and can be updated as new data become available. Historical trends in channel geomorphology, hydrology, habitat, and riparian vegetation may demonstrate fundamental relationships that increase our understanding and ability to monitor watersheds.

Objectives of this Study

This study of the McKenzie River from Trailbridge Dam to Leaburg Dam at Vida, Oregon, develops a historical context for quantification and analysis of ecosystem change over five decades based upon the following objectives:

Objective 1. Characterize the McKenzie River channel and riparian area in recent time.

- Define channel conditions in terms of channel area and position, existence of off-channel habitat (i.e., side channel number, length, and location), location of tributary junctions, area and location of stored sediment (exposed gravel bars), presence of large woody debris, and number and location of large pools.
- Describe and quantify riparian vegetation and land uses in terms of area, distribution, and type (residential or developed areas, roads, agriculture, three age classes of conifers, two age classes of hardwoods).

- Examine vegetation and land-use patterns on the riparian landscape (patch, shape, and edge characteristics).

Objective 2. Use equivalent measures (as in Objective 1) to characterize the McKenzie River channel and riparian area of the 1940s.

Objective 3. Determine the location, nature, and extent of the channel and riparian changes between the 1940s and 1980s (i.e., evaluate differences between conditions described in Objectives 1 and 2).

Objective 4. Examine specific areas showing change in main channel position at a finer time scale and develop the chronology of change through time for these locations. Investigate the possible influence of major disturbance events and human actions on the direction of change in these localized areas.

Objective 5. Assess the influence of dams (constructed during the study period) on hydrologic regime, sediment characteristics, flow competence, and change in channel position and structure.

Objective 6. Propose a context for understanding the susceptibility to change and the nature of change in this study area of the McKenzie River and possible implications for aquatic habitat.

Materials and Methods

Physical Features of the Study Area

The McKenzie River originates from Clear Lake in the Cascade Mountains east of Eugene, Oregon, flowing south for 24 km to Belknap Springs and then west 125 km, where it enters the Willamette River as a major tributary approximately doubling the discharge of the Willamette River. The elevation drops from 919 m at Clear Lake to 119 m near the junction with the Willamette River. The mean daily flow of the McKenzie River for the last 28 years is 168 cms with an average annual discharge of 5.3 x 10^9 m^3. The McKenzie River sub-basin of the Columbia River has a drainage area of 3,463 km^2.

The study area extended from Trailbridge Dam below Clear Lake, 70 km downstream to Leaburg Dam and included major tributary junctions at Lost Creek, Horse Creek, Blue River, and South Fork McKenzie River (Fig. 1). The study area comprised 72% of the McKenzie River watershed, or 2,499 km^2.

The McKenzie River begins in the broad volcanic ridge of the High Cascades where it flows through young volcanics and extensive lava flows, which contribute to the formation of a large aquifer (Wilson 1981)(Fig. 2). The river then follows a fault-defined valley 12 km south to Belkap Springs, where it turns west through the deeply incised canyons of the older Western Cascades, flowing across progressively older rocks and through a more dissected landscape (Sherrod et al. 1992). The most recent glacial advances are marked by the Lost Creek moraine downriver from Belknap Springs. Earlier glacial advances extended farther downriver to Blue River, below which bedrock outcrops are more prevalent in the channel (Walker and MacLeod 1991). Channel slope reflects the transition from volcanic to glaciated landforms as it

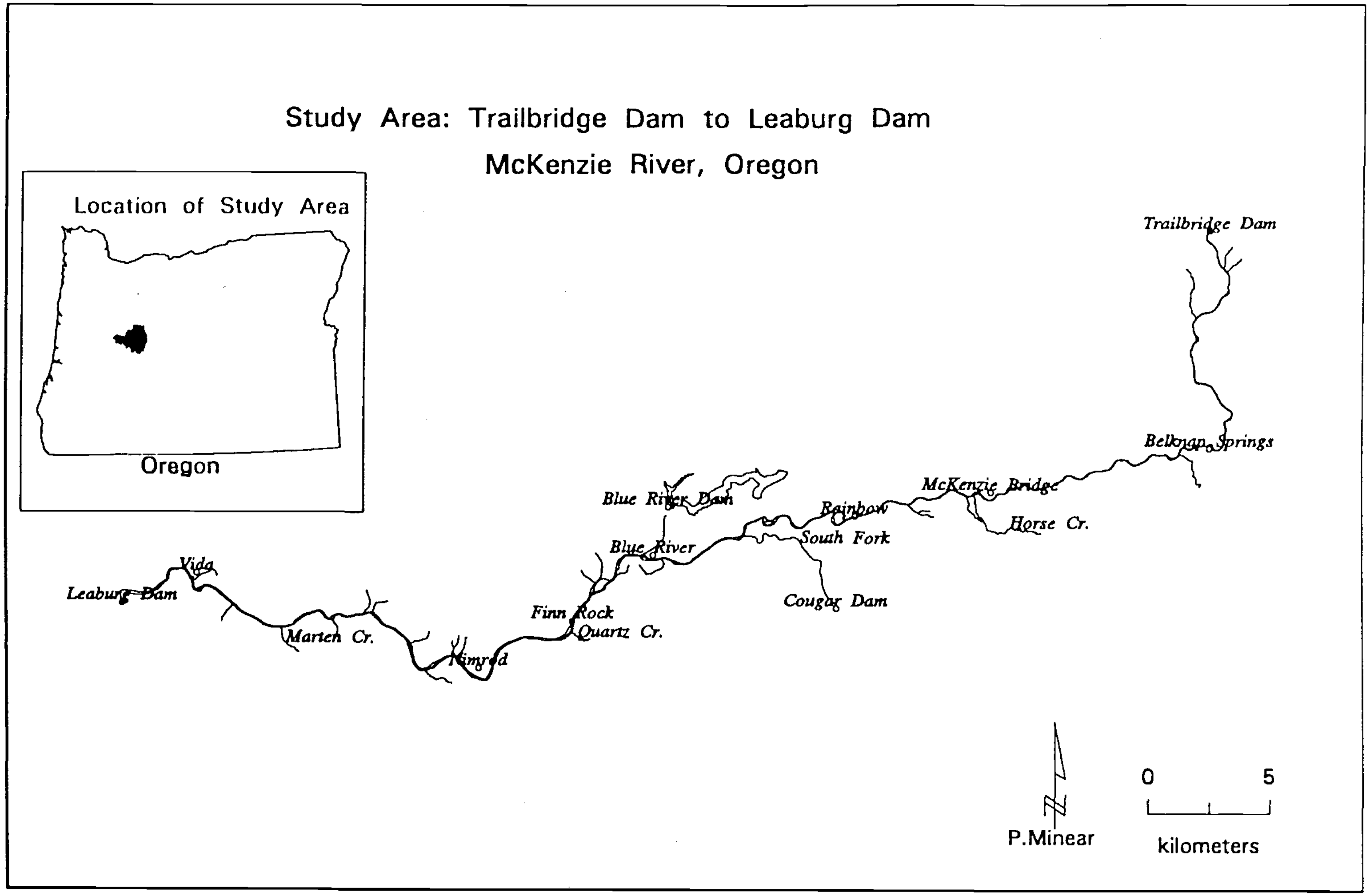

Fig. 1. Study area from Trailbridge Dam to Leaburg Dam, McKenzie River, OR.

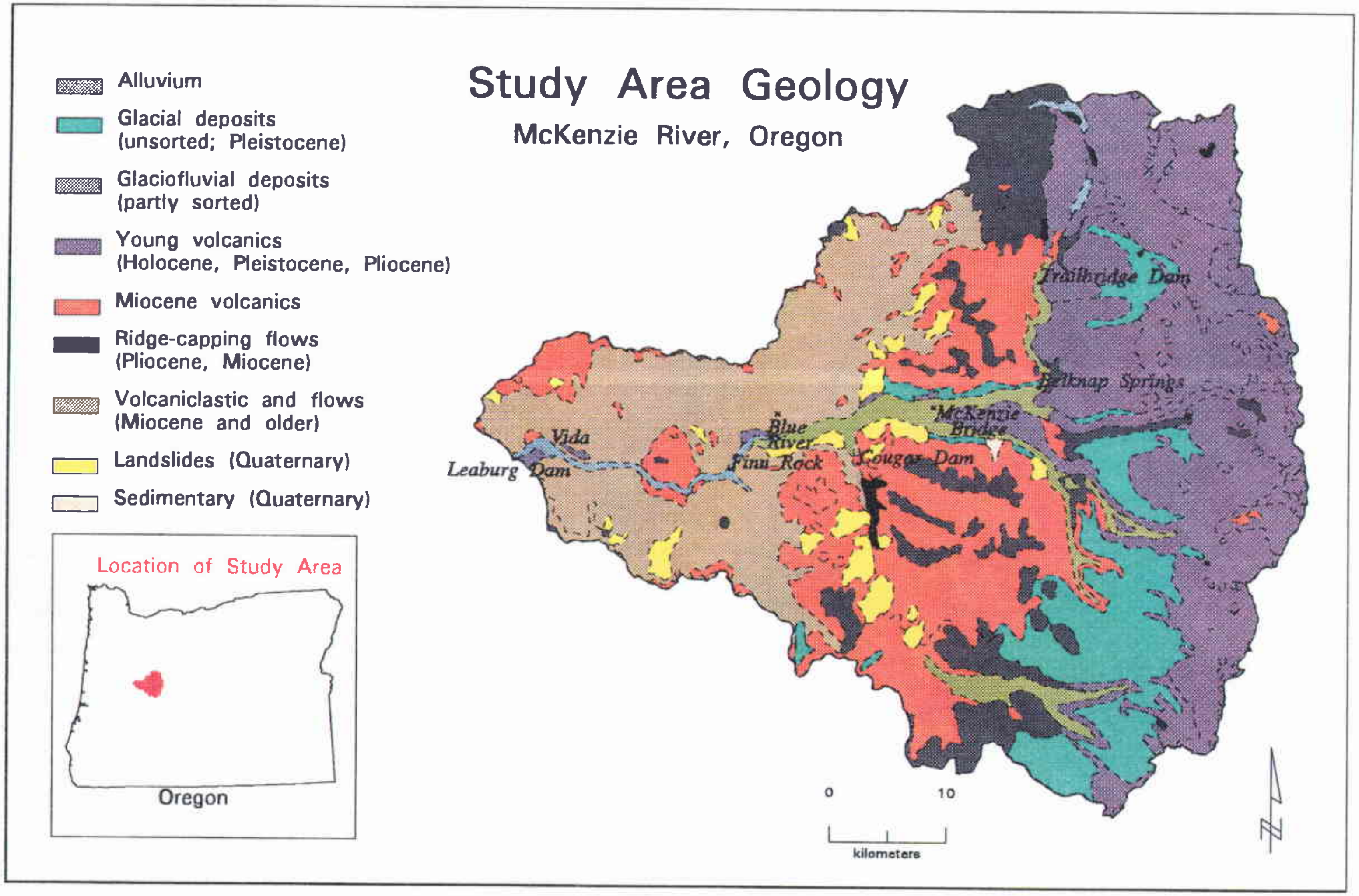

Fig. 2. Major geologic formations of the McKenzie River study area. (After Walker and MacLeod 1991).

decreases from 1.2% upriver of Belknap Springs to less than 0.4% in the area of Blue River. Major geologic formations in this portion of the McKenzie sub-basin are basaltic andesite and basalt, sorted and unsorted glacial and glaciofluvial deposits, undifferentiated flows and clastic rocks, and undifferentiated tuffaceous sedimentary rocks (Walker and MacLeod 1991). The area within the active channel and riparian area is primarily alluvium and partly sorted glacial or glaciofluvial deposits from the Pleistocene. (Appendix A: Geology and Ownership).

Natural vegetation in this area is characteristic of the *Tsuga heterophylla* zone, the most extensive vegetation zone in western Washington and Oregon, with prevalence of western hemlock, western red cedar, and Douglas fir in the overstory. (Franklin and Dyrness 1984). Land surveys from 1871 described the area between Blue River and South Fork McKenzie River as mountainous and rocky, divided by deep canyons, and heavily timbered with fir, cedar, maple, hemlock, alder and some pine (McClung and Pengra 1871).

History of Disturbance in the Study Area

The greatest natural disturbances have been fires and major floods. Lightning-caused fires occur more frequently at higher elevations than lower elevations in this region, are distributed unevenly over the landscape, and usually burn small areas (Burke 1979). The highest recorded discharge of the McKenzie River near Coburg was 2,498 cms (88,200 cfs) in 1945 (State Water Resources Board 1961), but the flood of 1861 is believed to be the largest post-settlement flood in the Willamette basin (U.S.Geological Survey 1993). A severe windstorm in 1962 caused considerable blow-down of timber and was followed by a 100-yr flood event in 1964.

The flood of 1964 left an imprint upon the landscape in widespread areas of Oregon and northern California, including the McKenzie River. Increased sediment delivered from deforested and roaded hillslopes, debris flows, and disturbed riparian vegetation caused channel widening and aggradation in the Middle Fork of the Willamette, a neighboring basin to the McKenzie River (Lyons and Beschta 1983). Flows reached 1,824 cms (64,400 cfs) at Leaburg Dam on the McKenzie River, mobilized downed wood, accelerated mass failures and increased soil erosion. Riparian areas, bridges and dwellings along the McKenzie River were damaged, and extensive salvage operations removed large amounts of wood from the river after the flood (Rothacher and Glazebrook 1968). The 1964 storm initiated debris slides and debris flows in three watersheds under study in the Andrews Experimental Forest in the McKenzie watershed and transported 85% of the total 30-yr sediment yield through the study watershed with higher road density and 25% of the area in clearcut, demonstrating the importance of prior watershed condition (Grant and Wolff 1991). At least a portion of the sediment from these smaller watersheds would have been transported into the mainstem McKenzie River. A single large disturbance, such as the 1964 flood, may leave a lasting imprint on the system, especially if hydrologic conditions following the event have been altered such that subsequent flows are not able to reestablish the previous characteristics of the river.

Historical land-use disturbances include habitation by native Americans before European settlement, followed by road building, livestock grazing, farming, mining, timber harvest, hydroelectric development, and residential and urban development and recreation. According to U.S. Census data, Lane County population has increased by 420% since 1930 to a present population of nearly 300,000 thus increasing human use of the McKenzie River watershed.

Ownership within the watershed above Leaburg Dam is predominantly federal (83%). Bureau of Land Management lands are 2% of the watershed and U.S. Forest Service lands are 81% of the watershed, primarily within the Willamette National Forest (Oregon State Service Center for GIS 1993; Fig. 3 and Appendix A). Private lands (timber holdings, small farms, residences and unincorporated communities) make up 16% of the total area of the watershed above Leaburg Dam. When ownership in the riparian area (defined as the area within 90 m of the active channel plus the floodplain) is considered apart from the upland areas, private lands make up 61% of the riparian land base, and total federal management is limited to 38% of the riparian area.

The floodplain area has a complex fire history resulting from its long history of human use. Extensive forest fires in the central Cascades occurred with settlement in the last half of the 19th century and the first decade of the 20th century, caused by activities associated with building roads, burning for grazing, clearing land, and carelessness (Burke 1979). A large area burned in the late 1890s between the communities of Leaburg and Blue River and above Belknap Springs on the McKenzie River (Thompson and Johnson 1900). As fire control measures were instituted in the early part of this century, the incidence of catastrophic fires was reduced (Burke 1979). By 1936 forest fires were limited to small patches in the area of this study, and previously burned areas were growing back predominantly in Douglas fir (Andrews and Cowlin 1936). During the 55-yr period examined in this study many small fires occurred, concentrated along highway 126, and two larger patches burned in 1949 covering over 2 km^2 along both sides of the McKenzie River between McKenzie Bridge and Paradise, caused by a timber operation (Burke 1979).

Timber harvest in the McKenzie River watershed began in the last century, primarily adjacent to the river, and continues today in roaded areas of

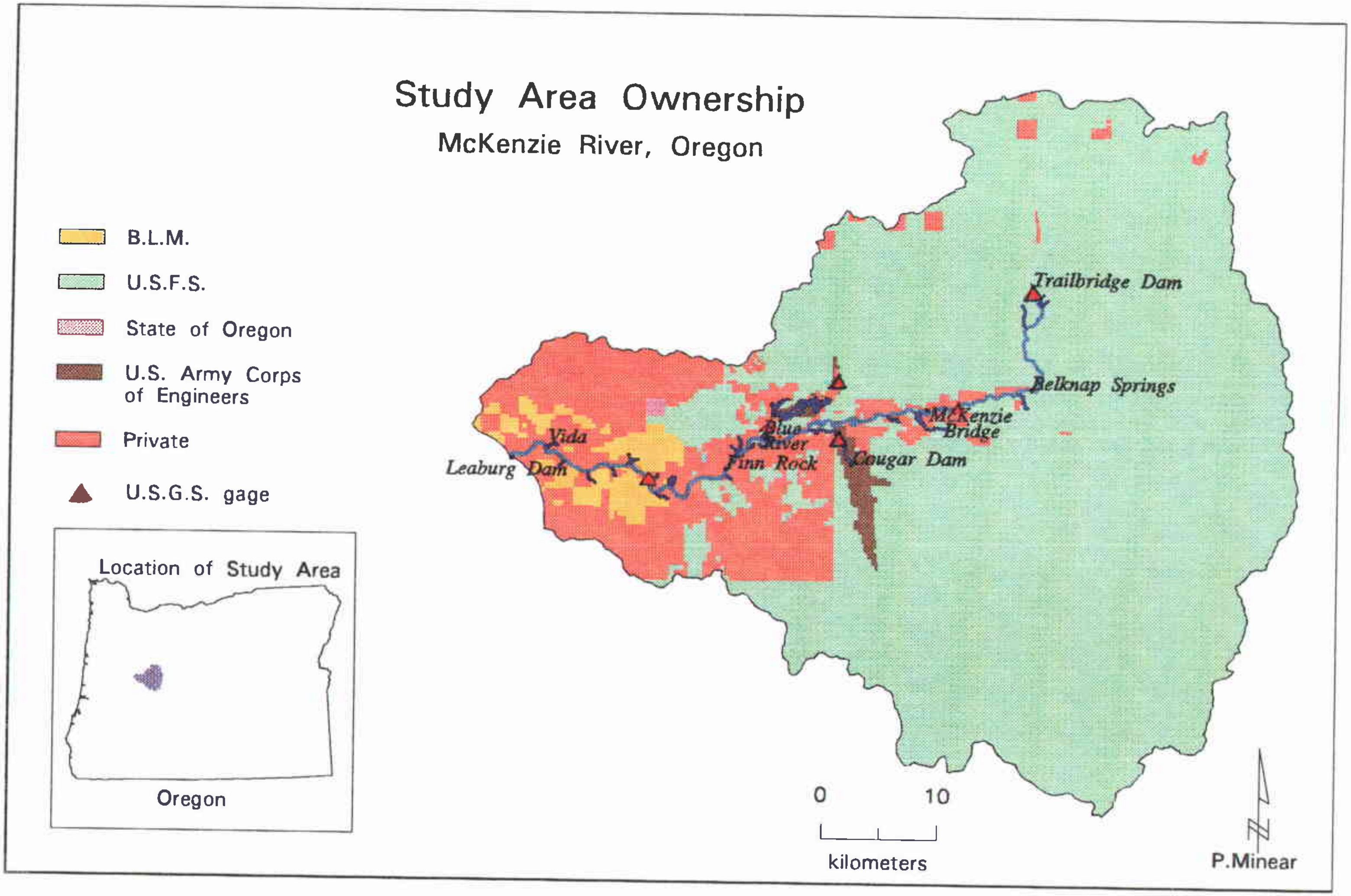

Fig. 3. General ownership categories in the McKenzie River study area. (After Oregon State Service Center for GIS 1993).

private and federal lands. Log driving on the river was the chief means of transporting logs to the mills in the late 1800s but was phased out around 1912 because of the difficulty imposed by diversion of water for generating power and reports that the drives were destroying spawning beds (Oregon Division of State Lands 1976). Private timber lands lower in the watershed and in the valley bottom were logged earlier in this century than federal lands that occur higher in the watershed and were less accessible. Harvest of federal forests in the basin began after World War II with increasing harvest through the 1980s. Timber harvest has continued on private lands in the watershed, while harvest on federal lands has been curtailed in the 1990s due to concerns related to endangered species and change in government management goals for the forests.

The Eugene Water and Electric Board (EWEB) began diverting the McKenzie River at Leaburg for power generation in 1910 and constructed the Leaburg Dam in 1930. In the early 1960s EWEB constructed Smith-Carmen project near the headwaters of the McKenzie, withdrawing water below Koosah Falls and diverting it to Smith Reservoir on the Smith River, then passing the flow to Trailbridge Reservoir to produce power. Trailbridge Dam (1963) is used to dampen the fluctuation in stream flow caused by releases from Smith Reservoir. No fish passage structure was constructed on any of the McKenzie River dams other than Leaburg Dam. Two projects constructed by the Army Corps of Engineers, Cougar Dam on the South Fork (1964) and Blue River Dam (1968), function primarily as storage projects and serve to modify the flows of the McKenzie and Willamette Rivers while producing some hydroelectricity at Cougar Dam (Morse et al. 1987).

The McKenzie River system supports a trout fishery composed of native rainbow, cutthroat and bull trout, supplemented by the largest legal-sized rainbow trout stocking program for any single water body in Oregon (Howell et al. 1988). Historically, the McKenzie River has been an important spawning area for spring chinook salmon and is considered the most important remaining area for natural production in the Willamette Basin. Prior to construction of dams, the McKenzie River produced an estimated 40% of the spring chinook run above Willamette Falls. Anadromous fish now can access 91 kilometers of habitat on the McKenzie, and an additional 112 kilometers of previously available habitat has been blocked by dams (Howell et al. 1988). The spring chinook run since 1980 is 57% less than estimated average runs from 1945 through 1960 (Howell et al. 1988). Spring chinook runs have been augmented by hatchery production since 1902. Resident fish populations on the mainstem McKenzie have not been assessed. Chinook redd counts and numbers of fish passing Leaburg Dam are available for the last 20 years.

Peak Flows and Competence

Flood frequency curves from the period before and after the dams were compared for the gage near Vida (Wellman et al. 1993). Amount of regulated flow reaching the Vida gage was estimated from mean daily flows at upstream gages (Moffatt et al. 1990).

Instantaneous peak flows for each year were analyzed for several gages before 1962 and after 1968 in different parts of the study area to examine the influence of dams on peak flow magnitude (t-tests for difference in means) and variability (F-tests)(95% confidence intervals on all tests). Discharge records back to 1937 were used in this analysis, if available. Otherwise, discharge records were used as available for each gage prior to 1962. All gages used for this analysis had complete records after 1968. Flows from the outlet of Clear

Lake, the origin of the McKenzie River (U.S.G.S. gage 14158500), have not been influenced by upstream dams. Flows at McKenzie Bridge (U.S.G.S. gage 14159000) reflected the influence of dams upstream at Smith-Carmen and Trailbridge Dams after 1963 and input of several undammed tributaries. Lookout Creek enters Blue River above Blue River Dam and was selected to reflect undammed flow conditions in the middle of the study area (U.S.G.S. gage 14161500). Mainstem flow conditions below Smith-Carmen, Trailbridge, Cougar and Blue River dams were represented by the Vida gage below the Mason Creek junction (U.S.G.S. gage 14162500). To insure that any differences in peak flow frequency, magnitude and variability were not a result of climate change, winter water year precipitation at Andrews Experimental Forest (Greenland 1993) was analyzed for differences in variability (F-test) or mean precipitation (t-test) from 1937 to 1962 (before dams) and after 1968 (after dams).

Flow regulation by dams tends to modify the ability of peak flows to mobilize bedload and transport sediment. To approximate the ability of peak flows to move existing bedload in this section of the McKenzie River, boundary shear stress and D_{50} (median diameter of bedload) were evaluated for an event with a 10-yr recurrence interval at several cross-sections between McKenzie Bridge and Leaburg Dam. Boundary shear stress and D_{50} were calculated for 2-yr and 5-yr flows, before and after dam construction at the Vida gage. Boundary shear stress was calculated using the formula:

$$\tau_o = \rho \mathbf{R} \mathbf{S}$$

where τ_o is the boundary shear stress, ρ is the unit weight of water, **R** is hydraulic radius (approximated by depth of flow) and **S** is water-surface slope (0.003 at Vida gage)(Leopold et al. 1964). Resulting units of boundary shear stress are dynes/cm^2. Competence to move bedload was then approximated by calculating D_{50} using the formula:

$$D_{50} = \frac{\tau_o}{(g_s - g_w)(\tau^*)}$$

where g_s is the assumed specific gravity of sediment (2.65 g/cm^3), g_w is the specific gravity of water (1.00 g/cm^3), and τ^* or critical dimensionless shear stress is assumed to be 0.045 (Petts and Foster 1985).

Stratification by Reach

To assess susceptibility of specific reaches to channel and riparian change, seven channel reaches were defined based on valley constraint, slope and channel type, contribution of major dammed or undammed tributaries, presence of historical landmarks, and approximate reach length. A constrained channel is limited in width by neighboring landforms and has a valley floor width less than two active channel widths (Gregory et al. 1991). The river is not free to meander and is usually restricted to a single channel in constrained areas. In some cases, a channel is effectively constrained by terraces after incising through deposits, even though the valley floor itself is not a long-term constraint to the channel. An unconstrained channel, on the other hand, has a wide valley floor with extensive floodplain surfaces and may meander and form bars and secondary channels.

To determine valley floor constraint, profiles of the valley floor were constructed from U.S.G.S. 1:24,000 topographical maps by centering at river mile markers in the main channel and extending away from the channel at right angles until 40-foot contour lines were crossed. These cross-sections were then evaluated for relative constraint of the valley floor upon the channel. The magnitude of channel slope, characteristic flow patterns, and typical bedforms described by Montgomery and Buffington (1993) in their channel classification scheme were compared to McKenzie River slope measured from 1:24,000 U.S.G.S. topographical maps and field observations.

The remaining criteria for defining study reaches were: tributary contributions and possible influence of regulated flows; presence of well-known landmarks on the river to serve as reach breaks that persisted in the same location throughout the study period; and reach length between 6 and 10 km in unconstrained reaches where most channel change would be expected. Sections of the river were evaluated for flow contributions from dammed versus undammed tributaries.

Field Survey

A field habitat survey, conducted in the summer of 1991, used methods compatible with historical habitat surveys and recent U.S.Forest Service resurveys (McIntosh 1992, McIntosh et al. 1994; Sedell and Everest 1991) to census the pools, visually estimate substrate composition by size classes, and collect additional information on habitat units and dimensions. Historical habitat surveys of more than 8,000 km of streams in the Columbia River basin were conducted between 1934 and 1942 by the U. S. Bureau of Fisheries to assess stream habitat conditions for salmonids (Rich 1948). The McKenzie River component of the survey was conducted in two stages in 1937 and 1938. Field notes on the 1937 and 1938 data sheets indicate that the habitat survey was conducted upstream from Belknap Springs on foot in August 1937, and from Belknap Springs downstream to the vicinity of Eagle Rock by boat, covering 37 km in one day. The team returned in June 1938 to complete the habitat survey by boat to Leaburg Dam, covering 20 km in one day. Principle observations included a census of large, deep pools (>6 ft deep, >50 yd^2 in area), identified as S_1 pools, and percent substrate every 100 "paces" (approximately 100 m).

In 1991 the McKenzie River was surveyed from the base of Trailbridge Dam to Leaburg Dam from a kayak and a cataraft during 15 days in July and August. The observer on the cataraft was able to view directly down into the water from standing height with polarizing lenses to assess substrate composition, which was estimated visually for each 100 m travelled downstream. Care was taken to pass back and forth across the thalweg to view as much as possible of the substrate in each 100-m section and to investigate side channels as separate units. Categories of substrate size corresponded to divisions used in the historical survey: large rubble >150 mm, medium rubble 75–150 mm, small rubble 6–75 mm, fine sediment <6 mm, and bedrock. Visibility through the water column was excellent except in turbulent, deep or heavily shaded areas. Ability to accurately capture substrate composition using this method is limited and different observers may vary up to 30% in their estimates.

At the same time, the kayaker conducted a census of large pools. The largest pools, designated S_1 pools, were greater than 40 m^2 in surface area and at least 2 m deep. Maximum pool depth was measured by plumb line to the nearest 0.1 m. Survey techniques used in 1991 were conservative and biased against the hypothesis of decrease in large pools over time because more time and effort were devoted to the survey in 1991 than in 1937 and 1938, making it more likely that large pools, if present, would be noted. Riparian vegetation was photographed for reference in later aerial photo interpretation. Locations of pools, riffles, and channelization (riprap) were marked on aerial photos in the field.

The S_1 pool census from 1991 was compared to the S_1 pool count from 1937-38 to determine difference in large pool frequency for the entire study area and by reach. Direct comparison of pool counts from 1937/38 and 1991 was justified by the ability to uniformly apply the pool size criteria with little difference between observers.

A direct comparison of visually-derived substrate composition from the observers in 1937/38 and 1991 was not justifiable, because no quantitative calibration for individual observers was available. Substrate data were useful, however, in qualitatively viewing trends in substrate composition as the same observer moved downstream and were used to determine median substrate size for computation of flow competence.

Aerial Photogrammetry

To determine the nature, extent, and location of historical channel and riparian changes, two series of high altitude, small-scale aerial photos (1945/49 and 1986) were interpreted and digitized and the data were subsequently imported into a GIS (Avery 1992; Warner et al. 1990). All field surveys, photo interpretation, digitizing, and GIS analysis were completed by the author to insure consistency. Types of data digitized from the aerial photos included locations and length or area of wetted channel, active channel, tributaries, side channels, large woody debris, exposed gravel bars, roads, and dominant vegetation or land use within 200 m of the active channel (<20-yr hardwoods, <20-yr conifer, 20–100-yr hardwoods, 20–100-yr conifers, >100-yr conifers, agricultural, and residential). Each line or point was given a unique category code for later identification in the GIS. Active channel was determined from aerial photos as the portion of river channel carrying water at normal high flows, and included the adjacent unvegetated channel shelf, exposed gravel bars and perennial secondary channels, all features readily discerned from the aerial photos.

Vegetation type (hardwood vs conifer) was determined by characteristic texture and shading patterns on the aerial photos. Dominant vegetation size and age were estimated by crown diameter and density. Vegetation categories indicate relative age, rather than absolute age, and field validation by dendrochronological studies was not conducted.

An AP190 analytical stereoplotter with 6x ocular (Carto Instruments A/S, Postboks 215, 1430 Aas, Norway) provided a stereoview for collecting digital data points interactively with a microcomputer. The computer corrected for parallax and computed the absolute positions of these photos to geographic coordinates using a least squares analysis (Carson 1987). Points on the aerial photos were measured to within 30 μm, which translates to a resolution of 1.3 meters on the ground for aerial photos at a scale of 1:40,000 (Kiser and Paine 1989).

Black and white aerial photos from 1945 (5M Project, National Archives) and 1949 (Forest Service project code DGS, National Archives) at a nominal photo scale of 1:40,000 were selected to represent the conditions in the 1940s. Complete photo coverage of the study area in any one year in the 1930s or 1940s was not available at the appropriate scale. The 1949 photos covered the majority of the study area, extending 60 km from Trailbridge Dam to Dorris State Park. The remaining 10 km was digitized from the 1945 series and included the lake behind Leaburg Dam. To depict current conditions, black and white aerial photos from 1986 (WAC-860R, WAC, Eugene, Oregon) at a scale of 1:31,000 were used.

The 1986 photo series was geographically controlled (absolute orientation) from 1:24,000 U.S.G.S. quad maps. Absolute orientation values represent the expected accuracy in location of a particular object in geographical space. All stereophoto pairs in the 1986 series were accurate within 11 meters for geographic position in any dimension (Table 1). All photos taken before 1986 were geographically controlled from the 1986 photos by gathering control points that were visible in both sets of photos and bridging control to the earlier photos. A minimum of five well-distributed control points was used to control each photopair (Appendix B: Aerial Photo Files).

Table 1. Relative and absolute orientation of stereo photopairs used in this study.

			Relative Orientation		Absolute Orientation		
Year	# of Photo-pairs	Nominal Photo Scale	Mean Relori (mm on photo)	Possible Error on Ground (m)	Mean Absori in X (m)	Y (m)	Z (m)
1945	4	1:40,000	0.02	0.80	3.18	4.22	2.48
1949	8	1:40,000	0.02	0.80	6.31	5.40	3.65
1959	3	1:12,000	0.01	0.12	4.07	4.40	3.73
1964	1	1:12,400	0.06	0.74	23.60	10.10	4.70
1967	2	1:15,840	0.02	0.32	3.45	3.05	2.90
1979	2	1:12,000	0.02	0.24	2.70	2.45	2.25
1986	13	1:31,000	0.01	0.31	6.73	7.61	2.38
1990	1	1:12,000	0.02	0.24	5.80	3.10	3.50

Larger-scale photos (1:12,000) from intervening years were digitized to track the sequence of channel change in three areas of the mainstem that showed marked channel movement between 1949 and 1986: below Blue River (1959 and 1967), near Delta campground (1959, 1964, 1967, 1979, 1990), and Dearborn Island (1959 and 1979).

The 100–yr floodplain was digitized from Federal Emergency Management Agency (FEMA) flood insurance rate maps (panels 405, 410, 430, 435, 195, 215, and 220) and imported into the GIS. The FEMA maps were used only for general guidelines because original maps were incomplete and inconsistent and made registration and digitizing inaccurate.

Data Analysis Using GIS

Data were imported into a Geographic Information System (ArcInfo, Version 6.1) for spatial and temporal analysis and data display on a Sun Sparks 10 workstation. Spatial and tabular queries were conducted within the ArcInfo program to evaluate and compare the extent of change over time (Appendix C: ArcInfo Procedures).

Overlays of the 1945/49 and 1986 channels identified areas of channel change and stability. Extent and locations of side channels, locations of large woody debris, area of exposed gravel bars, riparian roads, and relative amounts of riparian vegetation in each category were compared between 1945/49 and 1986. To compensate for differences in photo scale (1:40,000 vs 1:31,000) and differences in geographic alignment of the aerial photos due to control from U.S.G.S. quad maps, only land-use or vegetation polygons greater than 200 m^2 and exposed gravel bars greater than 100 m^2 were considered in the analysis.

Roads were buffered to reflect generalized width of the road bed according to type of road: state highway (both sides digitized), community (5 m), paved forest (4 m), timber access (3 m), unimproved roads (3 m). For the 1945/49 road coverage, each road was given the same buffer width as its 1986 counterpart, despite the probability that road widths were considerably narrower in the 1940s. A separate coverage buffered all roads with an additional 30 meter buffer to analyze possible ecological effects of road edges within the riparian buffer.

Riparian area was analyzed using a set-back of 90 m from the active channel on both sides of the river. Active channel area included side channels as delineated in the aerial photo analysis. In areas where the floodplain was wider than 90 m, the riparian area was extended to include the floodplain. Flood insurance rate maps from the Federal Emergency Management Agency (FEMA) were used for reference to define the floodplain.

Riparian areas of various widths (30 m, 60 m, 90 m, and 90 m plus floodplain) were analyzed to compare relative composition (vegetation and land use) using different riparian buffers. Oregon Forest Practices require a riparian buffer along Class I, fish-bearing streams of three times the stream width for a minimum of 8 meters (25 feet) and a maximum of 30 m (100 ft). The Willamette National Forest riparian management guidelines call for a variable riparian buffer depending on stream type of 46 to 123 m (150 – 400 ft) and include the floodplain (Gregory and Ashkenas 1990). Federal Ecosystem Management Assessment Team (FEMAT) recommendations for key watersheds include selecting the largest riparian buffer from among several options: extending to the outer edges of the 100-yr floodplain, the outer edges of riparian vegetation, equal to the average height of two site-potential trees or 92 m (300 ft) slope distance from fish-bearing streams (FEMAT 1993). Amount and percent of each land-use and vegetation category incorporated into the different riparian buffers were estimated using ArcInfo operations.

Channel and riparian conditions (data types as digitized from aerial photos) were analyzed for seven reaches in this section of the McKenzie River. Riparian area was divided into seven polygons at reach breaks, and each reach was given an identifying number. A union with the land-use coverage then produced land-use polygons with a reach designation. By combining the land-use code and the reach identification number, a statistical report was generated from ArcInfo summarizing vegetation and land use by reach. Queries were made in ArcEdit to obtain information on channel characteristics by reach (frequency and amount of exposed gravel bars, large woody debris, and side channels). Sinuosity was measured by splitting main channel arcs at reach breaks, measuring the distance along right and left banks for each reach, averaging the distance, then dividing by the straight-line distance between reach end points.

Complex interactions between biological, physical, and social processes produce spatial patterns at the landscape scale, resulting in a landscape mosaic that is a mixture of natural and human-influenced patches, varying in size, shape, and arrangement (Turner 1989). Many of these landscape patterns can be quantified and compared to identify changes over time. To compare landscape patterns in the riparian study area and identify changes between 1945/49 and 1986, the largest riparian coverage (90-m riparian area plus the FEMA floodplain) was analyzed using the vector version of FragStats program. FragStats was developed by Kevin McGarigal and Barbara Marks at Oregon State University (1993) to analyze spatial patterns on the landscape. Each class of riparian vegetation or land use was analyzed for patch characteristics (number, density, mean size, coefficient of variation), edge metrics (total edge, edge density), and shape metrics (double-log fractal index). The riparian landscape as a whole was analyzed for composite patch characteristics, total edge and edge density. Number, density, and size of patches gave an indication of fragmentation of the landscape, i.e. whether the riparian area was composed of a few large patches or many smaller patches. Amount of edge between different patches may be important for movement of organisms, and certain species require edge habitat while other species avoid edges in preference for interior habitat within patches. Double-log fractal dimension provided a measure of complexity of spatial pattern. Refer to Turner 1989 for a summary of uses of these metrics in landscape ecology.

Results

Peak Flow Magnitude and Variability

The discharge measured at the Vida gage above Leaburg Dam reflects the influence of flow regulation by upstream dams. According to U.S.G.S. records, the mean daily discharges from 1964 to 1987 were 28.9 cms at the gage below Trailbridge Dam near Belknap Springs, 23.2 cms at the South Fork gage below Cougar Dam, and 13.5 cms at the Blue River gage below the Blue River dam (Moffatt et al. 1990)(Fig. 4). Mean daily discharge at the Vida gage was 119.5 cms between 1969 and 1987. Based on these mean daily discharges, approximately 55% of the flow reaching the Vida gage has originated from dammed tributaries (Blue River and South Fork: 31%) or regulated mainstem flows (Smith-Carmen and Trailbridge Dams: 24%). The drainage area no longer supplying sediment to the mainstem McKenzie River due to these dams equals 52% of the area above the Vida gage, according to U.S.G.S. estimates of drainage area above each gage.

Annual peak flows above Leaburg Dam have been dampened by the construction of dams at Smith-Carmen, Trailbridge, Cougar (South Fork McKenzie River) and Blue River. Instantaneous peak flows at the Vida gage were markedly reduced following construction of the four dams farther up the watershed (Fig. 5). In the last 26 years, no peak flows at the Vida gage have exceeded 827 cms, the 2-yr recurrence flow calculated from pre-dam flow records.

Two distinct flood frequency curves have been calculated for the Vida gage, representing magnitude and probability of annual high flow before and after dam construction (Fig. 6). For the period of record before dams (1925–1962) a flow of 827 cms had a predicted recurrence interval of two years,

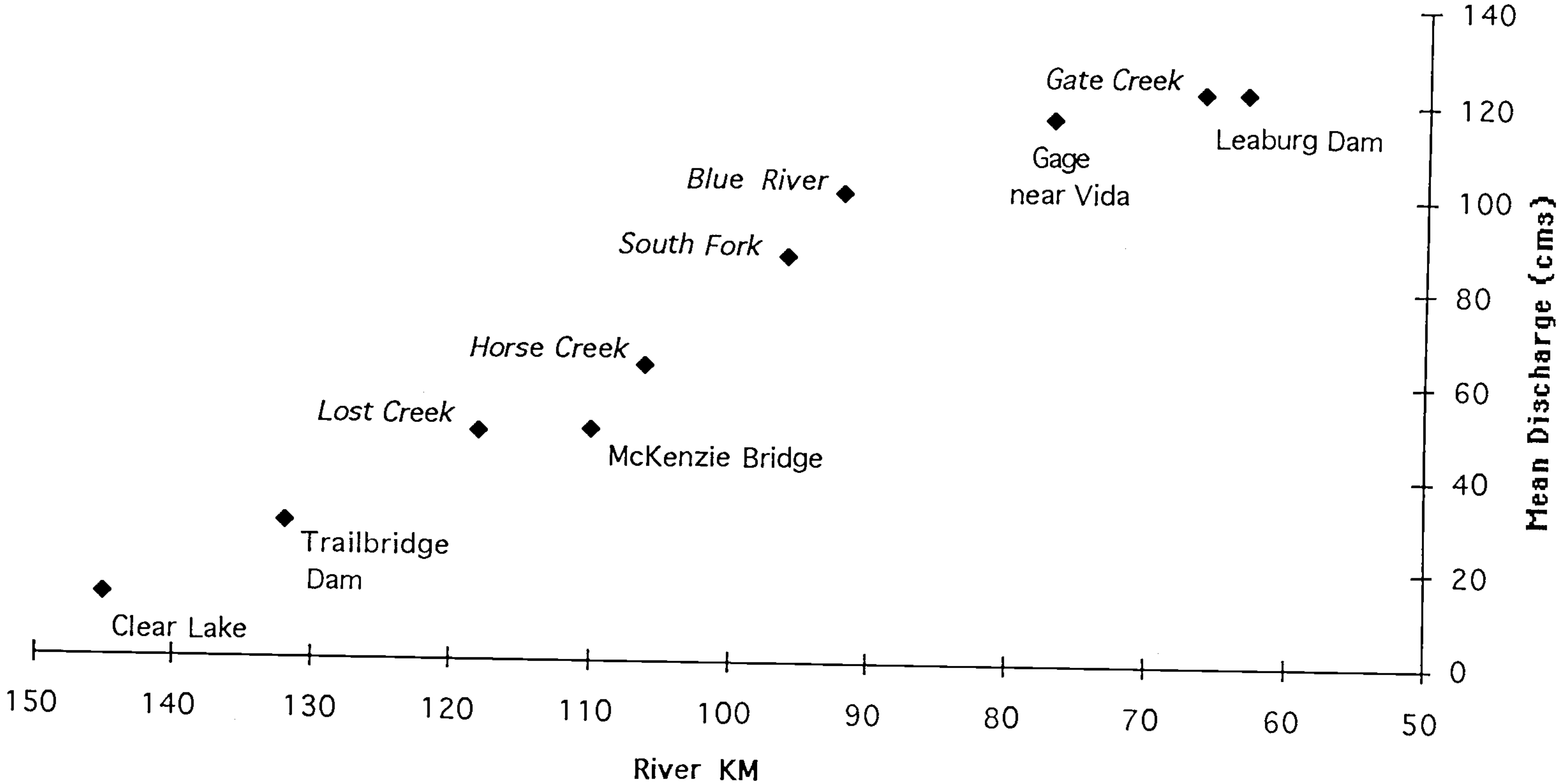

Fig. 4. Cumulative discharge from the origin of McKenzie River at Clear Lake to Leaburg Dam. Based on mean daily discharge at U.S.G.S. gages (Moffatt et al. 1990) and estimated discharge of ungaged tributaries (Morse et al. 1987).

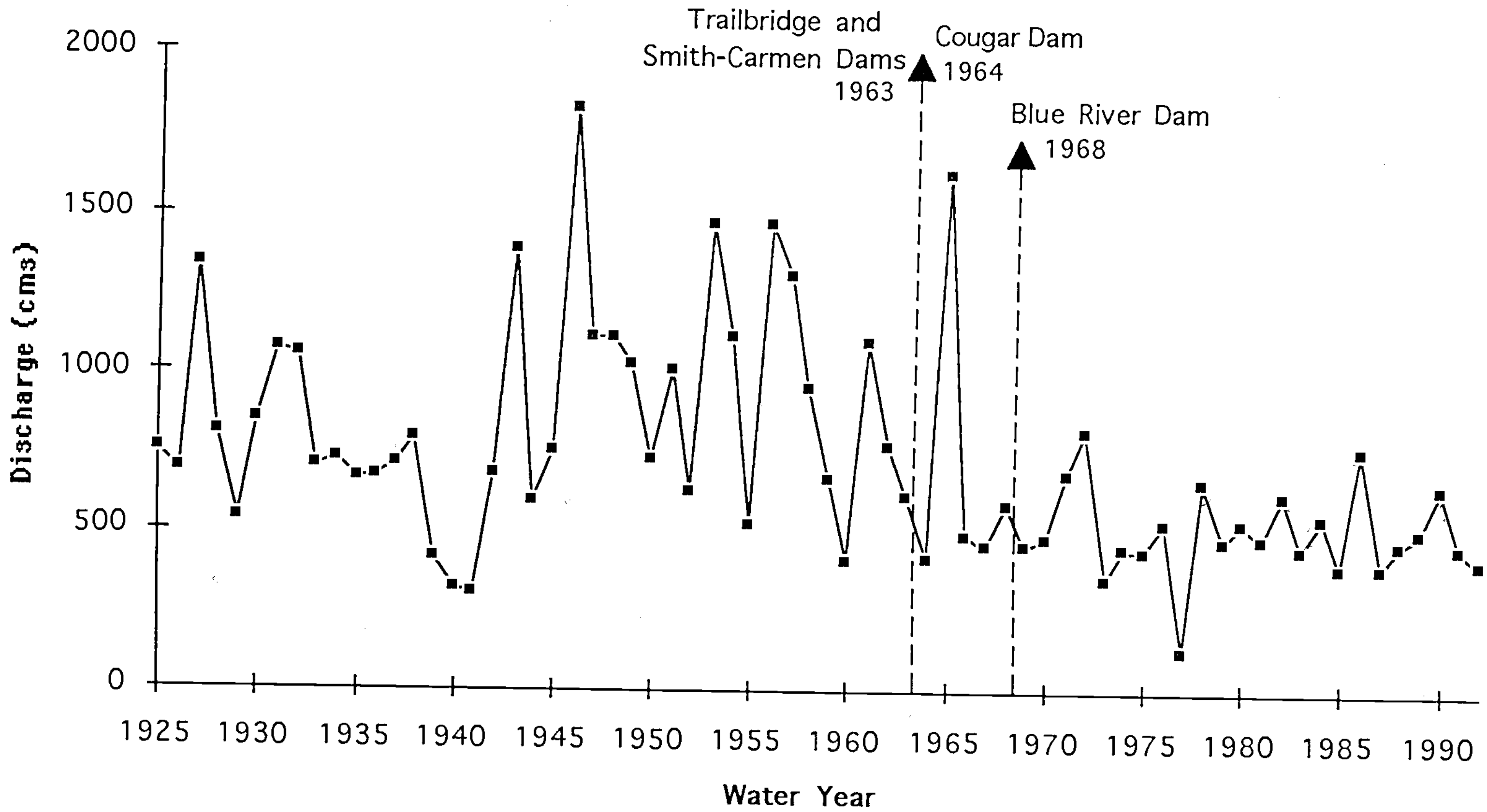

Fig. 5. Annual instantaneous peak discharge at gage near Vida on the McKenzie River, OR, 1925-1992. (U.S.G.S. station 14162500 at river km 77, 8.7 km east of Vida, OR.)

equivalent to a 50% exceedance probability (Wellman et al. 1993). Between 1926 and 1965 (before dams became fully operational), 17 years had peak flows at the Vida gage greater than 827 cms (29,200 cfs), which represents the 2-yr recurrence interval and approximate bankfull discharge (Ligon 1991). Six years had peak flows exceeding the 5-yr recurrence level of 1175 cms, and in four of these years (1946, 1953, 1956, and 1965) flows exceeded 1,402 cms (approximately 50,000 cfs), the 10-yr recurrence flow.

After dams were constructed above the Vida gage, flows of 505 cms and 662 cms were predicted to have a 2-yr and 5-yr recurrence intervals, respectively (U. S. Geological Survey 1994). Only three years (1971,1972, and 1986) have reached or exceeded this 5-yr recurrence flow at the Vida gage since 1966.

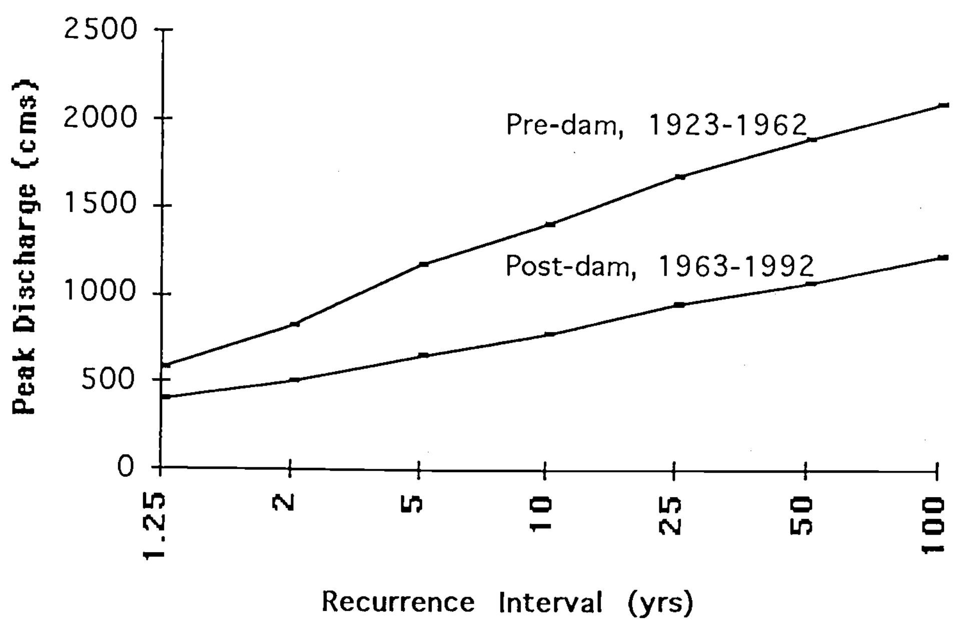

Fig. 6. Flood frequency curves at gage near Vida for the period before and after dam construction, McKenzie River, OR. (U.S.G.S. station 14162500, Wellman et al. 1993)

Comparison of variance and means of instantaneous peak flows before dams (1937–1961) and after dam construction (1969–1992) showed significant differences at the Vida gage at the 95% confidence level (p-values <0.0001)(Table 2). No conclusive evidence of difference in variation or means of peak flows before dams (1937–1961) and after dam construction (1969–1990) was detected at McKenzie Bridge (p-value 0.059), downriver of Smith-Carmen and Trailbridge Dams (Table 2, Fig. 7). No significant difference in variation or means of peak flows before dams (1948–1961) and after dam construction (1969–1990) was found at Clear Lake Outlet or Lookout Creek before dams (1950–1955) and after dam construction (1969–1992)(Table 2, Fig. 7). Land-use differences (i.e., increased road-building and clear-cutting) within sub-basins of the McKenzie watershed since the 1930s undoubtedly contribute to the variability observed in the discharge records at these gages but do not impart a signal sufficient to over-ride the decrease in peak flows at the Vida gage. (Appendix D: Hydrology and Climate)

Table 2. Analysis of variance (F-test) and difference in means (t-test) of instantaneous peak discharges at several gages in the McKenzie River watershed, OR, for the period before and after dam construction.

			Mean peak flow		p-values (0.05 alpha)	
Location of gage	Mainstem location	Dams above	before 1962 (cms)	after 1968 (cms)	Difference in variance F-test	Difference in means t-test
Clear Lake	yes	0	50.1	41.7	0.366	0.112
McKenzie Bridge	yes	2	202.9	197.3	0.059	0.819
Lookout Creek	no	0	58.3	48.3	0.343	0.364
near Vida (Mason Cr.)	yes	4	895.5	504.1	<0.001	<0.001

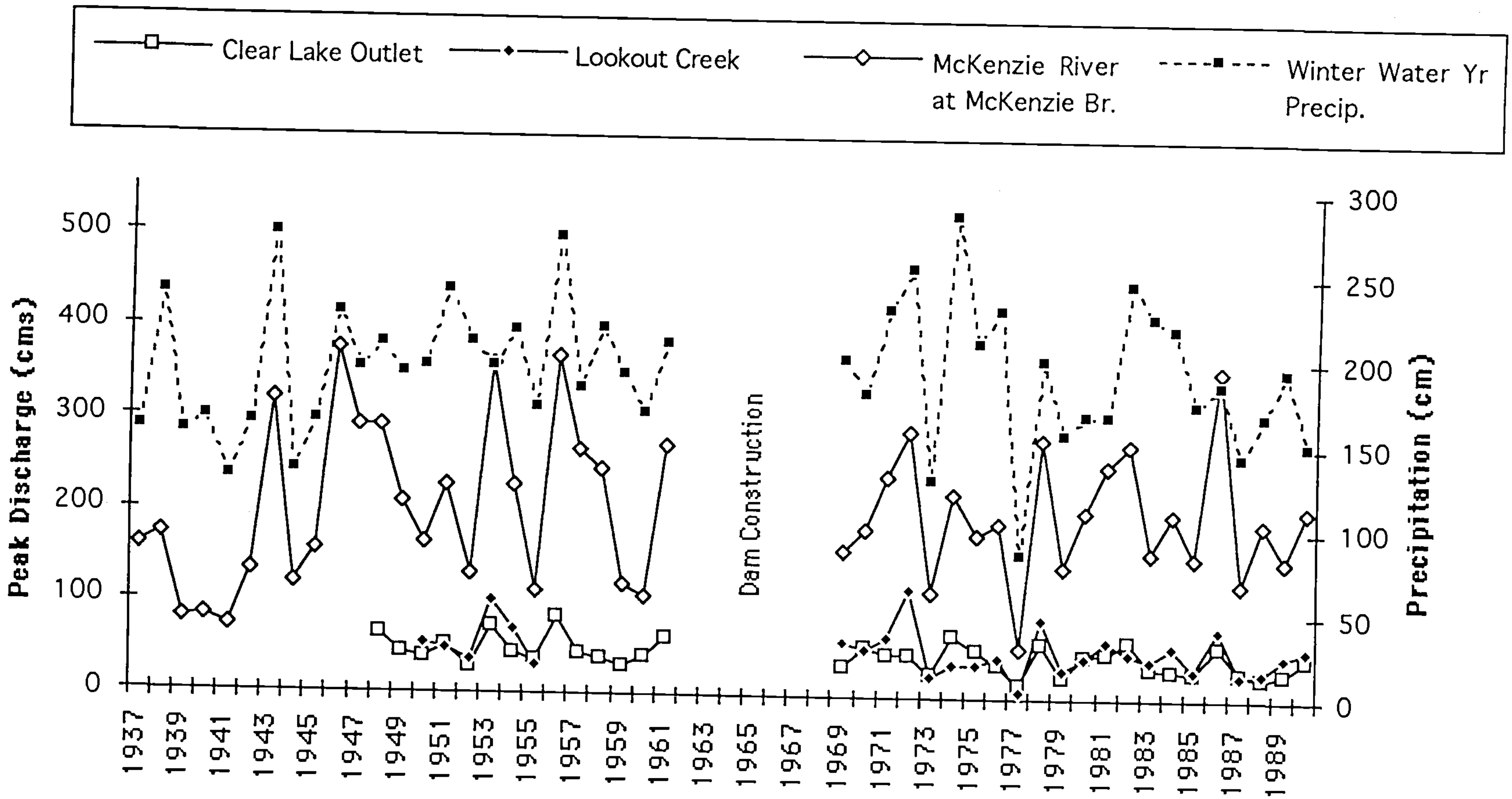

Fig. 7 Instantaneous peak discharges for several gages and winter water year precipitation at H.J. Andrews Experimental Forest in the McKenzie River watershed for the study period, before and after the decade of dam construction.

Differences in peak flows before and after dam construction at the gage near Vida cannot be attributed to climate change over this time period. Climate data has been collected since 1951 at the H. J. Andrews Experimental Forest (HJA), located in the Blue River sub-basin of the McKenzie River watershed. A synthetic record of the climate back to 1910 was constructed using multiple regression analysis of temperature and precipitation records from nearby stations with longer periods of record (Greenland 1993). Comparison of winter water year precipitation at HJA in 1937–1961 (before dams) and 1969–1991 (after dams) detected no significant difference in variance (F-test, p-value 0.21) or means (t-test, p-value 0.74)(Fig. 7). (Appendix D: Hydrology and Climate). These results imply that the observed differences in peak flows at the Vida gage are due primarily to the operation of Blue River and Cougar Dams.

Competence of Peak Flows

Reaches higher in the study area have a steeper slope, generate more force during high flow events, and are competent to move larger substrate than reaches lower in the study area. Boundary shear stress for a 10-yr recurrence interval flood (pre-dam; 1,113 cms) was calculated by Ligon (1993) at 250 cross-sections along the entire McKenzie River up to McKenzie Bridge and show the highest shear stress in upper reaches (McKenzie Bridge, approximately 2,475 dynes/cm^2) and lower values near Leaburg Dam (approximately 1,240 dynes/cm^2). These values were used to estimate the median substrate diameter, or D_{50}, that could be mobilized by a 10-yr peak flow (Fig. 8). Median substrate diameter that could be mobilized by this flow ranged from 347 mm at McKenzie Bridge to 270 mm at the South Fork junction and decreased to 174 mm at Leaburg Dam.

Visual substrate estimates from the historical habitat survey and estimates in 1991 give an indication that the substrate may have coarsened over the study period. The historical habitat survey (1937-38) visually estimated 56% of substrate of the study area to be greater than 150 mm diameter. The resurvey in 1991 estimated 76% of the sediment to be greater than 150 mm diameter. Unfortunately, more quantitative measures of substrate size (e.g., Wolman pebble counts) were not available for comparison with historical conditions. It is impossible to make a direct comparison of visually estimated substrate composition because no correction for observer bias was made, but these results were used to specify a probable median substrate diameter of 150 mm for the study area in the late 1930s and to estimate a median substrate diameter of 180 mm by 1991 (Fig 8). By these calculations, peak flows occurring approximately every 10 years (1,113 cms) before dams would generate the force required to mobilize 50% or more of the bedload throughout the entire study area, using 150 mm as the median diameter of bedload. Peak flows of this magnitude would be competent to move larger bedload, assuming bed coarsening to 180 mm median diameter. However, the probability of occurrence of peak flows of this size (1,113 cms) is much less under present conditions due to flow regulation, and these flows are projected to occur only once every 50 years. Prior to 1962, peak flows with a 5-yr recurrence interval, 1175 cms, were competent to move bedload particles up to the median diameter (D_{50} = 150 mm) at the Vida gage (Table 3). After dam construction, competence of peak flows with 2-yr and 5-yr recurrence intervals was reduced. Force generated by these flows would not have been competent to move the median size substrate (D_{50}) and probably would not have moved bedload due to the embedded nature of the substrate, though fine material (i.e., sand, mud) would have been moved readily by these flows.

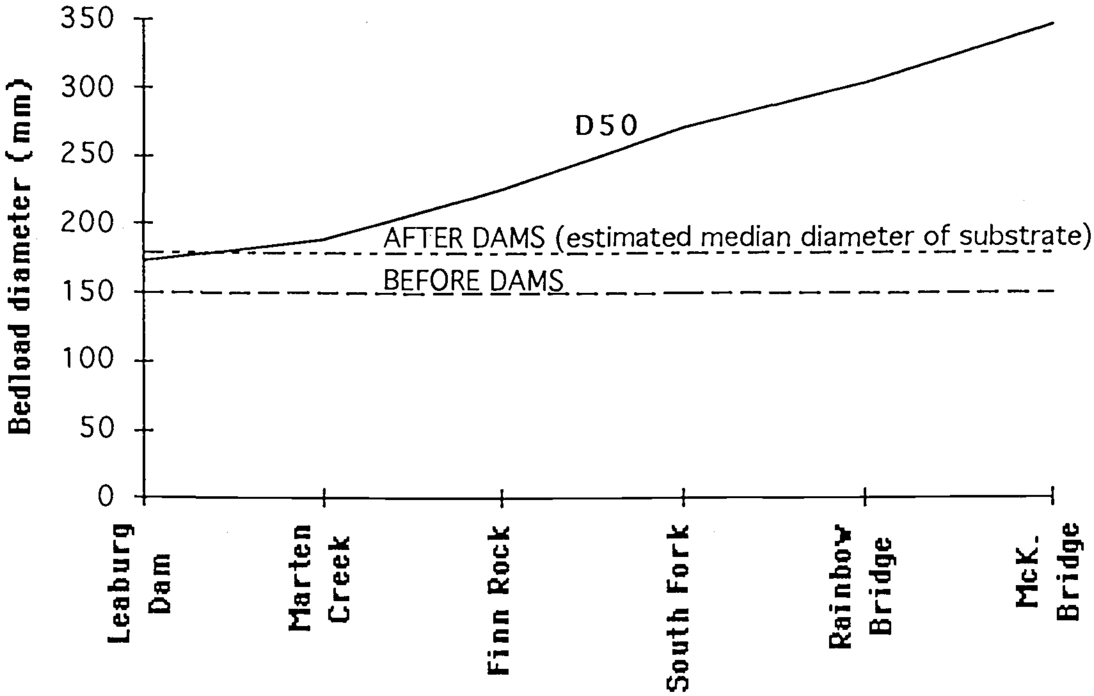

Fig. 8. Median size of bedload (D50) that could be mobilized by a peak flow with 10-yr recurrence probability, prior to flow regulation. Dotted lines indicate estimated median diameter of substrate before and after dams, assuming bed coarsening after flow regulation.

Table 3. Peak flow frequency and competence at gage near Vida, before and after dam construction upriver. Flood frequency probabilities were calculated by U.S.G.S. The period from 1963 through 1965 was not included when calculating occurrence of 2-yr and 5-yr events as dams were being phased in at that time.

	2-yr event: 0.5 annual exceedance probability		5-yr event: 0.2 annual exceedance probability	
	1925-1962: Pre-dam flows	1966-1992: Post-dam flows	1925-1962: Pre-dam flows	1966-1992: Post-dam flows
Discharge (cms)	827	505	1175	662
Gage height (cm)	295	210	377	253
Shear stress (dynes/ cm2)	868	618	1109	745
D50 (mm)	122	87	155	104
Number of years occurring	16	11	6	3
Recurrence interval (yrs)	2.4	2.5	6.3	9

Delineation of Reaches

Degree of valley floor constraint upon the channel, slope, reach-level channel types, and contribution of dammed or undammed tributaries were evaluated to determine reach breaks for this study (Table 4). Valley floor constraint upon the channel was most pronounced from Trailbridge Dam to Belknap Springs and from Finn Rock Bridge to Marten Creek (Helfrich Landing)(Fig. 9). The channel was less constrained from Belknap Springs to Finn Rock Bridge, with the widest floodplain between McKenzie Bridge and Finn Rock Bridge. Within unconstrained areas, roads were often located

Table 4. Characteristics used to delineate reaches in the study area, McKenzie River, OR. Slope and valley floor constraint determined from U.S.G.S. topographical maps. Reach-level channel type defined by Montgomery and Buffington (1993).

Reach	Upriver Landmark	Length (km)	Slope (%)	Reach-level Channel Type	Relative Valley Floor Constraint	Dam Influence	Other Factors
1	Trailbridge Dam	12.1	1.2	plane-bed	constrained	mainstem dam	north to south flow
2	Belknap Springs	10.4	0.8	pool-riffle	relatively unconstrained	–	east to west flow
3	McKenzie Bridge	6.0	0.8	pool-riffle	relatively unconstrained	–	
4	Rainbow Bridge	6.1	0.5	pool-riffle	unconstrained	–	
5	RM60 (above South Fork)	9.6	0.3	pool-riffle	unconstrained	2 major dammed tributaries	
6	Finn Rock Bridge	16.1	0.4	pool-riffle	constrained	–	reduced glacial influence
7	Marten Creek (to Leaburg Dam)	8.5	0.2	pool-riffle	unconstrained by valley walls; some terrace constr.	mainstem dam at end of reach	

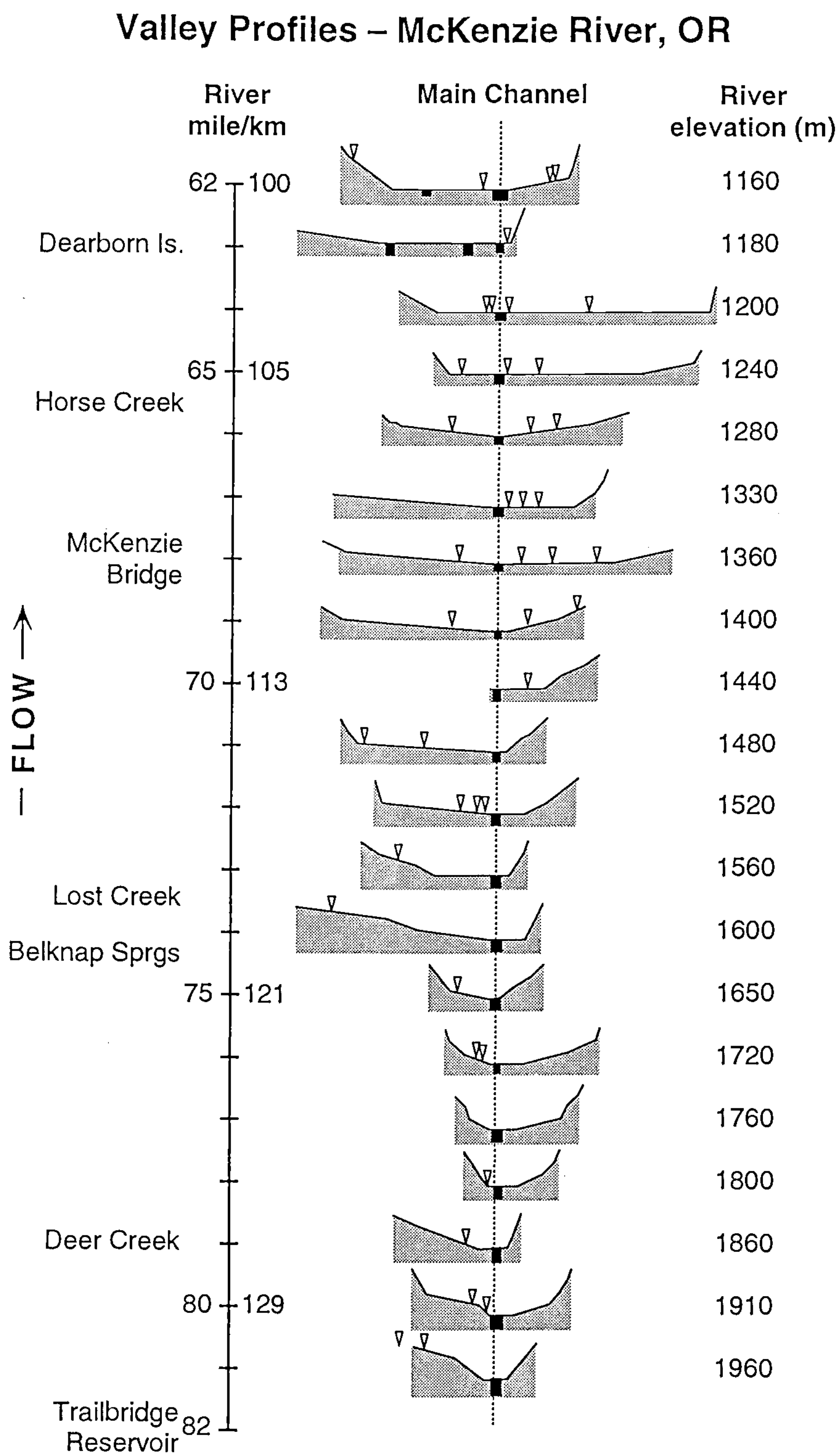

Fig. 9. Valley profiles taken from U.S.G.S. topographical maps at right angles to main channel, Trailbridge Dam to Leaburg Dam, McKenzie River, OR.; River channels are black, and inverted triangles indicate roads. The vertical axis is centered on the present main channel.

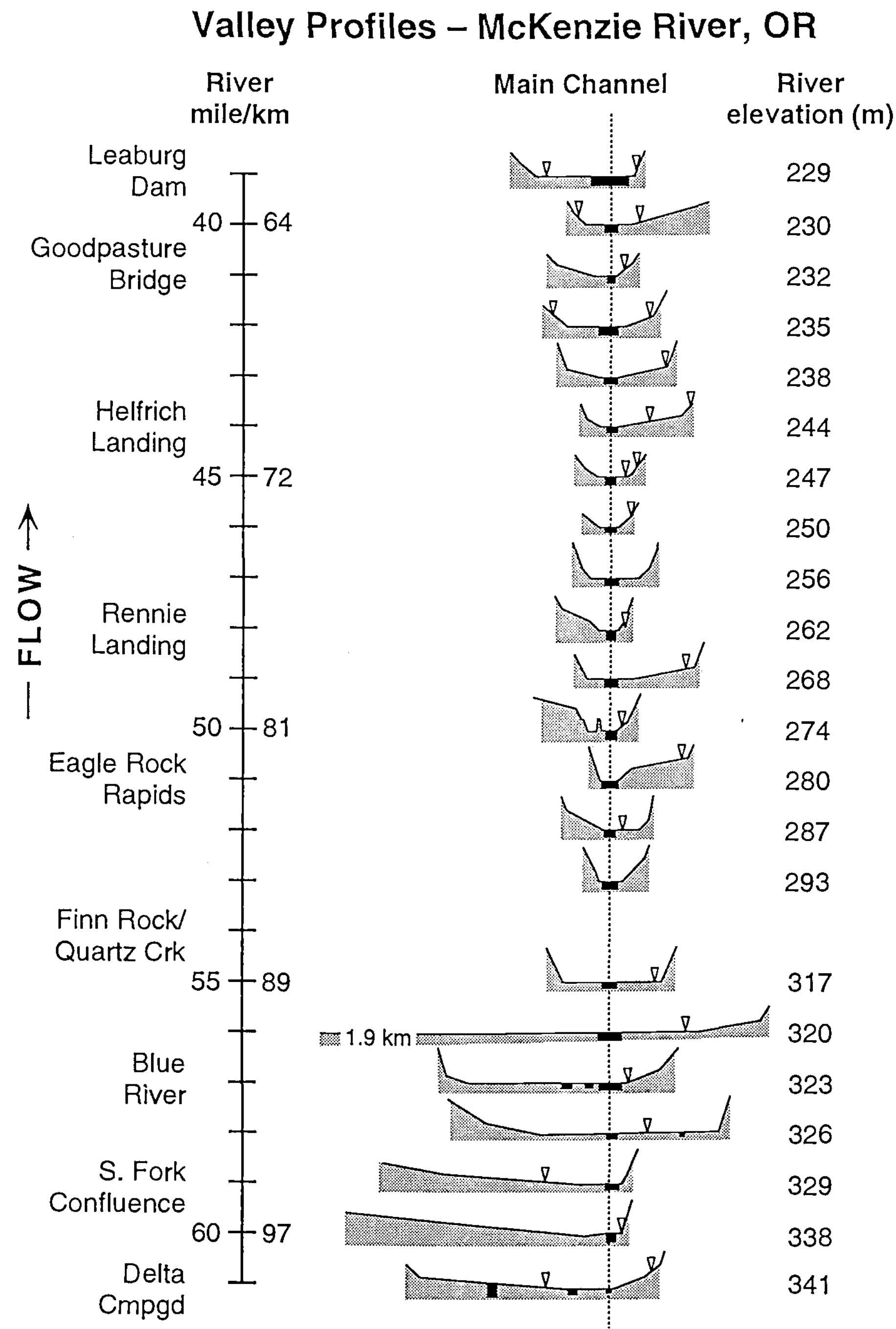
Valley Profiles – McKenzie River, OR
River mile/km
Main Channel
River elevation (m)
Leaburg Dam
40
64
Goodpasture Bridge
Helfrich Landing
45
72
FLOW
Rennie Landing
50
81
Eagle Rock Rapids
Finn Rock/ Quartz Crk
55
89
Blue River
S. Fork Confluence
60
97
Delta Cmpgd
1.9 km
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Fig. 9, cont'd.

immediately adjacent to the channel and would act as further agents of constraint upon channel movement. The channel from Trailbridge Dam to Belknap Springs had the greatest slope (1.2%) and the sections with the most gradual channel slope were between the South Fork junction and Finn Rock Bridge (0.3%) and from Marten Creek to Leaburg Dam (0.2%) (Table 4).

Two of the reach-level channel types described by Montgomery and Buffington (1993) occur within this study area: pool-riffle channels typically have channel slopes between 0.1% and 2% (as seen from Belknap Springs to Leaburg Dam), and plane-bed channels are steeper, generally between 1% and 3% (as seen from Trailbridge Dam to Belknap Springs). Additional characteristics of plane-bed channels agree with field observations on the McKenzie River and include: lack of well-defined bedforms except occasional channel-spanning rapids, relatively planar channel bed lacking rhythmic bedforms, insufficient lateral flow convergence to develop pools, and armored bed surface (Montgomery and Buffington 1993). Pool-riffle channels demonstrate a bed topography formed by cross-channel oscillating flow, which scours alternating banks of the channel, and is influenced by channel bends, bedrock outcrops and large woody debris in the channel, which may stabilize pool and bars, increasing channel complexity (Lisle 1986).

Below Belknap Springs, Lost Creek, a major undammed tributary, increases the mainstem flow by about 70% with its estimated mean discharge of 713 cfs (Morse et al. 1987). Below McKenzie Bridge, another major undammed tributary, Horse Creek, adds approximately 22% to McKenzie River flow with an estimated mean discharge of 500 cfs. Two major undammed tributaries contribute to the flow between river mile 60 (km 96) below which the South Fork McKenzie River joins the mainstem and the community of Blue River (km 92) where Blue River flows into the mainstem. Discharge from South Fork

McKenzie River increases mainstem flow approximately 24% (818 cfs mean discharge after dam construction), and Blue River increases mainstem flow by approximately 12% (481 cfs mean discharge after dam construction)(Morse et al. 1987).

Boundaries of the seven reaches selected on the basis of valley constraint, slope, channel type, tributary and dam influence, historical landmarks, and reach length, from upriver to downriver are: Trailbridge Dam, Belknap Springs, Rainbow Bridge, River Mile 60 (just above the South Fork confluence), Finn Rock, Marten Creek and Leaburg Dam (Fig. 10). Dimensions of each reach and its associated active channel and riparian area were obtained by GIS query (Table 5).

Analysis by Reach

Reach 1. Trailbridge Dam to Belknap Springs

The channel from Trailbridge Dam to Belknap Springs flows north to south for 12 km with a slope of 1.2% and sinuosity of 1.36 and can be characterized as a plane-bed channel (Fig. 11). A large aquifer and springs in the upper reach provide constant flow through the summer (historical survey notes, 1937). No exposed gravel bars were visible in this reach in either set of photos. No channel narrowing or shift in channel position was evident in this reach, though heavy shade by large riparian conifers made exact measurement of the active channel more difficult. Side channel length decreased from 1,039 m in the 1949 photos to 669 m in 1986 (Table 6). Ten S_1 pools (>40 m^2 area, ≥2 m depth) were counted in this reach in August 1937, and eight in 1991 (Table 7).

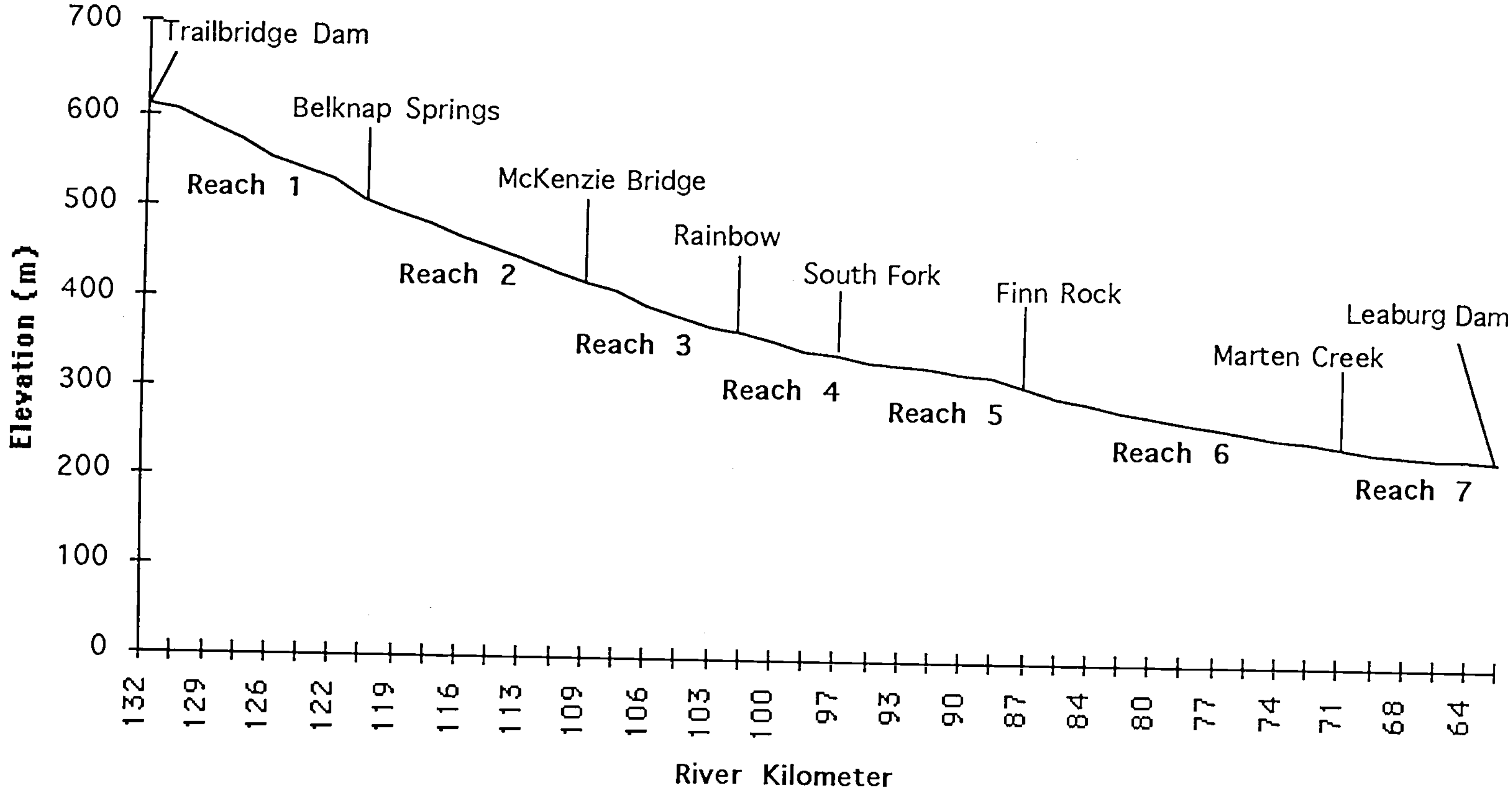

Fig. 10. Planform, reach breaks, and designated study reaches, Trailbridge Dam to Leaburg Dam, McKenzie River, OR.

Table 5. Dimensions and channel sinuosity of seven study reaches on the McKenzie River, OR, in 1945/49 and 1986. Slope was determined from U.S.G.S. topographical maps, all other measurements were digitized from aerial photos and imported into GIS. Riparian area includes area within 90-m of active channel, plus floodplain.

	Reach	Slope (%)	Sinuosity		Length in KM		Channel Area (ha)		Riparian Area (ha)	
			1945 1949	1986	1945 1949	1986	1945 1949	1986	1945 1949	1986
1	Trailbridge Dam	1.2	1.36	1.36	12.08	12.11	35	30	225	226
2	Belknap Springs	0.8	1.14	1.14	10.40	10.38	38	33	191	190
3	McKenzie Bridge	0.8	1.14	1.13	6.13	6.03	21	18	114	114
4	Rainbow Bridge	0.5	1.42	1.22	6.98	6.06	29	37	225	207
5	RM60 (above South Fork)	0.3	1.17	1.14	9.93	9.64	69	55	297	323
6	Finn Rock Bridge	0.4	1.32	1.34	15.95	16.09	119	100	305	314
7	Marten Cr. (to Leaburg Dam)	0.2	1.30	1.30	8.56	8.54	67	63	168	166
	(Means) or Totals	0.6	1.26	1.23	70.04	68.86	377	336	1,525	1,539

The most striking change in riparian vegetation in Reach 1 was the decrease in mature conifers from 62% of the riparian area to 39%, coupled with an increase in second-growth conifer (20-100-yr) from 35% of riparian area to 49% (Fig. 12). In the 1949 aerial photos, roads were scarce and difficult to detect because they were narrow gravel roads, often hidden by the forest canopy. This reach had not been logged and the riparian conifer forest was largely intact in 1949. In contrast, the 1986 aerial photos showed numerous clearcuts in the surrounding uplands, a lower abundance of mature conifers in the riparian area, and an increased area devoted to roads with extension of Highway 126 and a swath cut for transmission lines from the hydroprojects upriver (Fig. 10, Table 8). Residential development has been minimal in this reach because of federal ownership.

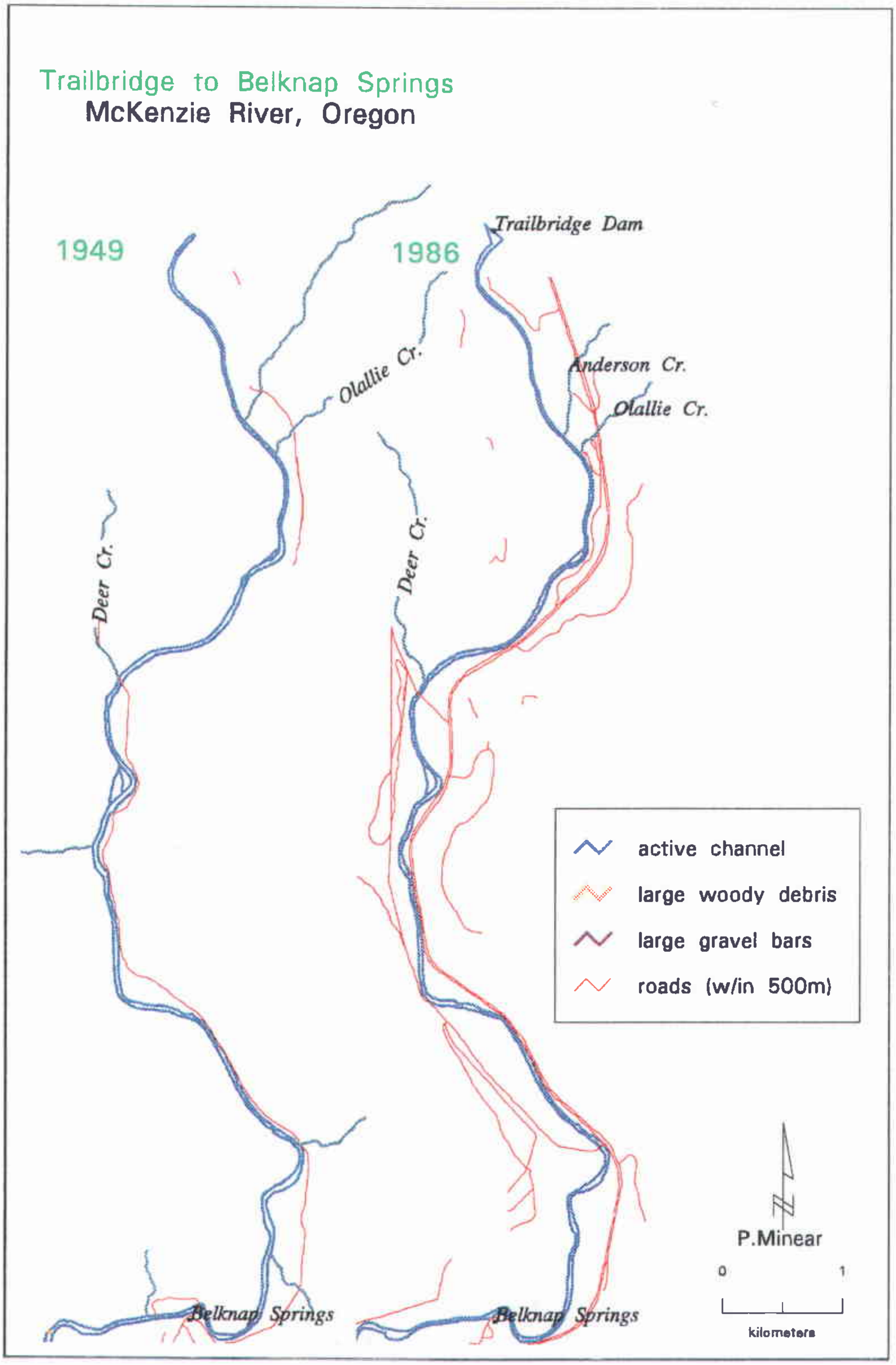

Fig. 11 Reach 1. Channel features and roads from Trailbridge Dam to Belknap Springs, McKenzie River, OR, digitized from aerial photos taken in 1949 and 1986.

Table 6. Side channel number and length and exposed gravel bar area, Reach 1 through Reach 7, Trailbridge Dam to Leaburg Dam, McKenzie River, OR, in 1945/49 and 1986.

Reach	Number of Side Channels		Side Channel Length (m)		Side Channel Length (m/km)		Gravel Bar Area (m2)		Gravel Bar Area (m2/km)	
	1945 1949	1986	1945 1949	1986	1945 1949	1986	1945 1949	1986	1945 1949	1986
REACH 1: Trailbridge Dam	10	3	1,039	669	86	55	0	0	0	0
REACH 2: Belknap Springs	7	11	998	1,263	96	122	165	6,457	16	622
REACH 3: McKenzie Bridge	2	2	730	677	119	112	894	0	146	0
REACH 4: Rainbow Bridge	21	7	6,027	973	864	161	11,825	40,763	1,695	6,724
REACH 5: RM60 (above South Fork)	7	9	5,957	3,077	600	319	124,276	13,053	12,520	1,353
REACH 6: Finn Rock Bridge	5	9	2,627	3,593	165	223	68,498	21,023	4,294	1,306
REACH 7: Marten Cr. (to Leaburg Dam)	1	1	314	387	37	45	2,725	7,217	318	845
Totals or (Means)	53	42	17,692	10,639	281	148	208,383	88,513	2,713	1,550

Table 7. Change in large pools with a minimum depth of 2 m and area of at least 40 m^2 from 1937/38 to 1991, Trailbridge Dam to Leaburg Dam, McKenzie River, OR.

Reach	1938	1991	% Change
1 Trailbridge Dam to Belknap Springs	8	10	25
2 Belknap Springs to McKenzie Bridge	19	6	-68
3 McKenzie Bridge to Rainbow	6	5	-17
4 Rainbow to South Fork junction	22	6	-73
5 South Fork to Finn Rock	21	13	-38
6 Finn Rock to Marten Creek	53	65	23
7 Marten Creek to Leaburg Dam	33	26	-21
TOTALS	162	131	-19

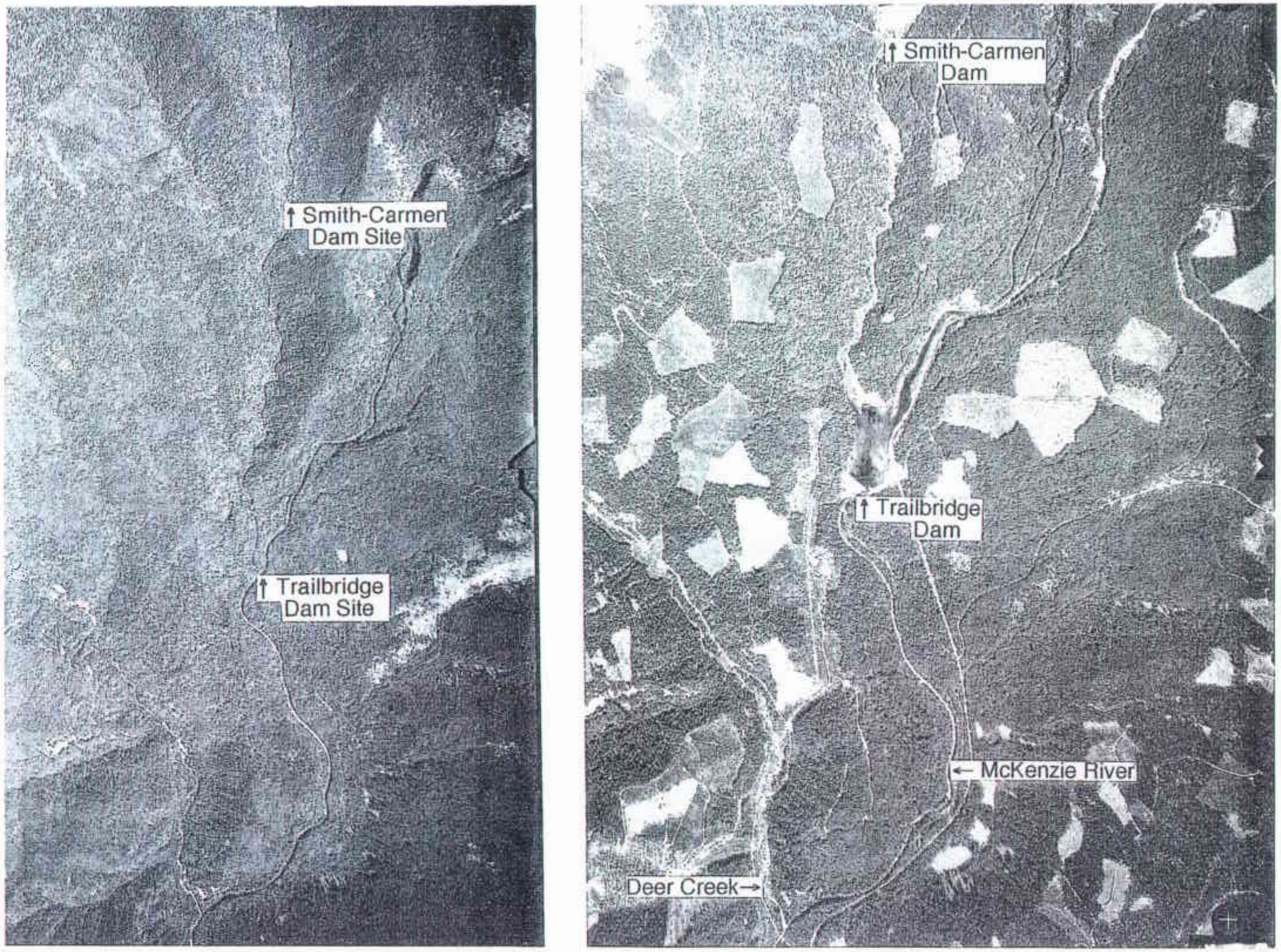

Fig. 12. Watershed vegetation and land use in 1949 (left) and 1986 (right) in aerial photos with slightly different scales. Smith-Carmen Dam to Deer Creek, McKenzie River, OR.

Table 8. Percent of riparian area in land-use and vegetation classes by reach, Trailbridge Dam to Leaburg Dam, McKenzie River, OR, in 1945/49 and 1986. Riparian area was within 90 m of active channel, plus floodplain.

Reach	Roads		Residential or Developed		Agriculture		<20 yr Hardwoods		20-100 yr Hardwoods		<20 yr Conifer		20-100 yr Conifer		>100 yr Conifer	
	1949	1986	1949	1986	1949	1986	1949	1986	1949	1986	1949	1986	1949	1986	1949	1986
REACH 1: Trailbridge Dam	1	5	0	0	0	0	0	1	0	2	0	3	35	49	62	39
REACH 2: Belknap Springs	1	3	1	3	0	0	1	1	1	6	14	0	61	60	20	27
REACH 3: McKenzie Bridge	3	4	4	11	1	0	1	0	0	6	9	0	65	67	17	12
REACH 4: Rainbow Bridge	2	4	1	5	3	1	0	1	6	8	3	0	32	63	53	17
REACH 5: RM60 (above South Fork)	2	4	3	3	1	1	9	20	16	15	4	0	57	54	9	3
REACH 6: Finn Rock Bridge	3	6	6	6	3	1	4	7	11	9	4	1	58	60	11	10
REACH 7: Marten Cr. (to Leaburg Dam)	3	3	11	21	14	11	6	5	5	14	1	0	38	46	22	0

Reach 2. Belknap Springs to McKenzie Bridge

At Belknap Springs, the McKenzie River changes direction of flow from north-south to east-west. Flowing toward the town of McKenzie Bridge 10.4 km downriver, the slope lessens (0.8%) and sinuosity decreases (1.14). Belknap Springs is the site of a natural hot spring that has been a recreation area for most of this century.

The channel maintained its position in this reach during the period from 1949 to 1986 (Fig. 13). More side channels were noted in the 1986 aerial photos (1,263 m) than in the 1949 photos (998 m)(Table 6). A decrease of 68% in S_1 pools (>40 m^2 area, ≥2 m depth) was noted in this reach since the Bureau of Fisheries survey in 1937 (Table 7). Two single pieces of large wood were visible in the 1949 aerial photos and one piece in the 1986 photos.

Gravel bar area in this reach increased from 165 m^2 in 1949 to 6,457 m^2 in 1986. Difference in flows during the photo dates accentuates the difference in gravel bar area. Flows were 55 cms and 56 cms at the Vida gage on the dates of the 1949 aerial photos. Flows were higher (64 cms and 72 cms) during the dates of the 1986 photos and would have covered more gravel bar area.

Land use and vegetation have changed little in this reach (Table 8). Roads and residential areas have increased, primarily around the community of McKenzie Bridge and the development at Belknap Springs. Clearcut areas comprised 14% of the riparian area in 1949, but none were seen in the 1986 photos.

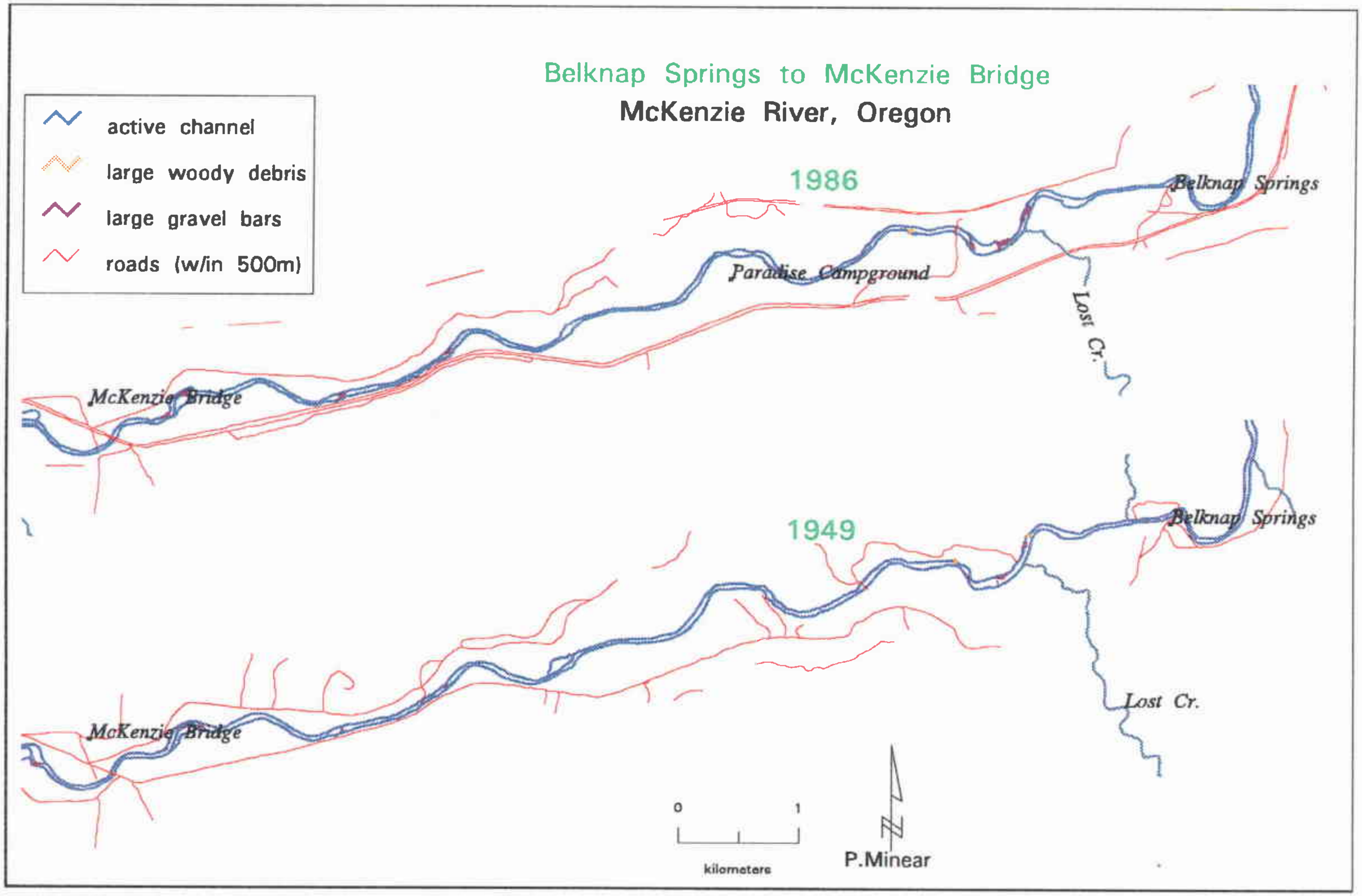

Fig. 13. Reach 2. Channel features and roads from Belknap Springs to McKenzie Bridge, McKenzie River, OR, digitized from aerial photos taken in 1949 and 1986.

Reach 3. McKenzie Bridge to Rainbow Bridge

Sinuosity and slope observed in Reach 2 do not change as the McKenzie River flows through the 6.1-km Reach 3 and the river remained close to its original channel (Fig. 14). The valley floor is wider in this section, allowing for greater opportunity for side channel development. The Horse Creek tributary junction migrated to a position 1.7 km downriver from the 1949 junction. The delta formed by this dynamic tributary junction with the mainstem has a high potential for change and development of side channels. Gravel bar area decreased from 894 m^2 in 1949 to none observed in 1986, though differences in flow (55 cms in 1949 versus 64 cms in 1986 at Vida) may account in part for lack of exposed gravel bars in the 1986 photos (Table 6). No large woody debris was observed in either year, and side channel length and S_1 pool number remained similar (Table 7).

Residential land use has increased from 4% of the riparian area in 1949 to 11% in 1986. Very young conifers (including clearcuts) in the riparian area have decreased (Table 8).

Reach 4. Rainbow Bridge to RM60 (above South Fork Confluence)

Reaches 4 and 5 exhibited the most dynamic channel changes in the last three decades, with two major channel changes noted in Reach 4 (Fig. 15). The valley floor is wide and unconstrained with a well developed floodplain, and the slope is gradual (0.47%).

The main channel flowed to the south around Dearborn Island in 1949. Between 1959 and 1967 the main channel around Dearborn Island shifted to occupy a side channel to the north, leaving the south channel with minimal

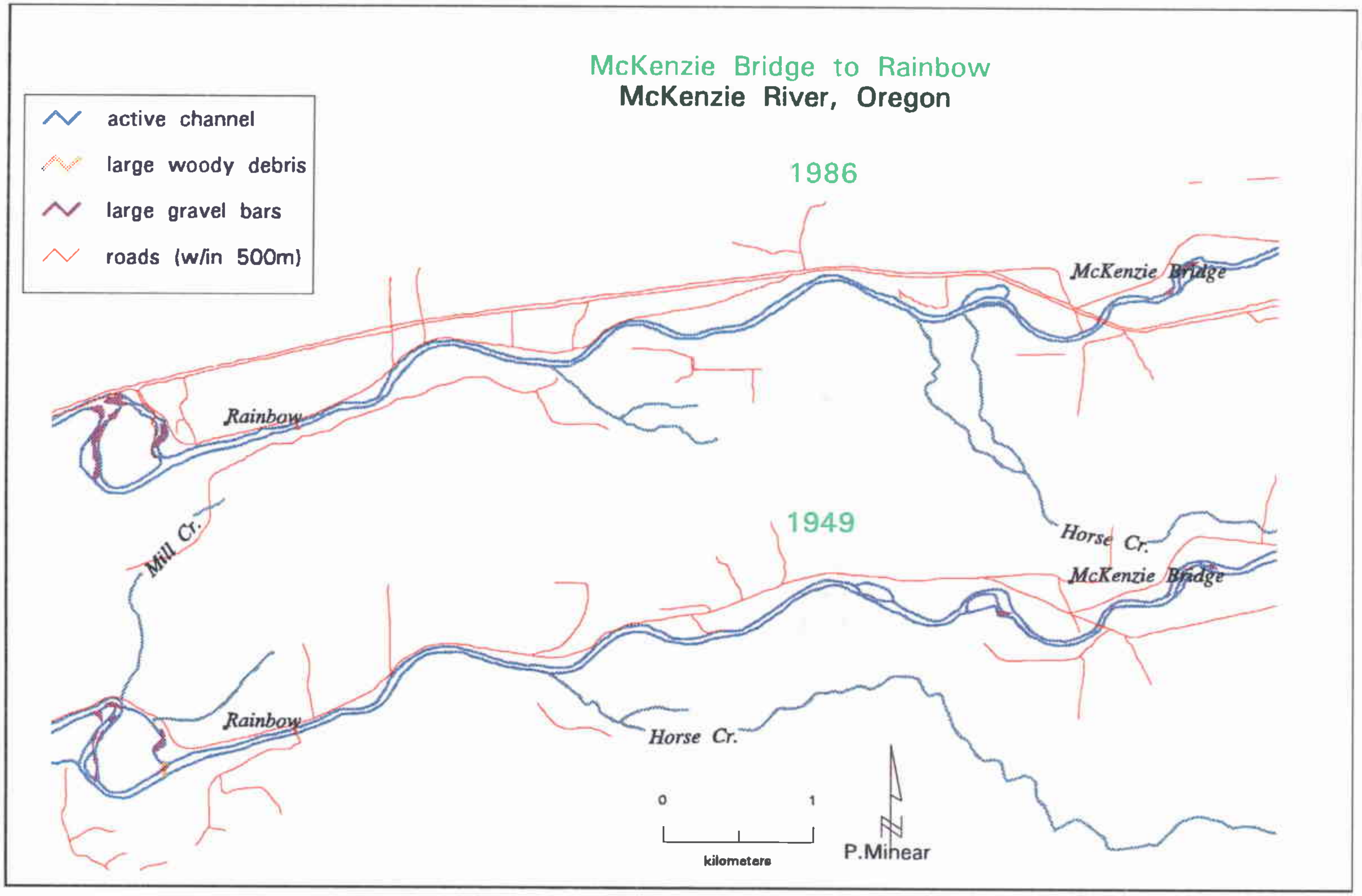

Fig. 14. Reach 3. Channel features and roads from McKenzie Bridge to Rainbow, McKenzie River, OR, digitized from aerial photos taken in 1949 and 1986.

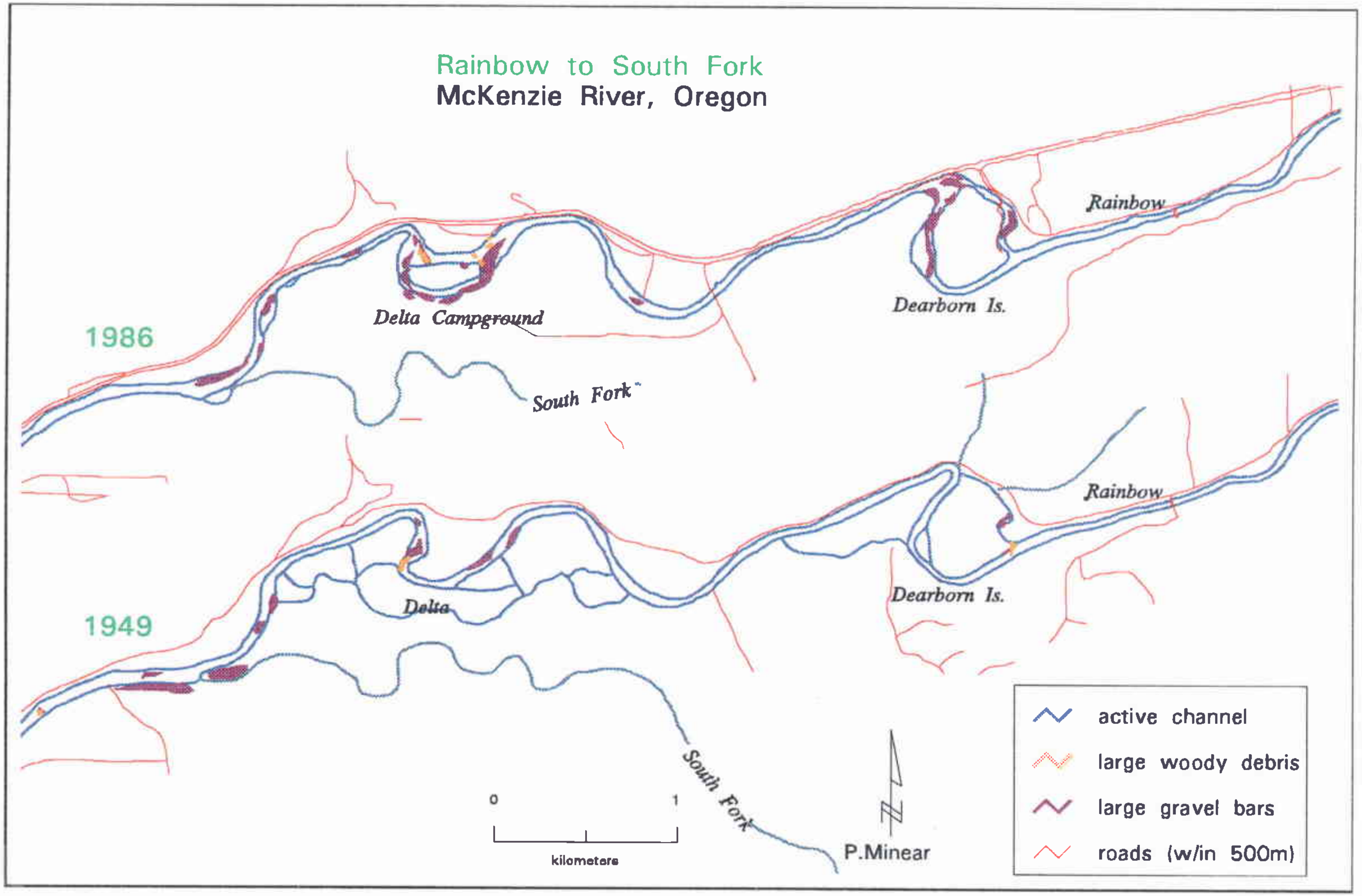

Fig. 15. Reach 4. Channel features and roads from Rainbow to River Mile 60, just above the junction with the South Fork McKenzie, McKenzie River, OR, digitized from aerial photos taken in 1949 and 1986.

summer flows (Fig. 16). A road along the north channel was evident in aerial photos after 1959. Roads on both sides of the new main channel may have channelized the majority of flow into the north channel. Before 1964 a resident of Dearborn Island rearranged the gravel on the bar at the top of the island with a bulldozer to direct more flow into the north channel, leaving the riffle in front of his home available for private bank fishing (Dick Helfrich, pers. comm.). The 1964 flood may have deposited some of its heavy sediment load above the island, redirecting flow to the north channel. Riprap placed in front of homes along the river above Dearborn Island may have encouraged bed scour and deepened flow on the north side of the channel, accentuating flow into the new north channel.

A more recent change in channel position was noted near Delta Campground (Fig. 17). The 1949 main channel flowed in front of the campground area, afterwards making a hard left turn against bedrock. During a high-flow event in 1986, the main channel shifted north away from the campground, toppling mature conifers as the channel assumed its new position in a previous secondary channel. The secondary channel was evident in 1979 aerial photos, and the entrance was protected by a large log jam. The gravel bar at the upriver end directed flow toward the opening of the secondary channel, and the road on the north bank prevented the river from shifting to the north. Removal or mobilization of the log jam would have exposed the secondary channel to direct flow from the main channel, thus accommodating the channel shift and reducing sinuosity and channel complexity. In both of these channel changes, sinuosity was lost as the channel assumed a more direct path. Channel straightening at Dearborn Island and Delta campground reduced sinuosity in this reach from 1.42 in 1949 to 1.22 in 1986, the largest decrease in sinuosity in the study area (Table 6).

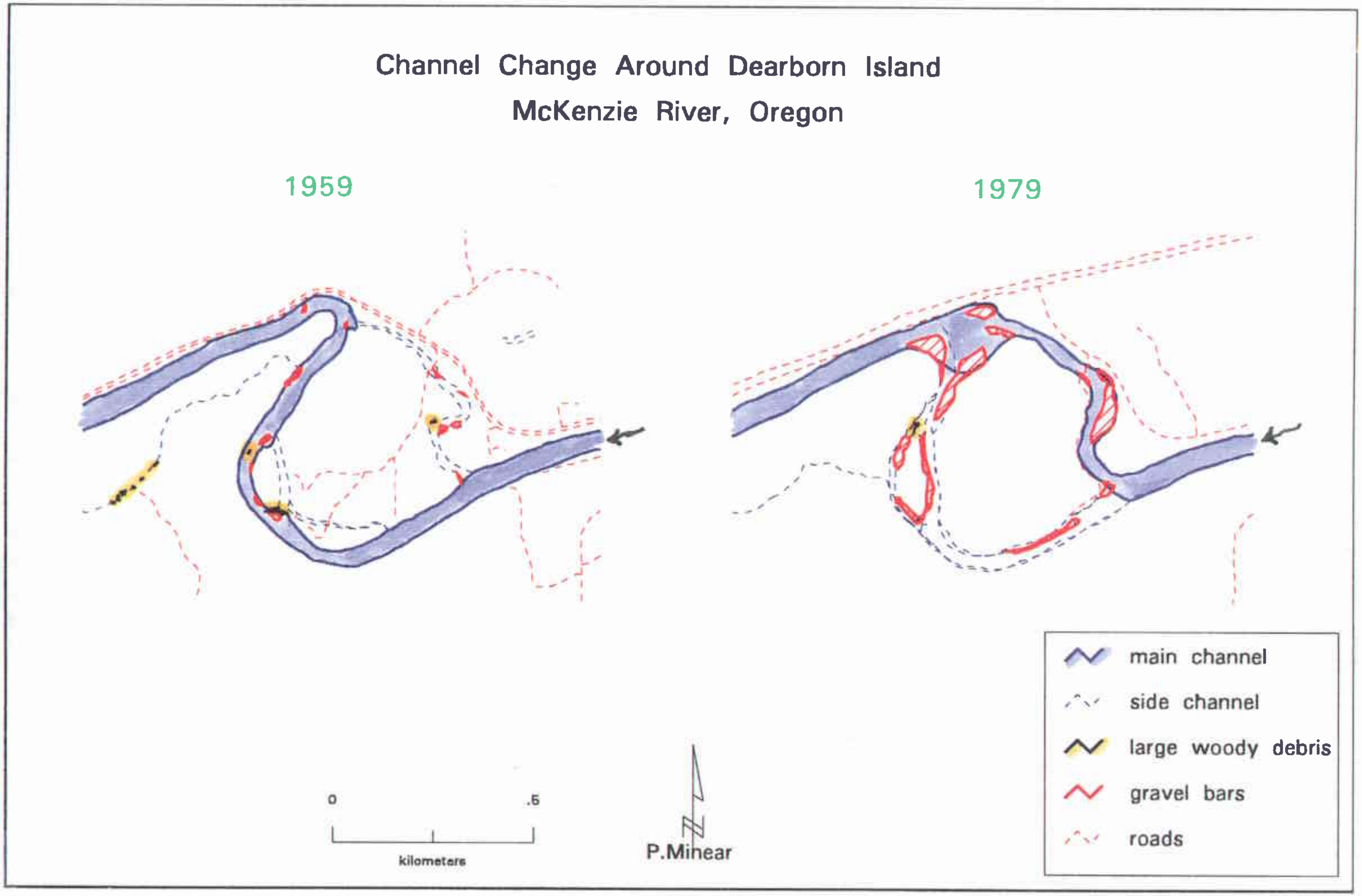

Fig. 16. Dearborn Island (in Reach 4), change in main channel flow, side channels and associated features between 1959 and 1979, McKenzie River, OR.

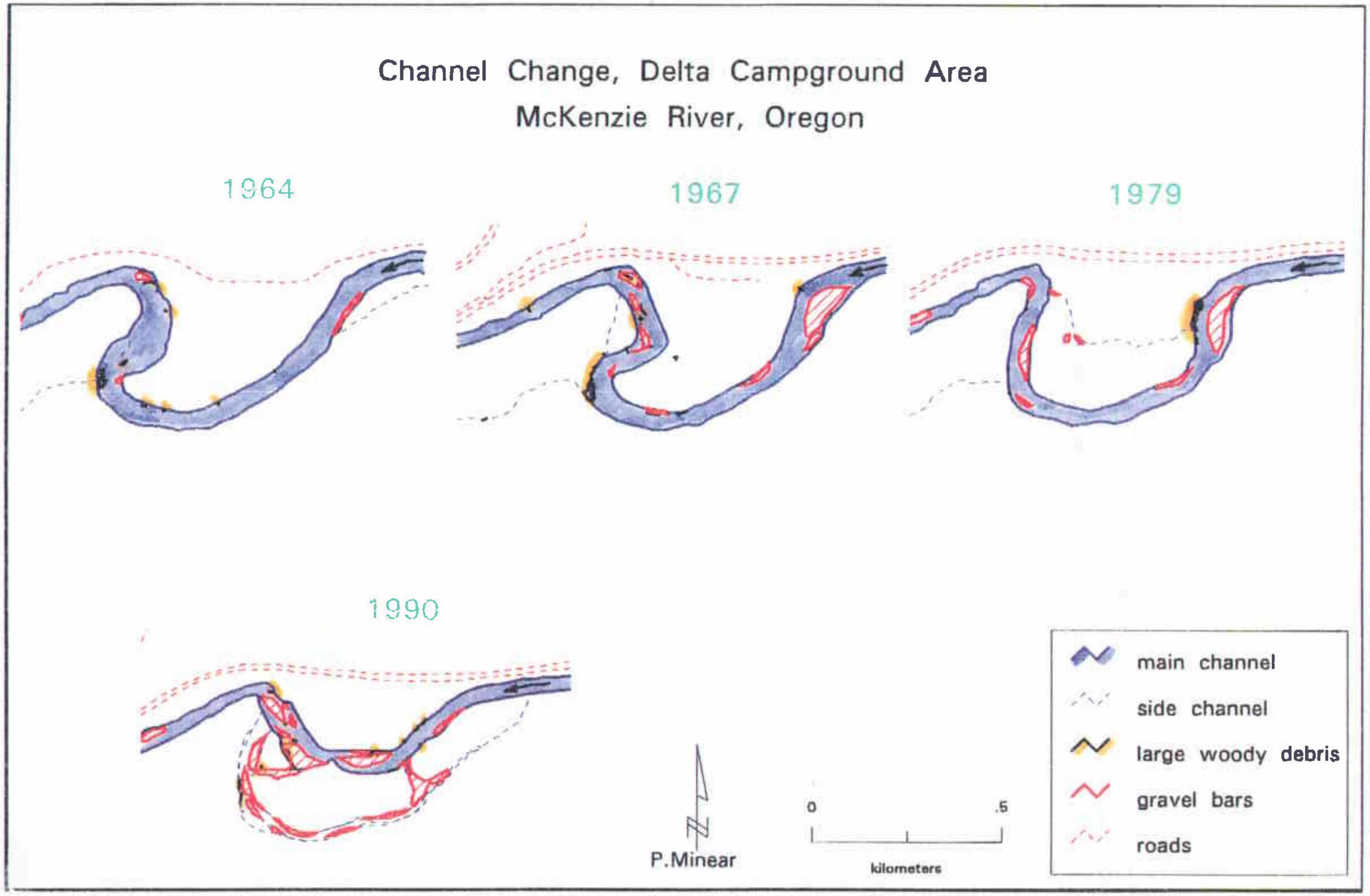

Fig. 17. Delta Campground area (in Reach 4), change in main channel flow, side channels and associated features between 1964 and 1990, McKenzie River, OR.

More exposed gravel bars were evident in the 1986 aerial photos than in the 1949 photos, most located in the isolated former main channels (Table 7). The 1937 historical survey noted good spawning area with suitable gravels in this section. Large woody debris in the channel increased in this reach from two aggregations in 1949 to four single pieces and two aggregations visible in the 1986 aerial photos. Total length of side channels (not counting the former main channels) decreased (Table 7). This reach had the greatest loss of large deep pools of any reach in this study, a decrease from 22 pools noted in the 1937 historical survey to 6 pools in the 1991 resurvey (Table 8).

Notes from the historical survey (1937) describe riparian vegetation as "thick, almost impenetrable" made up of conifers, alder, willow, maple and brush. The most striking change in vegetation in Reach 4 was a shift from mature conifer to second growth conifer (Table 8). Mature conifer decreased from 53% to 17% of the riparian area, while second-growth conifer (20–100-yr) increased from 32% of riparian area in 1949 to 63% in 1986.

Reach 5. RM 60 (above South Fork Confluence) to Finn Rock

Continuing in a wide valley with a gradual slope (0.3%), the mainstem McKenzie River is augmented by two major tributaries in this reach, the South Fork of the McKenzie and Blue River (Fig. 18). In 1949, neither of these major tributaries was dammed. By 1986, both had been dammed for nearly 20 years.

Below Blue River the main channel shifted to the east in several stages between 1949 and 1967, occupying a side channel on the outer side of two mid-channel islands and assuming a straighter path (Fig. 19). The first stage of channel change occurred between 1949 and 1959 and resulted in the shift of the main channel into a straighter secondary channel. Intensive logging of the entire riparian area and floodplain was evident in the 1959 photos and included spanning the channel to pull logs from the islands, leaving no woody riparian vegetation, exposing the banks to erosion, and destabilizing the channel. Striations were seen in the 1986 aerial photos where present vegetation patterns still reflect the tracks of dragged logs. Further channel straightening occurred between 1959 and 1967, presumably a consequence of the 1964 flood waters cutting a more direct channel.

As with the two channel changes upriver, the river assumed a more direct path and sinuosity decreased (Table 5). Side channel length and exposed gravel bar area were reduced (Table 6). In 1986, exposed gravel bar area was reduced to 10% of the 1949 amount. Unvegetated gravel bars along the South Fork McKenzie River below Cougar Dam were common in the 1949 photos but were no longer evident in the 1986 photos. Flows on the photo dates were 32% higher in 1986, but not enough to account for the change in gravel bar area by inundation. Young hardwoods increased from 9% of riparian area to 20% in this reach over the 37-yr period, possibly due to revegetation of previously exposed gravel bars (Table 8).

Occurrence of large woody debris decreased from three large single pieces and eight aggregations in 1949 to one single log and four aggregations visible in the 1986 aerial photos. The number of S_1 pools (>40 m^2 area, ≥2 m depth) decreased 38% from 1937 to 1991 (Table 7).

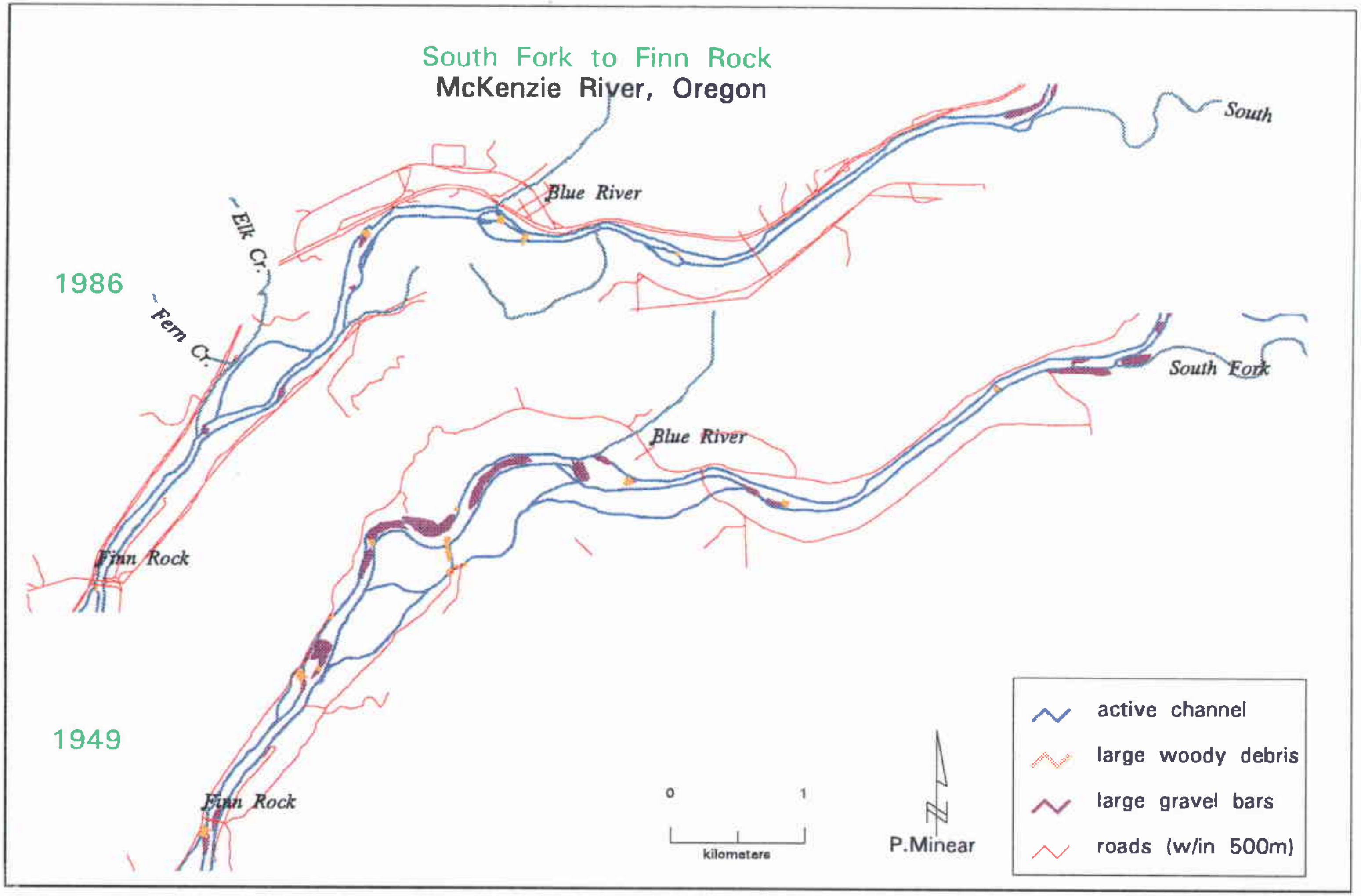

Fig. 18. Reach 5. Channel features and roads from River Mile 60 above South Fork Junction to Finn Rock Bridge, McKenzie River, OR, digitized from aerial photos taken in 1949 and 1986.

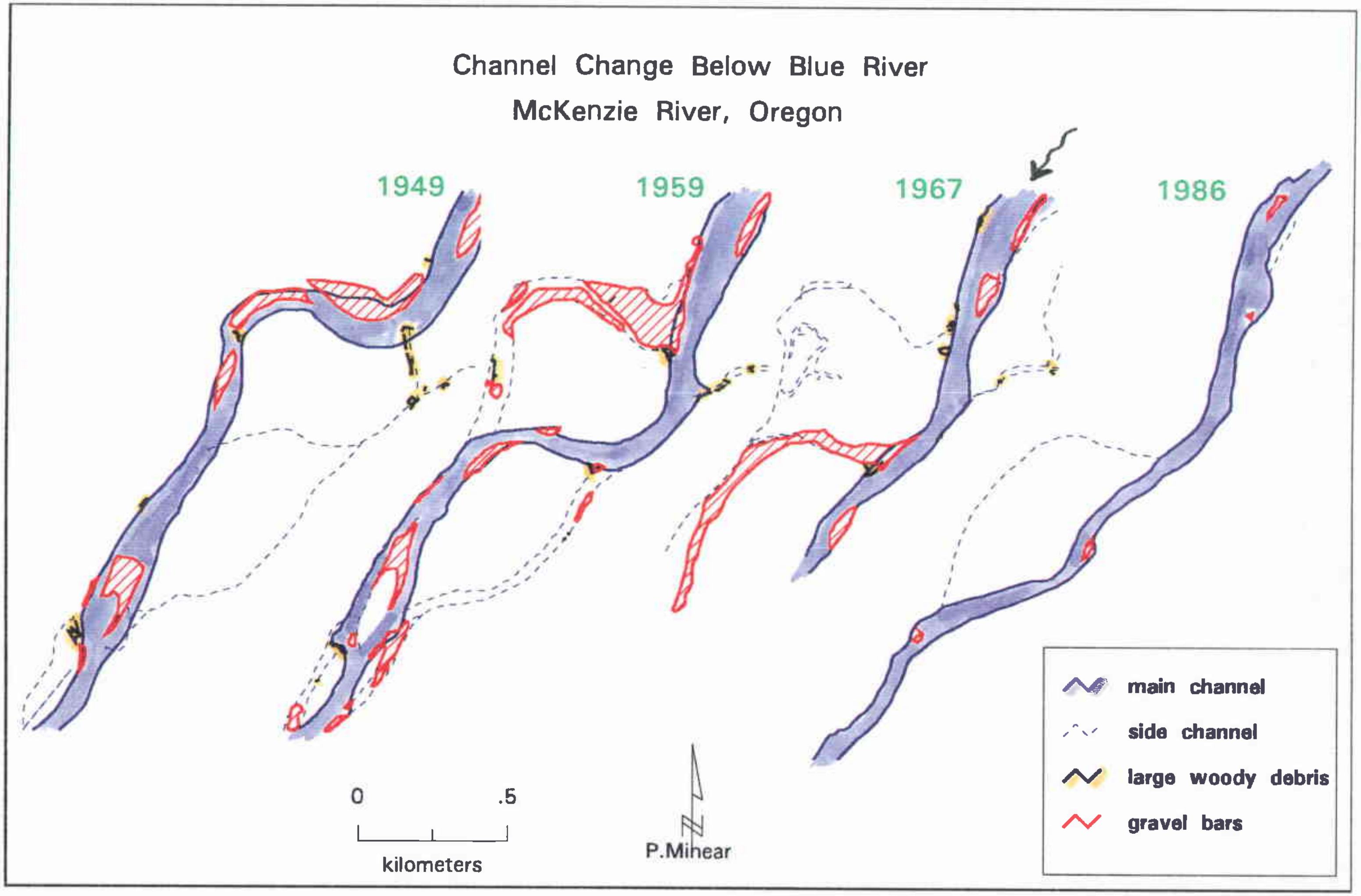

Fig. 19. Below Blue River (in Reach 5), change in main channel flow, side channels and associated features from 1949 to 1959, 1967, and 1986 , McKenzie River, OR.

Reach 6. Finn Rock to Marten Creek

Near Finn Rock, the valley floor again constrains the channel of the McKenzie River, and the slope and sinuosity increase. The longest reach in this study extends 16 km downriver from Finn Rock Bridge to Marten Creek, which enters the McKenzie River from the south near Helfrich Landing (Figs. 20 and 21).

No channel changes were noted in Reach 6. Gravel bar area in 1986 photos was 30% of the amount seen in the 1949 photos, though more side channels were noted in the 1986 photos than in 1949 (Table 6). Four aggregations of large woody debris, visible in the 1949 photos, were decreased to a single piece in the 1986 aerial photos. More S_1 pools (>40 m^2 area, ≥2 m depth) were found in 1991 (65 pools) than in the historical surveys in 1938 (53 pools)(Table 7). The field crew in 1991 noted large deep pools created by bedrock formations just under the surface of the river, which might not have been noticed by the historical survey crew travelling more rapidly down the thalweg. Relatively few changes in the riparian land use and vegetation were noted for this reach except that area devoted to roads doubled to 6% of the riparian area (Table 8).

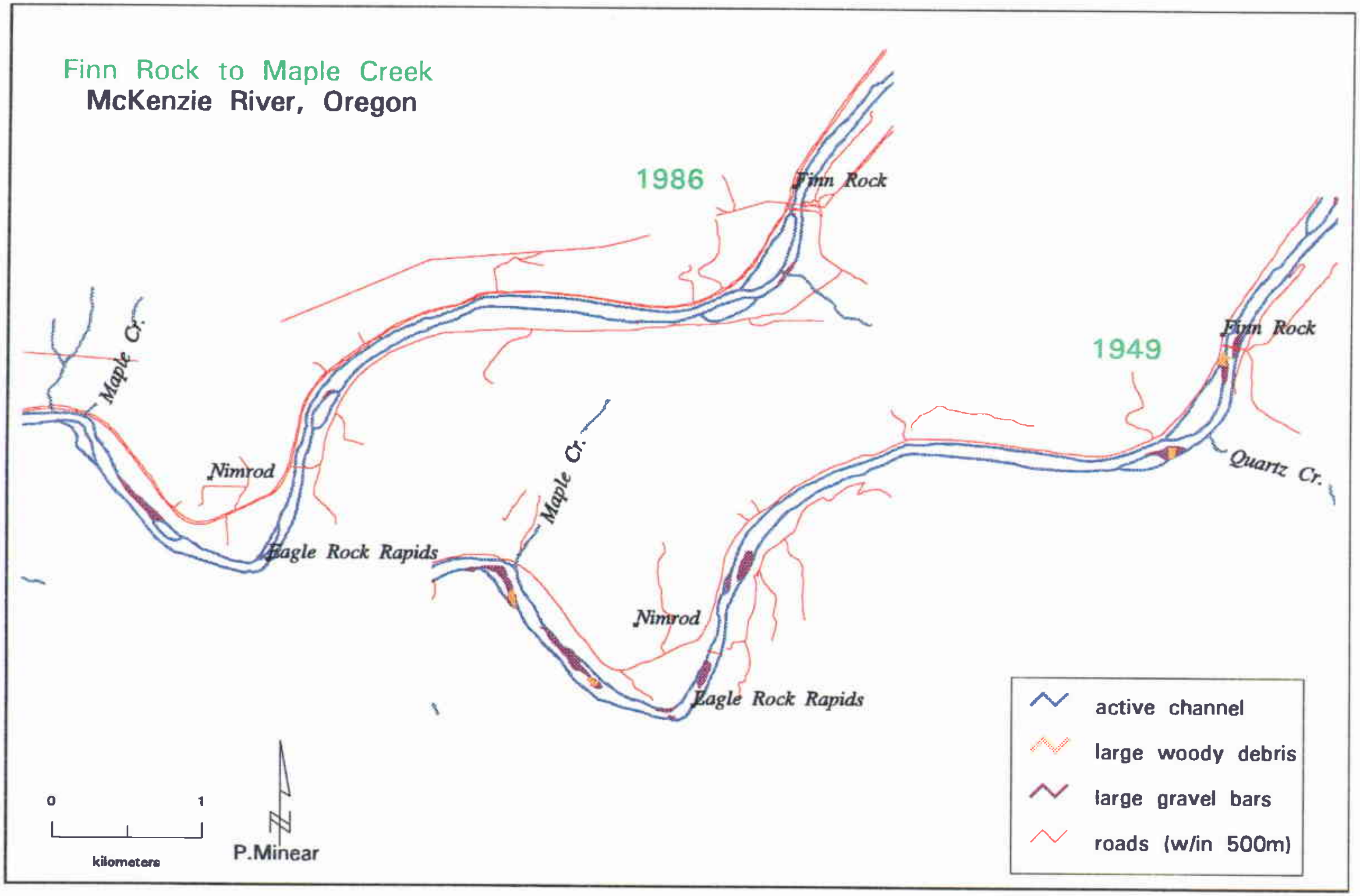

Fig. 20. Reach 6 (upriver section). Channel features and roads from Finn Rock Bridge to Maple Creek, McKenzie River, OR, digitized from aerial photos taken in 1945, 1949, and 1986.

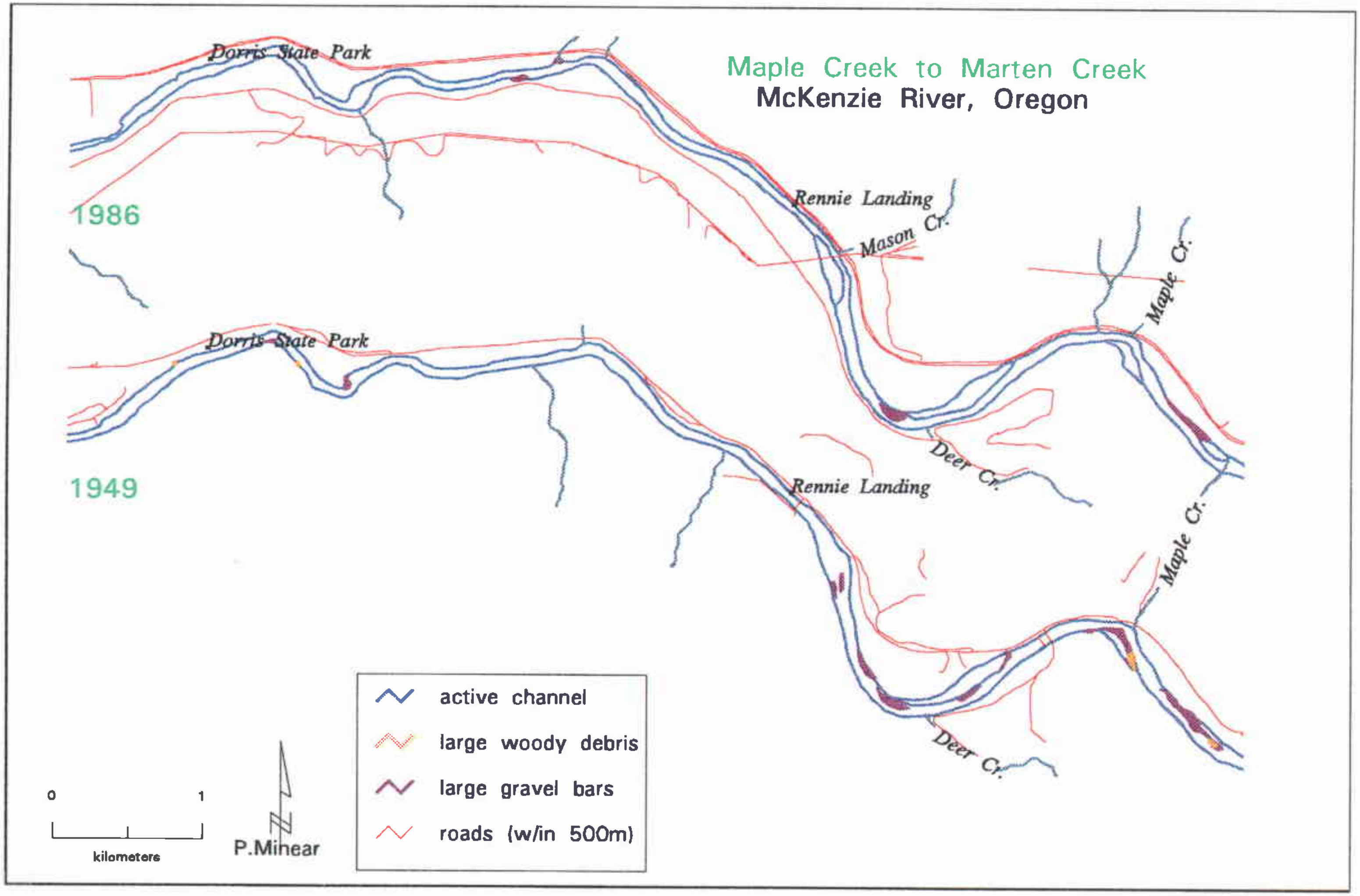

Fig. 21. Reach 6 (downriver section). Channel features and roads from Maple Creek to Dorris Park (1.4 km upriver from Marten Creek), McKenzie River, OR, digitized from aerial photos taken in 1945, 1949, and 1986.

Reach 7. Marten Creek to Leaburg Dam

The lowest reach in the study area has a gradual slope (0.2%) with a wide valley floor, ending at the large lake formed by Leaburg Dam near the town of Vida (Fig. 22). Gravel bar area increased in this reach between 1945 and 1986, and side channel length stayed about the same (Table 6). Observable large woody debris decreased (three single pieces and one aggregation in 1945 to none in 1986). The number of S_1 pools (>40 m^2 area, ≥2 m depth) decreased 15% in this reach, from 33 pools in 1938 to 26 pools in 1991 (Table 7).

Residential or developed areas increased more in Reach 7 than any other reaches, doubling the amount of riparian alteration for a total of 21% of the riparian area devoted to residences or businesses (Table 8). The historical habitat survey described this section of the watershed as predominantly second growth in 1938. The 20–100-yr age class of hardwoods increased between 1945 and 1986 from 5% to 14% of riparian area. No patches of mature conifer forest were detected in the 1986 photos as compared to 22% of the riparian area in mature conifers in 1945.

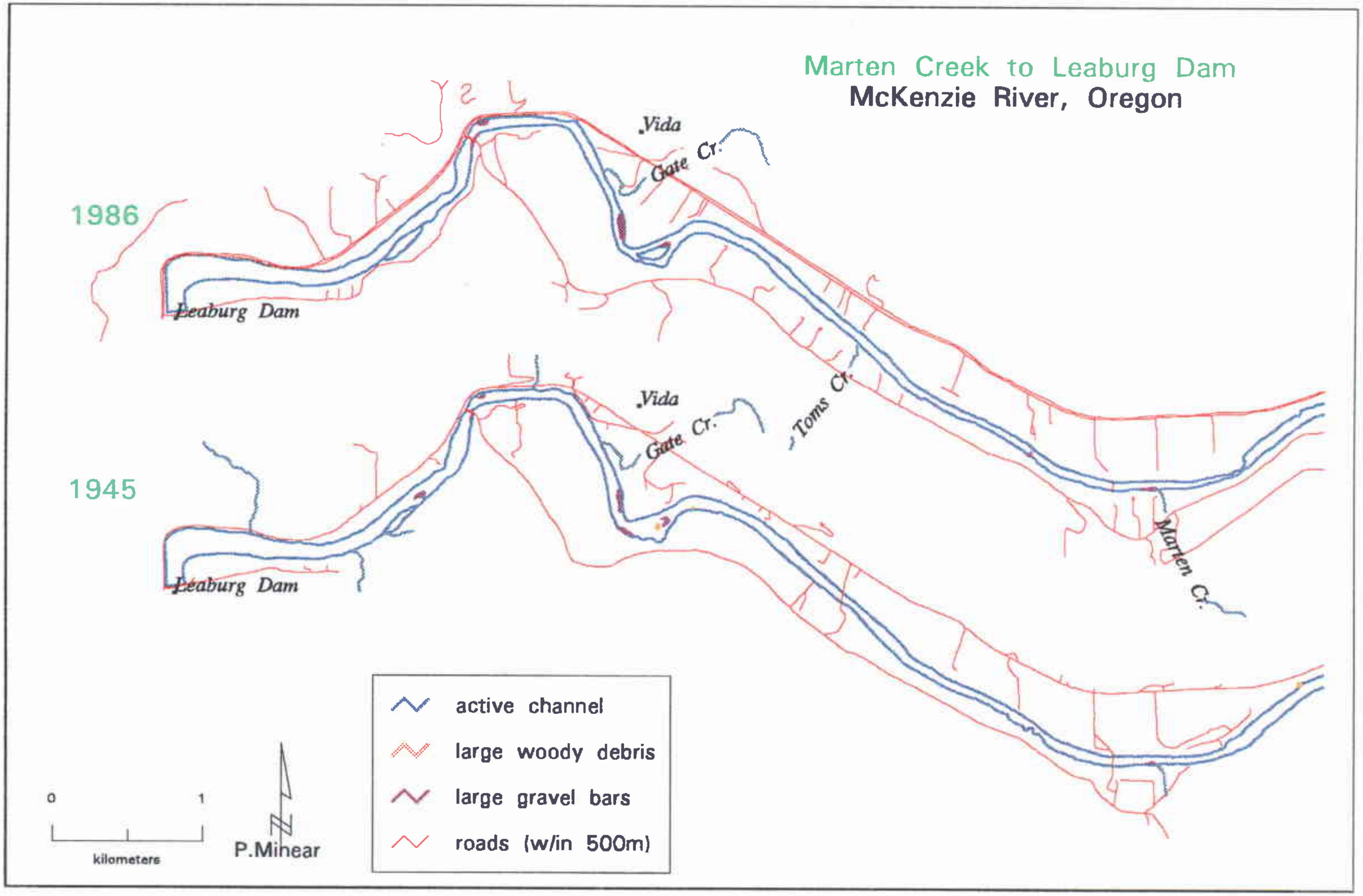

Fig. 22. Reach 7. Channel features and roads from Marten Creek to Leaburg Dam, McKenzie River, OR, digitized from aerial photos taken in 1945 and 1986.

Channel and Riparian Change for the Study Area

Channel Position, 1945/49 to 1986

Comparison of active channel position in 1945/49 and 1986 showed little change except in localized areas (i.e., Dearborn Island, Delta, below Blue River)(Fig. 23). Only 2% of active channel in 1986 was more than 30 m outside the 1945/49 active channel location. Less than 1% of the 1986 active channel differed from the 1945/49 channel by more than 60 m.

Slightly greater channel changes were noted when only main channels, without the addition of the secondary channels, were compared. From 1945/49 to 1986, 7% of the main channel shifted position by at least 30 meters. A change in main channel position of 60 m or greater was measured in 4% of the study area. The predominant changes noted were shifts from the main channel into existing secondary channels. The greatest loss in main channel sinuosity (14%) occurred in the reach from Rainbow Bridge past Dearborn Island and Delta Campground, the unconstrained reach with a well-developed floodplain.

Geomorphic Changes, 1945/49 to 1986

Overall changes in geomorphic conditions included reduction in sediment storage (i.e., gravel bar area), pool-forming elements (large woody debris), length of secondary channels, and channel sinuosity. Unvegetated gravel bars were smaller and less numerous in 1986 than in 1945/49 (Table 9). On the mainstem McKenzie River, unvegetated gravel bars decreased 11% in number and 57% in total area from 1945/49 to 1986. Average size of exposed gravel bars in 1986 was about one half of what it was in the 1940s (Table 9).

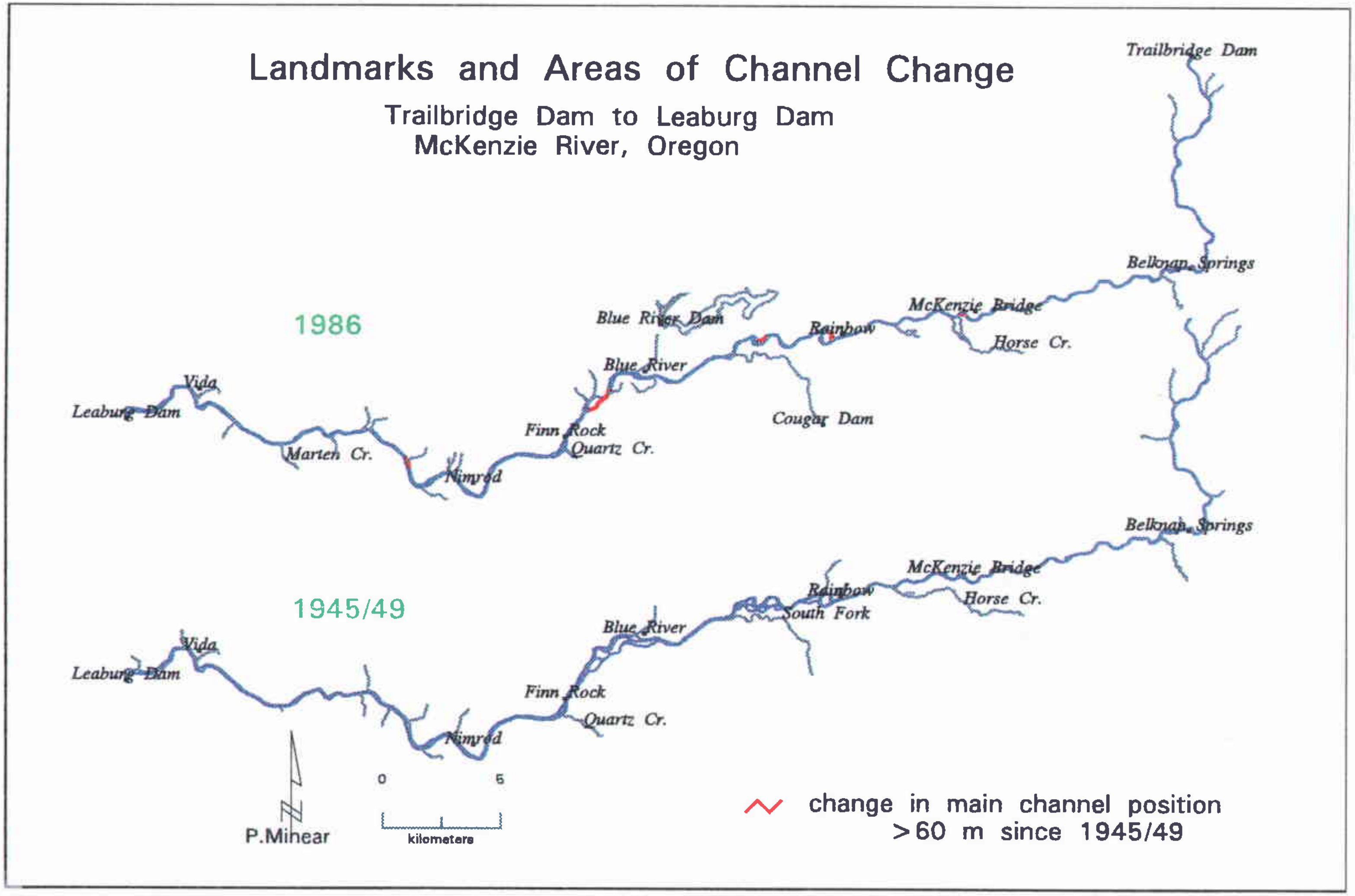

Fig. 23. Active channels, tributary junctions, and areas of change in main channel position greater than 60 m, digitized from aerial photos taken in 1945, 1949 and 1986, Trailbridge Dam to Leaburg Dam, McKenzie River, OR.

Area of exposed gravel bars per river kilometer decreased the most in Reach 5 where the major dammed tributaries of South Fork McKenzie River and Blue River joined the mainstem McKenzie River (Fig. 24). Reach 5 also had the largest increase in young hardwoods, probably due to vegetation of previously exposed gravel bars. Exposed gravel bar area increased most from Rainbow Bridge to the South Fork junction, where exposed gravel bars were found in the abandoned channels at Dearborn Island and Delta campground. As mentioned previously, higher flows during the 1986 photos may account for a small portion of the decrease in visible gravel bars due to inundation.

Table 9. Gravel bar number, area, and percent change, Trailbridge Dam to Leaburg Dam, McKenzie River, OR, 1945/49 and 1986. Gravel bars less than 100 m^2 area were not included in this analysis.

	Number of Gravel Bars	Sum Area (m2)	Max. Area (m2)	Mean Area (m2)	Standard Deviation
1945/49	53	207,900	27,700	3,900	5,600
1986	47	88,500	9,200	1,900	2,200
% change	-11	-57	-67	-52	-61

Number and length of side channels decreased from 53 side channels with a combined length of 17,692 meters in 1945/49 to 42 side channels with a length of 10,639 meters in 1986, representing a decrease of 21% in number and 40% in length. Decreases in side channel length were greatest from Rainbow Bridge to Finn Rock, encompassing the three areas of channel straightening at Dearborn Island, Delta campground and below Blue River.

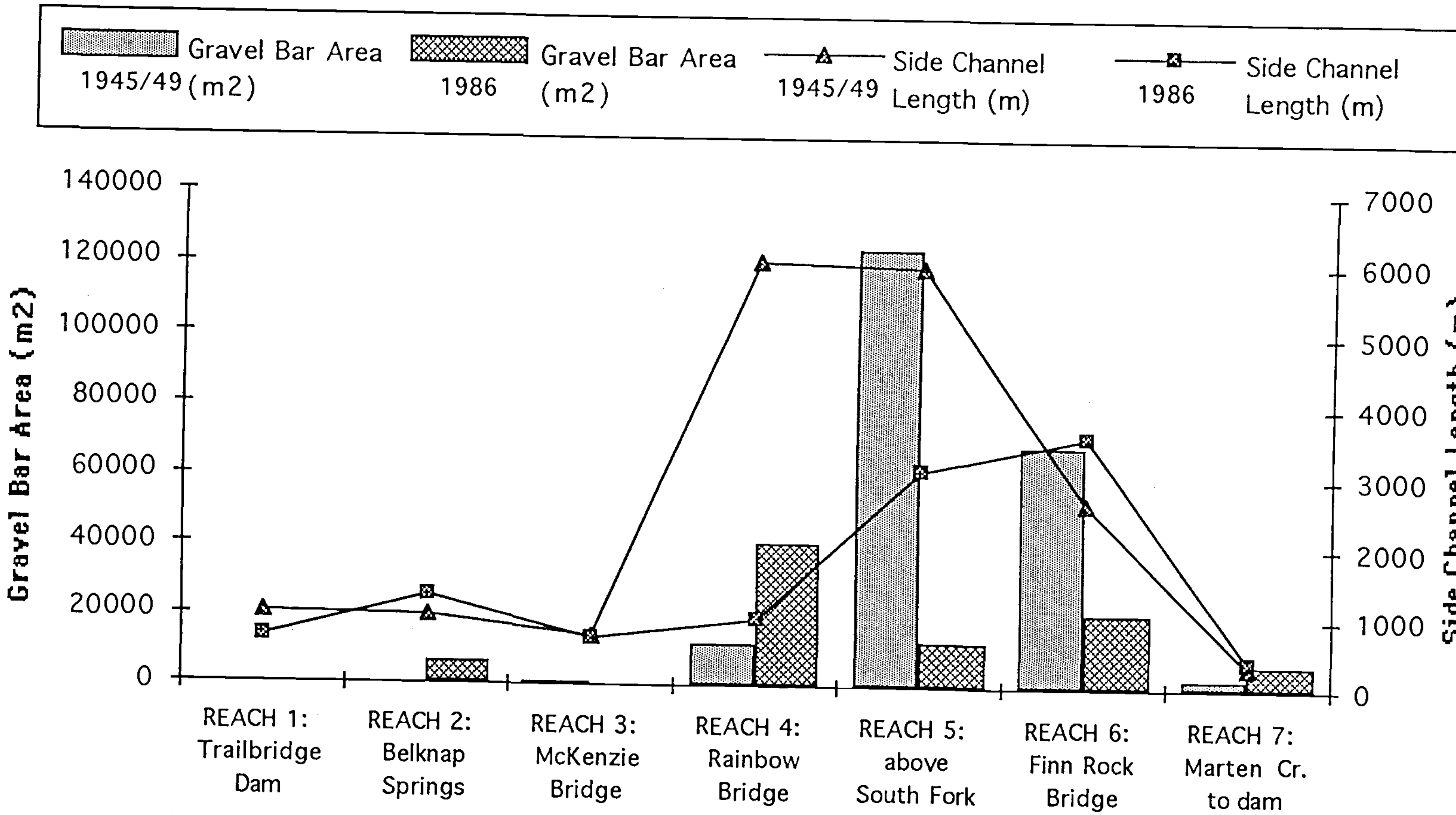

Fig. 24. Gravel bar area and side channel length by reach, Trailbridge Dam to Leaburg Dam, in 1945/49 and 1986, McKenzie River, OR.

More large woody debris was observed in the 1945/49 aerial photos (15 aggregations and 8 large single pieces) than in the 1986 photos (6 aggregations and 8 large single pieces). The majority of large wood was found in the unconstrained reaches between Rainbow Bridge and Finn Rock. Since the 1940s amounts of large woody debris increased only in the new main channel near Delta campground.

Large pool frequency from Trailbridge Dam to Leaburg Dam decreased by 19% (S_1 pools: >40 m^2 area and ≥2 m depth)(Table 7). The 1991 survey examined the river more thoroughly than the historical habitat survey and would have tended to detect more pools than the approach used in 1937-38. The greatest loss in pools (73%) was noted from Rainbow to the South Fork junction (Reach 4), the unconstrained reach that exhibited two areas of channel straightening and an increase in exposed gravel bars. Two large pools, one at the bottom of Dearborn Island and one at the junction with the South Fork, are much smaller now than in the 1950s (Dick Helfrich, pers. comm.).

Channelization (riprap) was noted in the 1991 field surveys in all reaches. More than 1.5 occurrences of riprap per kilometer were found in the unconstrained section (Reaches 3, 4, and 5) from McKenzie Bridge to Finn Rock, and riprap accounted for approximately 5 km of this 22-km section.

Riparian Road Density

Road area within the available riparian area (90-m buffer plus FEMA floodplain) increased from 3.3% in 1945/49 to 5.3% in 1986 (Table 10). This estimate of change in riparian road area was conservative due to the method used to assign road width to 1945/49 roads (equivalent to existing roads in the same location in 1986). A separate estimate of riparian road area in the 1940s buffered all 1945/49 roads by 4 m (8-m road width), the general width of paved forest roads, and yielded a total of 2.8% of the riparian area devoted to roads in 1945/49 versus 5.2% in 1986, a near doubling of road surface. Road density increased in all reaches over time and appeared to be greatest within 60 m of the active channel. Riparian road density was greatest in the reach from South Fork junction to Finn Rock, encompassing the Blue River community.

Table 10. Area in riparian roads, within varying distances from the active channel, 1945/49 and 1986, Trailbridge Dam to Leaburg Dam, McKenzie River, OR.

Riparian	Area (m2) in Roads		% of Riparian	
Buffer Width	1945/49	1986	1945/49	1986
30 m	175,300	248,200	3.3	5.3
60 m	335,000	542,200	3.4	6.0
90 m	446,700	757,600	3.1	5.7
90m +FEMA	452,800	790,000	3.0	5.2

When the effect of road edges was estimated by buffering roads an additional 30 m, percent of the riparian area affected by possible edge effects of roads in addition to actual road surface increased from 23% in 1945/49 to 30% in 1986.

Varying Riparian Buffer Widths

As the width of riparian buffer was increased from 30 m to 60 m, 90 m and 90 m plus the floodplain, several trends were noted in riparian vegetation or land use (Table 11). Hardwoods made up a larger percentage of the riparian area close to the channel, and conifers comprised a larger percentage farther away from the channel. Human impacts from roads, residential or developed areas, and agriculture were most concentrated between 30 m and 90 m from the active channel.

Table 11. Area and percent of land use or vegetation type within riparian areas of varying distance from the active channel, using the 1986 GIS coverages for the area between Trailbridge Dam and Leaburg Dam, McKenzie River, OR. Riparian area widths are 30 m, 60 m, 90 m and 90 m plus FEMA 100-yr floodplain, measured from the active channel on both sides of the river.

	30 m		60 m		90 m		90 m + FEMA	
Land Use or Vegetation	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Roads	21.8	4	48.6	5	66.7	5	69.1	4
Resid/Dev.	21.1	4	54.5	6	88.9	7	92.6	6
Agriculture	1.3	0	10.2	1	25.3	2	27.3	2
<20yr Hardwood	52.0	10	64.4	7	73.5	5	101.6	7
20-100yr Hardwood	67.1	13	98.2	11	125.1	9	140.1	9
<20yr Conifer	0.6	0	3.9	0	11.1	1	11.1	1
20-100yr Conifer	282.1	55	509.2	55	746.0	55	875.4	56
>100yr Conifer	69.6	13	139.3	15	203.6	15	227.7	15
Bare	1.5	0	3.0	0	4.5	0	5.0	0
LAND AREA IN BUFFER	517.0		931.3		1,344.7		1,549.9	

Riparian Land Use

Several trends in riparian land use over the study period were noted in the reach analysis (Table 8). Percent of riparian area in residential or developed uses increased in six of the seven reaches from Belknap Springs to

Leaburg Dam. Agricultural use of riparian area decreased or remained minimal in all reaches. Clear cuts and young conifers (<20-yr) made up less of the riparian area in 1986 than in 1945/49 in all reaches except Reach 1, the reach that was farthest upriver and last opened to logging. Riparian area in mature conifers decreased in all reaches except the reach on Forest Service land from Belknap Springs to McKenzie Bridge.

When land use within the entire riparian study area was considered, additional trends were evident (Table 12). Slight increases in riparian hardwoods of both age classes were noted, as were increases in second-growth conifers (20-100-yr age class). (For this analysis of riparian land use and vegetation, priority was given to vegetation when road and vegetation polygons overlapped in the GIS combined coverages, yielding a reduced estimate of riparian road area due to the complexity of the coverage.)

Table 12. Land use and vegetation within the riparian area, between Trailbridge Dam and Leaburg Dam, digitized from aerial photos taken in 1945/49 and 1986. The riparian area included 90 m from active channel plus the floodplain on each side of the river.

Riparian Land Use and Vegetation	Area (ha) 1945/49	Area (ha) 1986	% of Land Area 1945/49	% of Land Area 1986
(Active Channel)	377.4	335.8	NA	NA
Roads	32.9	69.1	2	4
Residential or Developed	52.1	92.6	3	6
Agriculture	43.3	27.3	3	2
<20 yr Hardwood	56.1	101.6	4	7
20-100 yr Hardwood	108.1	140.1	7	9
<20 yr Conifer	69.6	11.1	4	1
20-100 yr Conifer	767.9	875.4	49	56
>100 yr Conifer	420.6	227.7	27	15
Bare	3.4	5.0	0	0
Area Including Channel	1,931.5	1,885.7		
Total Land Area	1,554.0	1,549.9		

Riparian Landscape Pattern

The riparian landscape of the McKenzie River study area had a mean patch size of 2.2 ha and patch density of 46 patches per 100 ha by the 1940s. This patch size and density indicate that the riparian area was composed of many small patches, rather than large contiguous patches, as early as the 1940s, possibly a reflection of the long history of human occupation of this river corridor. By 1986 the mean patch size decreased to 1.6 ha and patch density increased 38% to 64 patches per 100 ha, reflecting further fragmention of the riparian area by division of existing patches (Table 13). Fractal dimension stayed the same, indicating that the patches were similar in shape. (A simple shape like a circle would have a double-log fractal dimension of 1. More complex shapes approach a value of 2.) Edge density increased by 21%, also indicating a more fragmented landscape and increasing heterogeneity of patches in 1986 than in the 1940s.

Table 13. Landscape indices from FragStats analysis of riparian land-use and vegetation coverages, 1945/49 and 1986, from Trailbridge Dam to Leaburg Dam, McKenzie River, Oregon.

	1945/49	**1986**
Riparian and Channel Area (ha)	1,932	1886
Number of patches	895	1202
Patch Density (#/100 ha)	46.3	63.7
Mean Patch Size (ha)	2.2	1.6
Patch Size Coeff of Variation (%)	289	335
Total Edge (m)	383,910	452,690
Edge Density (m/ha)	198.8	240.1
Double Log Fractal Dimension	1.4	1.4

FragStats analysis of each riparian land-use and vegetation type (i.e., class metrics) reinforced patterns noted from previous GIS analysis and revealed information about riparian patch characteristics (Table 14). Residential (including developed) patches were more numerous and smaller in 1986 than 1945/49, resulting in more edges where residential land bordered other vegetation patches. Number and density of hardwood patches increased, possibly reflecting the regrowth of previous clearcuts, residential landscaping, and areas impacted by the 1964 flood, which revegetated in hardwoods. Patches of mature conifers (>100 yr) decreased in number, density and mean patch size. Second-growth conifer (20-100-yr) had the largest mean patch size and more edges (borders with other vegetation or land-use patches) than other vegetation types in 1986 and was considered to be the matrix vegetation in this landscape. Double-log fractal index showed no apparent trends in complexity of patch shape that could not be explained by difference in original photoscale. (Appendix E: Landscape and Class Indices, FragStats Program.)

Summary of Major Findings

The major findings of this study were summarized in three categories: discharge and sediment, channel position and structure, and riparian land use (Table 15). Reaches directly below mainstem dams or dammed tributaries (Reaches 1, 5, 6, 7) were presumed to be most susceptible to changes related to flow regulation and restriction of sediment supply. Unconstrained reaches (primarily reaches 4 and 5) showed the most change in channel position and structure. Riparian land-use changes were most pronounced in reaches with low road and population density in the 1940s (reaches 1 and 2), in reaches near local communities (reaches 3 and 7), or in areas of channel change (reaches 4 and 5).

Table 14. Class metrics from FragStats analysis of patch characteristics for each vegetation and land-use type in the riparian area, Leaburg Dam to Trailbridge Dam, McKenzie River, OR. Riparian area is area within 90 m of active channel plus floodplain on both sides of river.

Year	Land Use or Vegetation Type	Percent of Landscape	Number of Patches	Patch Density (number/ 100ha)	Mean Patch Size (ha)	Patch Size Coeff. of Variation (%)	Total Class Edge (m)	Class Edge Density (m/ha)	Dble. Log Fractal Index
1949	Roads	1.7	97	5.0	0.3	133	75,600	39.1	1.8
1986		3.7	107	5.7	0.7	145	114,900	60.9	1.6
1949	Residential or Developed	2.7	66	3.4	0.8	111	19,700	10.2	1.1
1986		4.9	202	10.7	0.5	177	45,760	24.3	1.2
1949	Bare	0.2	6	0.3	0.6	60	1,870	1.0	1.2
1986		0.3	6	0.3	0.8	52	2,400	1.3	1.2
1949	Agricultural	2.2	27	1.4	1.6	100	10,980	5.7	1.1
1986		1.5	23	1.2	1.2	91	9,350	5.0	1.3
1949	<20-yr Hardwoods	2.9	69	3.6	0.8	197	27,100	14.0	1.2
1986		5.4	111	5.9	0.9	316	56,440	29.9	1.3
1949	20-100-yr Hardwoods	5.6	82	4.3	1.3	197	38,670	20.0	1.2
1986		7.4	175	9.3	0.8	168	70,940	37.6	1.2
1949	<20-yr Conifers	3.6	37	1.9	1.9	93	16,130	8.4	1.1
1986		0.6	10	0.5	1.1	70	3,900	2.1	1.2
1949	20-100-yr Conifers	39.8	317	16.4	2.4	220	334,770	173.3	1.3
1986		46.4	402	21.3	2.2	306	384,450	203.9	1.3
1949	>100-yr Conifers	21.8	183	9.5	2.3	287	99,140	51.3	1.2
1986		12.1	151	8.0	1.5	213	71,650	38.0	1.2

Table 15. Summary of major findings relating to discharge and sediment, channel position and structure, and riparian land use, including overall trends and reaches showing the most change.

Parameter	Overall Change (1945/49 to 1986)	Reaches Most Affected
DISCHARGE AND SEDIMENT		
Peak discharge	decrease 44%	Reaches 1, 5, 6, 7
Drainage area to supply sediment	decrease 52%	Reach 1, 5, 6, 7 (?)
Competence of 2-yr flow (D50)	decrease 29%	Reaches 1, 5, 6, 7
Competence of 5-yr flow (D50)	decrease 33%	Reaches 1, 5, 6, 7
CHANNEL POSITION AND STRUCTURE		
Main channel position	7% change > 30 m	Reaches 4 & 5
Sinuosity	decrease 2.4%	Reach 4
Side channel length	decrease 40%	Reaches 4 & 5
Exposed gravel bar area	decrease 57%	Reach 5
Large woody debris	decrease about 50%	Reach 5
Large pools	decrease 19%	Reaches 2 and 4
RIPARIAN LAND-USE		
Roads	increase 60%- 85%	Reaches 1, 2
Density of residential or developed patches	increase 215%	Reaches 3 & 7
Hardwoods	increase 45%	Reach 5
Mature conifers	decrease 44%	Reaches 1, 4, 7

Discussion

The McKenzie River today, as in the past, is generally perceived as a beautiful river, flowing past towering trees, providing habitat for aquatic species, high-quality water supply for nearby communities, and scenic value for humans in the watershed. The system is not shifting radically: hardwood and coniferous vegetation is apparent along the river, sediment does not cloud the water during much of the year, and people still catch fish. Over the last half-century, however, changes in hydrologic regime and reduction of sediment supply due to dams and increased human encroachment into the riparian area have altered the channel and riparian structure, establishing trends that may have further effects in the decades to come.

Flow regulation will cause readjustment of channel morphology throughout the entire river system downstream of the dams (Petts 1979). Construction of Smith-Carmen, Trailbridge and Leaburg Dams on the mainstem and Blue River and Cougar Dams on major tributaries has altered the flow regime and sediment supply of the McKenzie River with possible effects upon channel dynamics and morphology, riparian and floodplain function, and habitat structure and availability.

Change in Main Channel Position

The McKenzie River is not a system prone to frequent changes in channel position, because it is a high-energy system with predominantly cobble and boulder substrate and flows through many kilometers with constrained valley floors. A large aquifer sustains and moderates annual flows. The channel straightening detected in this study may not at first seem to be cause for alarm as the sinuosity loss amounted to 2.4% over the study period for all reaches combined. When this amount of straightening is put into the perspective of amount of change possible before achieving a perfectly straight channel (i.e., sinuosity equal to 1), this channel has come 12% closer to being straight in the last 40 years. In the three reaches least constrained by the valley floor where the channel is most likely to change its position on the floodplain (McKenzie Bridge to Finn Rock Bridge), the channel has lost 6% of its sinuosity and has come one third of the way toward being perfectly straight. Considering only the unconstrained reach from Rainbow to South Fork where two major channel straightenings occurred, the sinuosity decrease amounted to half of the change needed to produce a straight channel. Straight channels lack hydraulic complexity, (i. e., variation in local flow and bedforms) and provide less habitat variability and fewer options for refuge for aquatic organisms.

The channel straightening noted in this study may be due to the interaction of several factors with high flow events: lack of instream structures, such as large woody debris, to deflect flow; presence of riparian roads and riprap along the channel, which channelize and direct the flow; loss of riparian vegetation for bank stability; and human intervention. At Dearborn Island and Delta campground, roads and riprap near the channel appear to have constrained and directed channel movement during high flow events. Human movement of the gravel bar at the head of Dearborn Island redirected flow into the new channel. Removal of woody debris at Delta, probably for wood salvage, exposed a side channel more directly to flow from the main channel. Logging in the riparian area below Blue River apparently destabilized the channel, allowing the channel to shift position during high flow.

Reduction in Peak Flows and Flood Disturbance

Decrease of peak flows by dams lowers the likelihood of overbank flows into the floodplain and alters the disturbance regime. A peak flow that had a recurrence interval of 2 to 5 years prior to dams is likely to occur only once each century at the Vida gage--quite an alteration of the disturbance regime for this system. In unconstrained channel reaches with erodible alluvial boundaries, high flows may cause extensive erosion at specific locations, determined by valley and channel geometry, roughness elements, and local flow obstructions (Miller 1990). Channel positions in this study changed in three local areas in unconstrained reaches during high flow events. No changes were noted in channel reaches constrained by valley walls because they are likely to have resistant boundaries and a straighter shape with less opportunities to flow out of the active channel during flood flows (Miller 1990). A single large event, such as the 1964 flood, may leave a lasting imprint on the system, especially if hydrologic conditions following the disturbance have been altered such that subsequent flows are not able to reestablish the previous characteristics of the river

Alteration of the flow regime on the McKenzie River has a bearing on overall reduction in exposed gravel bar number and area. High flows are important to maintenance of unvegetated gravel bars and alteration of channel bedforms. Floods scour channel bars and subsequently redeposit the sediment where the transport competence declines, causing adjustments in channel shape usually at the apex of channel bends, at wide channel areas, and at channel junctions (Church and Jones 1982). Changing shape and location of the channel bar upriver of Delta campground served to direct the mainstem flow into a secondary channel in one of the three major channel changes noted in this study. Gravel bars seen in the 1949 photos were not yet vegetated due to the relatively recent entrainment and deposition caused by the 1945 flood. Absence of historical peak flows in the nineteen years since 1964 has allowed some of the remaining gravel bars to vegetate and stabilize.

Not only do the dams reduce peak flows, but they alter the seasonal pattern of flows and temperature. A study of the effects of Blue River Dam and Cougar Dam found that these projects have significantly altered the natural temperature and flow regime of the McKenzie River (Morse et al. 1987). In combination, these two hydroprojects increase the McKenzie River flow during late summer and fall by more than 35 percent, reversing the natural seasonal input pattern to the mainstem. Both dams have caused changes in the temperature regime with implications for salmonid spawning and rearing. Downstream temperatures are 8°C to 12°C lower during spring and early summer and 3°C to 6°C higher in later summer and early fall than under the natural pre-dam temperature regime.

Reduction in Competence

Construction of dams in the McKenzie River system coincided with a decrease in magnitude, variability and occurrence of peak flows competent to mobilize bedload. Predicting bedload transport in coarse-grained rivers can be difficult (Reid et al. 1985), but simple calculations of shear stress generated by typical flows before and after dams on the McKenzie River indicate reduced ability of the present flow regime to mobilize sediment. With reduced competence, large cobble and boulders become permanent features of the channel. In a study of boulder rapids in the Green River below Flaming Gorge Dam in Utah, Graf (1980) estimated that 62% of the rapids were stable features before dam construction, but 93% of the rapids became stable features after the dam was constructed. Undammed tributaries will contribute sediment that subsequently may remain in the main channel due to reduced competence of regulated flows to move sediment (Petts 1979).

Below-Dam Erosion and Channel Capacity

Release of water with low sediment load below a dam causes the river downstream to degrade, coarsens bed material, and eventually reduces the sediment transport as the bed becomes armored and more resistant to transport (Petts 1979, Shen and Lu 1983). The reduction in side channel length in Reach 1 below Trailbridge Dam and Reach 5 where both dammed tributaries (South Fork and Blue River) contribute to mainstem flow might be an indication that these reaches are down-cutting, isolating some existing side channels. Another possible result of reduced sediment load below the dams in Reach 5 was the reduction in gravel bar area per river km to 11% of 1949 amounts. Revegetation of exposed gravel bars in Reach 5 due to lack of disturbance from historical peak flows below the dams can account for 35% or less of the reduction in gravel bar area since 1949.

Numerous studies have shown channel capacity reduction below dams (Komura and Simons 1967, Petts 1979, Petts 1982). Channel capacity may be reduced further by redistribution of existing sediment eroded from narrow sections and deposited at wide sections (Petts 1979). Gregory and Park (1974) found a reduction in channel capacity for 11 km below a dam, until the catchment area increased to four times the drainage area behind the dam. In the present study, no channel narrowing or shift in channel position was evident below Trailbridge Dam, though heavy shade by large riparian conifers made exact measurement of the active channel more difficult in this reach. Future comparison of channel cross-sections would be helpful in evaluating any reduction in channel capacity. It is possible that down-cutting below these dams is restricted by the large size of sediment and armored bed surface.

Deposits of coarse sediment are sometimes created as bed material is eroded below the dam and transported downstream until flows are no longer competent and sediment is deposited (Petts 1979). Gravel bar area increased in Reach 2 since 1949 and could have been moved from the reach above due to down-cutting below Trailbridge Dam, or it could have entered the mainstem from a tributary. Dam construction at Trailbridge and Smith-Carmen projects may have introduced additional sediment that gradually moved into Reach 2. The major tributary in this reach is Lost Creek, entering from the east, downriver from Belknap Springs. The Lost Creek drainage and riparian area are relatively undisturbed and would not be a likely source for quantities of additional substrate. Deer Creek in Reach 1 was heavily logged in the last decade and might have been a sediment source. No coarse deposits that may have eroded below Blue River and Cougar Dams were evident in Reach 6, possibly because of potentially higher stream power due to greater slope.

Relative Effects of Reduction in Peak Flow and Sediment Supply

Reduced competence of flow would tend to decrease the median size of sediment in the system. Small and medium sediment would make up a higher proportion of the substrate than prior to dams because of inability of peak flows to transport them after flow regulation. On the McKenzie River, there is no evidence of such a shift in sediment size or an accumulation of sediment due to reduced peak flows. Exposed gravel bars have decreased. Visual estimates of substrate composition (when compared to historical estimates) provide some evidence that the bed has coarsened. Admittedly, visual estimation of substrate composition is subjective and not qualitative enough to make a strong case, but this estimate is the only available indication of historical substrate composition. If the bed has coarsened rather than accumulated smaller sediment, relative effects of sediment capture by the dams may have outweighed the effects of decreased peak flows on sediment transport.

Sediment contributions from undammed tributaries, which make up less than half of the drainage area may not be sufficient to maintain the historical substrate sizes or amounts. Discharges from undammed tributaries contribute approximately half of the mean flow reaching Leaburg Dam, and only half of this unregulated flow comes from larger tributaries, Horse Creek and Lost Creek. The remaining flow is from smaller tributaries, which are less likely to carry large sediment loads.

Channel Constraint

Reduced sediment supply, reduction of peak flows, plus the addition of near-channel roads and riprap to channelize the river, have constrained the active channel of the McKenzie River within its banks. Dietrich et al. (1989) demonstrated in flume experiments that a reduction in sediment supply causes alteration of channel bedforms, surface armoring, and gradual confinement of the zone of active bedload transport. Inactive areas on margins of the channel consist of coarser material that was deposited during previous flow regimes and for which little transport is presently possible.

Confinement of the active channel over time would gradually isolate secondary (side) channels from mainstem flow, reducing critical off-stream habitat. This study demonstrated a decrease in side channel length on the mainstem McKenzie River. Historical reconstruction of the Willamette River channel and streamside forest by Sedell and Froggatt (1984) provides a graphic example of extensive habitat simplification brought about by large-scale channelization, intentional reduction of side channels, removal of large woody debris and riparian vegetation from North American rivers in the late 1800s and early 1900s when navigable waters were used for commercial waterways.

Geomorphic Conditions in the Lower McKenzie River

Findings in the present study are consistent with concerns raised in a study of geomorphological changes in the lower McKenzie River that attributes habitat simplification to flood control and riprapping (Ligon 1991). The lower McKenzie River below Leaburg Dam flows in an unconfined valley with a more gradual slope and wider floodplain than upriver. Land uses are more urban, residential, and agricultural than in the portion of the basin examined in the present study. By examining historical maps and aerial photos, Ligon determined that this section of the McKenzie River had a dynamic wandering character with many islands and shifting channels prior to flood control and extensive riprapping. Dam control led to more uniformly high shear stress, bed coarsening and reduced sediment supply, causing a reduction in hydraulic complexity, confinement of the river to a set channel, and a presumed reduction in habitat complexity. The river scoured holes in the bed along riprapped banks, creating a narrowed, stabilized channel. The number of mid-channel islands decreased from 60 islands (combined area 2,263,342 m^2) in 1930 to 28 islands (area 1,111,680 m^2) in 1990. Channel gravel bars became stabilized by vegetation, which trapped additional sediment and woody debris, elevated the bars, and further confined the channel. Ligon found no significant deposits of fine sediment from timber harvest in the watershed and attributed this to the high sediment transport competence of the McKenzie River, even after flow regulation.

Loss of Large Pools

Loss of large pools (67%) noted in the lower McKenzie River between Leaburg Dam and the junction with the Willamette River was much more than the overall loss of pools in the present study (19%) (Table 16).

Table 16. Change in large pools with a minimum depth of 2 m and area of at least 40 m^2 from 1938 to 1991, Leaburg Dam to Willamette River confluence, lower McKenzie River, OR (after Sedell et al. 1991).

Reach	1938	1991	% Change
Leaburg Dam to Hendricks Bridge	95	28	-71
Hendricks Bridge to Hayden Bridge	41	20	-51
Hayden Bridge to Coburg Bridge	53	15	-72
Coburg Bridge to mouth (Willamette River junction)	17	5	-71
TOTALS	206	68	-67

Smaller, higher gradient tributary streams in the McKenzie basin have also shown reductions in frequency of large pools (S_1 and S_2 pools; >20 m^2 and >1 m deep) when resurveyed by Oregon State University and the U.S. Forest Service. Horse Creek showed a 38% loss of large pools, South Fork of the McKenzie showed a 75% loss, and Augusta Creek lost 48% (Sedell et al. 1991).

Other channels in the Columbia River basin have shown similar or greater losses in large pools since the 1940s. Habitat resurveys conducted of more than 1500 km of streams throughout the Columbia River basin have shown a 28 percent decline in frequency of large pools (S_1 and S_2 pools; >20 m^2 and >1 m deep) over the past 50 years in "managed" (i.e., human-impacted) portions of river basins and a 77 percent increase in frequency of large pools in "unmanaged" portions (i.e., wilderness or roadless areas) (McIntosh et al. 1994). These habitat resurveys have found a high variability in pool frequency, and this pattern of pool loss in managed sections is not uniformly consistent throughout all sub-basins . The present study of the McKenzie River, with an overall decrease of 19% in S_1 pools, indicates somewhat less of a decline in pools than the average loss observed in other managed systems, though individual reaches show a high variability. The measure of pool loss in this study is conservative because more time was devoted to the 1991 survey. The 1937/38 survey made one pass by boat down the river from Belknap Springs in two days, did not investigate any side channels, and probably followed the thalweg. In contrast, the resurvey in 1991 thoroughly examined the river, travelled from side to side, even in rapids, surveyed the side channels, spent 15 days on the river, and may have counted pools previously missed in the historical survey.

Loss of large pools in the mainstem McKenzie River above Leaburg Dam may be due to reduction in peak flows, channel straightening, and removal of large woody debris. Pools in the McKenzie River study area often occur where the channel is abruptly deflected by bedrock, primarily at bends in the channel. When the bends are taken out by channel straightening, pool size may be diminished. At flows competent to move the largest substrate along the channel, pools will remain scoured and the transported materials will be deposited in the riffles (Church and Jones 1982). Reduction in peak flows will reduce opportunities for pool scour.

Large wood in the McKenzie River would be an important channel roughness element and might increase pool formation, especially if large, channel-spanning aggregations were permitted. Conifers growing in the riparian area at the present time are capable of extending entirely across the channel in the upper reaches. Presence of large woody debris in plane-bed channels (e.g., Reach 1) may induce the lateral flow necessary to create and maintain pools and bars, and high loading of large wood in pool-riffle channels (Reaches 2-7) creates complex sequences of bars, pools, and riffles (Montgomery and Buffington 1993).

Estimates of the amount of large woody debris present in the mainstem McKenzie River prior to settlement are not available, so the role of large wood in pool formation and channel structure or position is unknown. It is quite possible that early settlers and loggers removed wood from this channel in a manner similar to snag removal in the Willamette River (Sedell and Froggatt 1984). Log drives extended for several km above Leaburg in the late 1800s and early 1900s (Division of State Lands 1976). In this century it has been common practice for land owners or river guides to salvage wood that fell into or near the channel to market the lumber and to keep the channel navigable (Dick Helfrich, pers. comm.). Extensive log drifts deposited in the river and on islands during the 1964 flood were salvaged for lumber by land owners or others who had the means to retrieve the wood (Gene Carver and Robert Kellison, pers. comm.).

Prior harvest near the channel and removal of riparian vegetation for residential development and roads have reduced the number of available mature conifers for future recruitment into the channel. It is probable that natural wood loading rates on the mainstem McKenzie River would be higher than today, given greater area of older conifers in the riparian area in the past.

Other studies of stream habitat have shown a decline in frequency and size of pools, especially plunge and scour pools (Bisson and Sedell 1984; Sedell and Everest 1991), filling of pools by sediment (Megahan 1982), loss of pool-forming structures (Sullivan et al. 1987; Meehan 1991) including woody debris removal for navigation, log transportation, and as a misguided aid to fish passage (Sedell and Luchessa 1982).

Implications for Aquatic Habitat and Fish Populations

Direct observation and quantification of fish populations in the McKenzie River above Leaburg Dam are difficult because of the size and energy of this river. Fish can be observed passing through the fish ladder at Leaburg Dam, but non-migrating fish would not be counted. Fish identification by snorkeling would be possible in some pools, but dangerous in rapids. The river is too wide and deep to walk, and flows are too turbulent to allow for motorized boats as on large, floodplain rivers.

Geomorphic changes and trends in the watershed have ecological implications, and knowledge of channel and riparian structure can give insight into habitat conditions that influence fish abundance and diversity. For example, numerous studies have demonstrated a relationship between the decline in fish populations and loss of pools due to decrease in large woody debris (Bisson et al. 1987). Fausch and Northcote (1992) found that stream sections where large woody debris had been removed had a significantly smaller standing crop of coho salmon and cutthroat trout due to simpler habitat (less sinuosity, wider, shallower channels with less cover and smaller pools) than stream sections with greater abundance of large wood.

A review of long-term trends in fish abundance and diversity in the Pacific Northwest noted a relationship between simplification of stream channels and decrease in habitat complexity due to human alteration of watersheds (Bisson et al. 1992). Simplification of stream channels (e.g., removal of large wood, channelization) decreases habitat complexity needed by salmonids (Bisson and Sedell 1984; Hicks et al. 1991). Construction of dams and revetments creates barriers to migrating fish, restricts the occurrence of overbank flows onto the floodplain and concurrent nutrient exchange, disrupts continuity of flow and temperature down the channel, and may decreases biodiversity downstream (Stanford and Ward 1992). Elimination of edge habitat by forestry and other land-uses, such as road-building, has decreased the available habitat for resting, feeding and protection of young fish (Moore and Gregory 1989).

Implications for Management of the McKenzie River

Many of the changes noted in this study may be caused or exacerbated by human actions: alteration of the flow regime and reduced sediment supply from dams, channel constraint from riprap and roads, conversion of riparian vegetation to roads and residential uses, fragmentation of riparian vegetation into smaller patches, reduction of large conifers in the riparian area, intentional movement of gravel bars, and removal of large wood from the channel. From a management perspective, each of these actions should be reviewed and decisions to continue these activities should consider possible detrimental effects. Private land owners must be involved in this decision-making process because they own the majority of riparian land.

Watershed Assessment

Development of a historical perspective is an important component of any watershed assessment. Retrospective analysis reveals ecosystem functions, factors related to change, and natural watershed conditions prior to anthropogenic modification. Historical aerial photographs are high-quality references and sources of data for watershed analysis but often do not exist for periods before watershed alteration.

Cumulative effects that operate on a watershed scale are difficult to understand and quantify due to the numerous variables involved and their interactions across differing scales of time and space. Change was not uniform either across this entire study area or through time. Upslope conditions and land uses directly influence riparian areas and the river network and should be incorporated into any complete assessment of watershed conditions. This complexity prevents analysis of simple cause and effect relationships. GIS incorporates many variables and facilitates analysis of large data sets. Application of environmental and ecological conceptual frameworks, experimentation, modeling, and monitoring may enhance our ability to detect and quantify changes and probable trends that have implications for watershed condition and function.

References

Andrews, E. D. 1983. Entrainment of gravel from naturally sorted riverbed material. Geol. Soc. Amer. Bull. 94: 1225-1231.

Andrews, H. J., and R. W. Cowlin. 1936. Forest type map, State of Oregon. USDA Forest Service, Pacific NW Forest Experiment Station. Portland, OR. Scale: 1 inch=4 miles.

Avery, T. E., and G. L. Berlin. 1992. Fundamentals of remote sensing and airphoto interpretation. Macmillan Publ., New York, NY. 472 p.

Bisson, P. A., R. E. Bilby, M. D. Bryant, C. A. Dolloff, G. B. Grette, R. A. House, M. L. Murphy, K. V. Koski, and J. R. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future, p. 143-190. *In* : E. O. Salo and T. W. Cundy [ed.] Streamside management: forestry and fishery interactions. Contribution 57, Institute of Forest Resources, University of Washington, Seattle, WA.

Bisson, P. A., T. P. Quinn, G. H. Reeves, and S. V. Gregory. 1992. Best management practices, cumulative effects and long-term trends in fish abundance in Pacific Northwest river systems, p. 189-232. *In* : Naiman, R. J. [ed.] Watershed management: balancing sustainability and environmental change. Springer-Verlag Publ. New York, NY.

Bisson, P. A., and J. R. Sedell 1984. Salmonid populations in streams in clearcut vs. old-growth forests of western Washington, p. 121-129. *In* : W. R. Meehan, T.R. Merrill, Jr., and T. A. Hanley [ed.] Fish and wildlife relationships in old-growth forests. American Institute of Fishery Research Biologists, Juneau, Alaska.

Burke, C. 1979. Historic fires in the central western Cascades. Master's thesis, Oregon State University, Corvallis, OR. 130 p.

Carson, W. W. 1987. Development of an inexpensive analytical plotter. Photogrammetric Record 12(69): 303–306.

Carver, E. Personal communication. U.S.F.S., McKenzie Ranger District, McKenzie Bridge, OR.

Church, M., and D. Jones. 1982. Channel bars in gravel-bed rivers, p. 291-339. *In*: R.D. Hey, J. C. Bathurst, and C. R. Thorne [ed.] Gravel-bed rivers: fluvial processes, engineering, and management. John Wiley, Publ., New York, NY.

Dietrich, W. E., J. W. Kirchner, H. Ikeda, and F. Iseya. 1989. Sediment supply and the development of the coarse surface layer in gravel-bedded rivers. Nature 240:215-217.

Fausch, K. D., and T. G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Can. J. Fish. Aq. Sci. 49: 682-693.

FEMAT (Forest Ecosystem Management Assessment Team) 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the Forest Management Assessment Team. U.S. Government Printing Office 1993-793-071.

Franklin, J. F., and C. T. Dyrness. 1984. Natural vegetation of Oregon and Washington. Oregon State University Press, Corvallis, OR. 452 p.

Gardner, J. S. 1977. Some geomorphic effects of a catastrophic flood on the Grand River, Ontario. Can. J. of Earth Sci. 14: 2294-2300.

Gore, J. A., J. R. Kelly, and J. D. Yount. 1990. Application of ecological theory to determining recovery potential of disturbed lotic ecosystems: research needs and priorities. Envir. Man. 14 (5): 755-762.

Graf, W. L. 1980. The effect of dam closure on downstream rapids. Wat. Res. Res. 16(1):129-136.

Grant, G. E., and A. L. Wolff. 1991. Long-term patterns of sediment transport after timber harvest, western Cascade Mountains, Oregon, USA, p. 31-40. *In* : D. E. Walling and N. Peters [eds.] Sediment and stream water quality in a changing environment. Proceedings of the Vienna IAHS Symposium, International Association of Hydrological Sciences, Oxfordshire, U K.

Greenland, D. 1993. The climate of the H. J. Andrews Experimental Forest and its regional synthesis. Final report on research performed under U.S.D.A. Forest Service, Pacific Northwest Research Station, Cooperative Agreement No. PNW 92-0221. 30 p.

Gregory, K. J., and C. C. Park. 1974. Adjustment of river channel capacity downstream from a reservoir. Wat. Res. Res. 10:870-873.

Gregory, S. V., and L. Ashkenas. 1990. Riparian management guide, Willamette National Forest. USDA Forest Service, Pacific Northwest Region, Portland, Oregon. U.S. Government Printing Office publication 1990-591-401/35008. 120 p.

Gregory, S. V., G. A. Lamberti, and K. M. S. Moore. 1989. Influence of valley floor landforms on stream ecosystems, p. 3–8 . *In* : D.L. Abell [ed.] Proceedings of the California Riparian Systems Conference. General Technical Report PSW-110. U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Gregory, S. V. , F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41: 540-551.

Gupta, A. 1983. High-magnitude floods and stream channel response. Special Publication of the International Association of Sedimentologists 6: 219–227.

Gupta A., and H. Fox. 1974. Effects of high-magnitude floods on channel form: a case study in Maryland Piedmont. Wat. Res. Res. 10(3): 499-509.

Helfrich, R. Personal communication. P.O. Box 149, Vida, OR 97488.

Hey, R. D. 1978. Determinate hydraulic geometry of river channels. ASCE Journal of the Hydraulics Division 104: 869–885.

Hickin, E. J., and H. M. Sichingabula. 1987. The geomorphic impact of the catastrophic October 1984 flood on the planform of Squamish River, southwestern British Columbia. Can. J. of Earth Sci. 25: 1078-1087.

Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell. 1991. Response of salmonids to habitat changes, p. 483-518. *In* : W. R. Meehan [ed.] Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, MD.

Howell, P., J. Hutchison, and R. Hooton. 1988. McKenzie subbasin fish management plan. Oregon Department of Fish and Wildlife, Springfield, OR. 109 p.

Johnson, K. N., J. F. Franklin, J. W. Thomas, and J. Gordon. 1991. Alternatives for management of late-successional forests of the Pacific Northwest. A Report to the Agricultural Committee and the Merchant Marine and Fisheries Committee of the U.S. House of Representatives. 59 p.

Johnson, L. B. 1990. Analyzing spatial and temporal phenomena using geographical information systems: a review of ecological applications. Landscape Ecology 4(1): 31-43.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river–floodplain systems, p. 110–127. *In* : D.P. Dodge [ed.] Proceedings of International Large River Symposium (LARS), Toronto, Ontario, September 14–21, 1986. Can. Spec. Publ. of Fish. and Aquat. Sci.

Kellison, R. Personal communication. U.S.F.S., Blue River Ranger District, Blue River, OR.

Kiser, J. D., and D. P. Paine. 1989. Accuracy of the analytical stereoplotter as an input devide to a GIS. Coastal Oregon Productivity Enhancement Report (COPE) 2(4): 7-9.

Kochel, R. C. 1988. Geomorphic impact of large floods: review and new perspectives on magnitude and frequency, p. 169-187. *In* : V. R. Baker, R. C. Kochel, and P. C. Patton [eds.] Flood geomorphology. John Wiley Publ., New York, NY.

Komura, S., and D. B. Simons. 1967. River-bed degradation below dams. ASCE Journal of the Hydraulics Division 93:1–14.

Knighton, D. 1984. Fluvial forms and processes. Edward Arnold, Baltimore, MD. 218 p.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman, San Francisco, CA.

Lienkaemper, G. W., and F. J. Swanson. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Can. Jour. For. Res. 17:150-156.

Ligon, F. 1991. The fluvial geomorphology of the lower McKenzie River. Report prepared for Eugene Water and Electric Board, 500 East Fourth Avenue, Eugene, Oregon 97440, by EA Engineering, Science, and Technology, 41 Lafayette Circle, Lafayette, California (415)283-7077. 51 p.

Lisle, T. E. 1986. Stabilization of a gravel channel by large streamside obstructions and bedrock bends, Jacoby Creek, northwestern California. Geological Society of America Bulletin 97: 999-1011.

Lyons, J. K., and R. L. Beschta. 1983. Land use, floods, and channel changes: Upper Middle Fork Willamette River, Oregon (1936–1980). Wat. Res. Res. 19(2): 463-471.

McClung and Pengra. 1871. Meander surveys. Surveyor Generals Office, U. S. Dept. of Interior, Washington, D.C.

McGarigal, K., and B. Marks. 1993. FragStats: spatial pattern analysis program for quantifying landscape structure. Unpublished software. Forest Science Department, Oregon State University, Corvallis, Oregon.

McIntosh, B. A. 1992. Historical changes in anadromous fish habitat in the Upper Grand Ronde River, Oregon 1941-1990. Masters thesis, Oregon State University. 88 p.

McIntosh, B. A., J. R. Sedell, J. E. Smith, R. C. Wissmar, S. E. Clarke, G. H. Reeves, and L. A. Brown. 1994. Management history of eastside ecosystems: changes in fish habitat over 50 years, 1935 to 1992. Gen. Tech. Rep. PNW–GTR-327. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 67 p.

Meehan, W. R. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, MD. 750 p.

Megahan, W. F. 1982. Channel sediment storage behind obstructions in forested drainage basins draining the granitic bedrock of the Idaho batholith, p. 114-121. *In* : Swanson et al. [ed.] Sediment budgets and routing in forested drainage basins. U.S.F.S., Pacific Northwest Research Station, General Technical Report PNW-141. Portland, OR.

Miller, A. J. 1990. Flood hydrology and geomorphic effectiveness in the Central Appalachians. Earth Surface Processes and Landforms 15:119-134.

Moffatt, R. L., R. E. Wellman, and J. M. Gordon. 1990. Statistical summaries of streamflow data in Oregon: volume 1--monthly and annual sreamflow, and flow-duration values. U.S. Geological Survey, Portland, OR. Open-File Report 90-118. 413 p.

Montgomery, D. R., and J. M. Buffington. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Report TFW-SH10-93-00s prepared for the SHAMW committee of the Washington State Timber/Fish/Wildlife Agreement, Seattle, WA. 84 p.

Moore, K. M. S., and S. V. Gregory. 1989. Geomorphic and riparian influences on the distribution and abundance of salmonids in a Cascade mountain stream, p. 256-261. *In* : D.L. Abell [ed.] Proceedings of the California Riparian Systems Conference. General Technical Report PSW-110. U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Morse, T. E., R. P. Hansen, and D. L. Mueller. 1987. Potential of improving McKenzie River temperatures using multilevel water withdrawal towers. Willamette System Temperature Control Study, McKenzie River Sub-Basin, WSTCS Phase I Study Report. U.S. Army Corps of Engineers, Portland, OR. 291 p.

Nakamura, F., and F. J. Swanson. 1993. Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in western Oregon. Earth Surface Processes and Landforms 18:43-61.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2): 4-21.

Newson, M. D. 1980. The geomorpholgical effectiveness of floods -- a contribution stimulated by two recent events in mid-Wales. Earth Surface Processes 5: 1-16.

Nolan, K. M., and D. C. Marron. 1985. Contrast in stream-channel response to major storms in two mountainous areas of California. Geology 13: 135-138.

Oregon Division of State Lands. 1976. The navigability of the McKenzie River. Report to the State Land Board. Salem, OR. 25 p.

Oregon State Service Center for GIS. 1993. General land ownership status. 1:100,000 scale GIS data layer. Salem, OR

Ornstein, R., and P. R. Ehrlich. 1989. New world new mind: moving toward conscious evolution. Simon and Schuster, Inc., New York, NY. 302 p.

Patton, P. C. 1988. Geomorphic response of streams to floods in the glaciated terrain of southern New England, p. 261–277. *In* : V. R. Baker, R. C. Kochel, P. C. Patton [ed.] Flood geomorphology. Wiley Publ., New York, NY.

Petts, G. E. 1979. Complex response of river channel morphology subsequent to reservoir construction. Progress in Physical Geography 3(3): 329–362.

Petts, G. E. 1982. Channel changes within regulated rivers, p. 117–142. *In*: B. H. Adlan, C. R. Fenn, and L. Morris [eds.] Papers in earth studies, Geobooks, Norwich.

Petts, G. E., and D. L. Foster. 1985. Rivers and landscape. Edward Arnold Publ. Baltimore, MD. 274 p.

Pickett, S. T. A., and P. S. White. 1985. The ecology of natural disturbance and patch dynamics. Academic Press, New York. 472 p.

Pickup G., and R. F. Warner. 1976. Effects of hydrologic regime on magnitude and frequency of dominant discharge. Journal of Hydrology 19: 51-75.

Poff, N. L., and J. V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. Can. J. Fish. Aquat. Sci. 46: 1805–1817.

Reid, I., L. E. Fostick, and J. T. Layman. 1985. The incidence and nature of bedload transport during flood flows in coarse-grained alluvial channels. Earth Surface Processes and Landforms 10: 33-44.

Rich, W. H. 1948. A survey of the Columbia River and its tributaries with special reference to the management of its fishery resources. U. S. Fish and Wildlife Service Special Scientific Report No. 51. 25 p.

Richards, K. 1982. Rivers, form and process in alluvial channels. Methuen & Co., New York, NY. 358 p.

Rothacher, J. S., and T. B. Glazebrook. 1968. Flood damage in the National Forests of Region 6. Pacific NW Forest and Range Experiment Station, U.S. Dept. of Agriculture, Portland, OR. 20 p.

Schumm, S. A. 1965. Time, space, and causality in geomorphology. Amer. Journal of Sci. 263:110-119.

Schumm, S. A. 1969. River metamorphosis. ASCE Journal of Hydraulics Division 95: 255–273.

Sedell, J. R., and F. H. Everest. 1991. Historic changes in pool habitat for Columbia River Basin salmon under study for TES listing. U.S.F.S. Gen. Tech. Report, P. N. W. Research Station, Portland, OR. 7 p.

Sedell, J. R., and J. L. Froggatt. 1984. Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. Verh. Verein. Int. Limnol. 20: 1366-1375.

Sedell, J. R., and K. J. Luchessa. 1982. Using the historical record as an aid to salmonid habitat enhancement, p. 210-223. *In* : N. B. Armantrout [ed.] Acquisition and utilization of aquatic inventory information. Proceedings of symposium, American Fisheries Society, Western Division. Bethesda, MD.

Sedell, J. R., B. A. McIntosh, and P. J. Minear. 1991. Evaluation of past and present stream habitat conditions. Report for the Army Corps of Engineers McKenzie River Temperature Control Feasibility Study. U.S.F.S. Pacific Northwest Research Station, Corvallis OR. 13 p.

Sedell, J. R., G. H. Reeves, F. R. Hauer, J. A. Stanford, and C. P. Hawkins. 1990. Role of refugia in recovery from disturbance: modern fragmented and disconnected river systems. Environmental Management 14: 711-724.

Shen, H. W., and J. Y. Lu. 1983. Development and prediction of bed armoring. Journal of Hydraulic Engineering 109:611-629.

Sherrod, D. R., S. E. Ingebritsen, J. M. Curless, T E.C. Keith, N. M. Diaz, and S. L. Hurlocker. 1992. Water, rocks, and woods: a field excursion to examine the geology, hydrology, and geothermal resources in the Clackamas, North Santiam, and McKenzie River drainages, Cascade Range, Oregon. Geological Society of America Penrose Conference on fluid-volcano interactions, October 4–9, Kahneeta, Oregon.

Stanford, J. A., and J. V. Ward. 1992. Management of aquatic resources in large catchments: recognizing interactions between ecosystem connectivity and environmental disturbance, p. 91-124. *In* : Naiman, R. J. [ed.] Watershed management: balancing sustainability and environmental change. Springer-Verlag Publ. New York, NY.

State Water Resources Board. 1961. Upper Willamette River Basin. Salem, OR. 186 p.

Statzner, B., J. A. Gore, and V. H. Resh. 1988. Hydraulic stream ecology: observed patterns and potential applications. J. N. Am. Benthol. Soc. 7(4): 307–360.

Sullivan, K., T. E. Lisle, C. A. Dolloff, G. E. Grant, and L. M. Reid. 1987. Stream channels: the link between forests and fishes, p. 39-97. *In* E. O. Salo and T. W. Cundy [ed.] Streamside management: forestry and fishery interactions. Contribution 57, Institute of Forest Resources, University of Washington, Seattle, WA.

Thompson, G., and A. J. Johnson. 1900. Classification of lands and forests, State of Oregon. Scale: 1 inch=10 miles.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process. Annu. Rev. Ecol. Syst. 20: 171-197.

U.S. Geological Survey. 1993. National water summary 1988-89–Floods and droughts: Oregon. U.S. Geological Survey Water-Supply Paper.

U.S. Geological Survey. 1994. Expanded rating table and annual peak flow frequency analysis, following WRC guidelines Bull. 17B. Portland, OR. Unpublished records.

Walker, G. W., and N. S. MacLeod 1991. Geologic map of Oregon, GIS data layer. U. S. Department of Interior, U.S.G.S., Portland, OR.

Warner, W. S., W. W. Carson, and O. M. Braaten. 1990. GIS data capture from aerial photographs–a case study. Presented at the Thompson Symposium of the Photogrammetric Society, March 31, 1990. 12 p.

Wellman, R. E., J. M. Gordon, and R. L. Moffatt. 1993. Statistical summaries of streamflow data in Oregon: volume 2--annual low and high flow, and instantaneous peak flow. U.S. Geological Survey, Portland, OR. Open-File Report 93-63. 406 p.

Wilson, J. S. 1981. Landforms of the McKenzie River Basin. Willamette National Forest, U. S. Forest Service, Publication 43-04R4-1-00170, Eugene, OR. 71 p.

Wolman M. G., and J. P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. Jour. Geol. 68: 54-74.

APPENDICES

APPENDIX A: Geology and Ownership

Table A1. Geologic formations of the study watershed McKenzie River, OR to Leaburg Dam. (Walker and MacLeod 1991, digital coverage)

DESCRIPTION of MAJOR GEOLOGIC FORMATIONS	PTYPE	FREQ.	AREA (m2)	PERCENT
	'OW'	9	10236785	0 %
Basalt and basaltic andesite; Pleistocene and Pliocene	'QTba'	11	187348637	7 %
	'QTmv'	4	12622669	1 %
	'QTp'	50	24006906	1 %
	'QTs'	1	1593111	0 %
	'Qa'	3	20231784	1 %
Alluvium	'Qal'	4	21606631	1 %
Basaltic andesite and basalt; Holocene and Pleistocene	'Qba'	9	353384207	14 %
Glacial deposits; Pelistocene; unsorted	'Qg'	14	263245308	11 %
Glaciofluvial deposits; Pleistocene; partly sorted	'Qgf'	4	97585138	4 %
	'Qls'	24	70528381	3 %
	'Qrd'	3	18198014	1 %
	'Qt'	5	5948815	0 %
	'Qyb'	3	128837529	5 %
	'Tba'	1	1671926	0 %
	'Tbaa'	25	111537384	4 %
Flows and clastic rocks, undifferentiated; Miocene	'Tfc'	4	370933465	15 %
	'Thi'	7	24427269	1 %
	'Tib'	3	1869019	0 %
	'Tmv'	8	3621304	0 %
Ridge-capping basalt and basaltic andesite; Pliocene and upper Miocene	'Trb'	32	243794151	10 %
	'Tsv'	7	4894399	0 %
Undifferentiated tuffaceous sedimentary rocks, tuffs, and basalt; Miocene and Oligocene	'Tu'	7	513997405	21 %
	'Tub'	2	6760802	0 %
	'Tvi'	1	69325	0 %

Table A2. Geologic formations of riparian area, which includes 90-m buffer of active channel plus floodplain, Trailbridge Dam to Leaburg Dam, McKenzie River, OR. (Walker and MacLeod 1991, digital coverage)

DESCRIPTION of MAJOR GEOLOGIC FORMATIONS	PTYPE	FREQ.	AREA (m2)	PERCENT
Basalt and basaltic andesite; Pleistocene and Pliocene	'QTba'	4	152796	1 %
fluvial sands, gravels w/ minor lacustrine deposits of modern stream valleys	'Qal'	3	6386348	34%
Basaltic andesite and basalt; Holocene (?) and Pleistocene	'Qba'	1	23282	0 %
unsorted	'Qg'	1	374	0 %
Glacial, Glaciofluvial deposits; Pleistocene; partly sorted	'Qgf'	2	10154107	54%
Terrace, pediment, and lag gravels; Pleistocene	'Qt'	1	254456	1 %
Miocene	'Thi'	3	786035	4 %
andesity; Pleiocene and upper Miocene	'Trb'	2	166473	1 %
Undifferentiated tuffaceous sedimentary rocks, tuffs, and basalt; Miocene and Oligocene	'Tu'	11	914879	5 %

Table A3. Ownership within the study area watershed, McKenzie River, OR, to Leaburg Dam. (Oregon State Service Center for GIS 1993, digital coverage)

OWNER	CODE	FREQ.	AREA (m2)	PERCENT
BLM	1	12	4041144	0.16%
O & C LANDS (BLM adm.)	2	20	53270827	2.13%
NATIONAL FOREST (USFS)	3	26	2018001433	80.75%
O & C (USFS adm.)	4	2	190753	0.01%
STATE	5	4	2976325	0.12%
ARMY CORPS	7	15	17486307	0.70%
PRIVATE	9999	33	402983751	16.13%
				100.00%

State of Oregon 1:100,000 Scale
General Land Ownership Status
GIS Data Layer
Data originated from the BLM Surface Management Status map.

Table A4. Ownership within riparian area, which includes 90-m buffer of active channel plus floodplain, Trailbridge Dam to Leaburg Dam, McKenzie River, OR. (Oregon State Service Center for GIS 1993, digital coverage)

OWNER	CODE	FREQ.	AREA (m2)	PERCENT
BLM	1	3	102704	1%
O & C LANDS (BLM adm.)	2	6	326515	2%
NATIONAL FOREST (USFS)	3	17	6697159	36%
ARMY CORPS	7	1	197987	1%
PRIVATE	9999	15	11514367	61%

State of Oregon 1:100,000 Scale
General Land Ownership Status
GIS Data Layer
Data originated from the BLM Surface Management Status map.

APPENDIX B: Aerial Photo Files

Part 1. Digitizing codes.

Table C1: List of object and theme codes assigned via AP190 analytical stereoplotter when digitizing aerial photos used in this study. Object codes were used to separate features into Arc/Info coverages.

Object Code	AP190 Theme/Color	Geographic Object	Notes
100-999		points for photo registration	
1000	1/dark blue	wetted channel	
1200	9/med. blue	active channel	
1600	1/dark blue	tributaries	
1700	9/med. blue	trib. active channel	zoom views only
1800	7	weir	upper McK only
1850	9	salmon channel	upper McK only
1900	1/dark blue	reservoir	Blue River
3000	3	side channel	(wetted: zoom)
3200	9	active side channel	zoom only
4000	9	ponds, open water	
6000	4/red	roads	
6500	5/magenta	transmission lines	not zooms
6800		dam	
6900	7/white	bridges	
7000	14/yellow	residential, trailer park, golf course, buildings	
7200	8/grey	bare soil, rock	

Table C1, cont'd.

Object Code	Theme/Color	Geographic Object	Notes
7300	14/yellow	grass, agricultural	
7350	10/lt. green	orchards	
7400	10/lt. green	<20 yr. hardwoods	
7500	10/lt. green	<20 yr. conifer, clearcuts	
7600	2/green	20-100 yr. hardwood	
7700	2/green	20-100 yr. conifer	
7900	11/cyan	>100 yr. conifer	

Table C1, cont'd.

Object Code	Theme/Color	Geographic Object	Notes
8000	12/pink	Large Woody Debris	location, not quantitative
9000		Geomorphic Features	
9100	8/grey	large gravel bars	
9300	15/white	landslides	not consistently observed
9500	8/grey	(bed)rock outcrops	
9900	8/grey	riprap	added from photos in field
10,000	7	Special Landmarks	

Part 2. Aerial photography data and notes.

Year 1945 **Date** 7-27-45 **Scale** 1:40000

Camera 209.15mm **Film** ☒ B&W ☐ Color

Photo # 967 & 968 **Job File** 967-968

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks Leaburg Dam to Goodpasture Bridge

Raw ARC file prefix 1 A1

Relative Orientation 0.027 millimeters

Absolute Orientation: X 4.0 meters

Absolute Orientation: Y 5.3 meters

Absolute Orientation: Z 3.9 meters

FLOW at Vida 1760 cfs

Notes Photo notes for the 1945 photos: 5M Project, available from National Archives. These were borrowed from the U of O Map Library. Flying altitude was 17,000 ft. Numbers on photos included 5M158, vv16pl. Photo conditions were not optimal; they were wrinkled andgrainy. It was hard to determine if cleared areas were growing back in hardwood or conifer. I had to make 4 models due to the arrangement of photos. Not much LWD or large gravel bars visible.

This stereopair had no visible LWD but some docks, lots of parallax, grainy appearance with deep shadows on river left.

Year 1945 **Date** 7-27-45 **Scale** 1:40000

Camera 209.15mm **Film** ☒ B&W ☐ Color

Photo # 966 & 967 **Job File** 966-967

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks Goodpasture Bridge

Raw ARC file prefix 1 A2

Relative Orientation 0.022 millimeters

Absolute Orientation: X 3.5 meters

Absolute Orientation: Y 4.66 meters

Absolute Orientation: Z 2.13 meters

FLOW at Vida 1760 cfs

Notes When imported into ArcInfo, there seemed to be a difference in channel location of about 15 m between this file and the next one upriver.

Year **1945** Date **7-27-45**

Camera 209.15mm

Photo # 965 & 966

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks Helfrich

Relative Orientation 0.021 millimeters

Absolute Orientation: X 3.1 meters

Absolute Orientation: Y 2.9 meters

Absolute Orientation: Z 1.3 meters

Notes No wood or gravel bars apparent.

Scale 1:40000

Film ☒ B&W ☐ Color

Job File 965-966

Raw ARC file prefix 2 A1

FLOW at Vida 1760 cfs

Year **1945** Date **7-27-45**

Camera 209.15mm

Photo # 964 & 965

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks Marten's Rapids

Relative Orientation 0.018 millimeters

Absolute Orientation: X 2.1 meters

Absolute Orientation: Y 4.0 meters

Absolute Orientation: Z 2.6 meters

Notes When imported into ArcInfo, there appeared to be an offset of 20 - 30 meters in channel location. Since the 1986 channel location more closely matched this file, this channel was preferentially used, rather than the 1949 channel, when both were available.

Scale 1:40000

Film ☒ B&W ☐ Color

Job File 964-965

Raw ARC file prefix 2 A2

FLOW at Vida 1760 cfs

Summary Photo Orientation

1945

Mean Relori (mm)	0.02
Mean Absori: X in meters	3.18
Mean Absori: Y in meters	4.22
Mean Absori: Z in meters	2.48

Year 1949 **Date** 8-29-49 **Scale** 1:40000

Camera focal length estim. 152.4mm, DGS project, **Film** ☒ B&W ☐ Color

Photo # roll 5; photos 7 & 8

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos **Job File** 05-7-8

Landmarks Nimrod, Rennie, Dorris Park **Raw ARC file prefix** 3 A

Relative Orientation 0.023 millimeters **FLOW at Vida** 1930 cfs

Absolute Orientation: X 6.2 meters

Absolute Orientation: Y 3.3 meters

Absolute Orientation: Z 4.2 meters

Notes When imported into ArcInfo, this channel position was different by 20 to 30 meters from 2A, 1946, and also not lined up with the 1986 channel. In areas where the channel was digitized in both 1946 and 1949, the 1946 channel was used preferentially.

Year 1949 **Date** 8-29-49 **Scale** 1:40000

Camera focal length estim. 152.4mm, DGS project, **Film** ☒ B&W ☐ Color

Photo # roll 5; photos 50 & 51

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos **Job File** 05-50-1

Landmarks Quartz Creek, Nimrod, Eagle Rock **Raw ARC file prefix** 4 A

Relative Orientation 0.016 millimeters **FLOW at Vida** 1930 cfs

Absolute Orientation: X 21.3 meters

Absolute Orientation: Y 13.3 meters

Absolute Orientation: Z 5.9 meters

Notes Logging on river left, upriver of Quartz Creek appears to be downward yarding cable.

Highway 126 much narrower than it is in the present day, making it hard to see sometimes. Logging road failures are evident. A timber labor camp is located on river left at Quartz Creek, just upriver. In later photos an enormous log pond is seen in this same area.

Boat ramp is located at Clover Point.

Year **1949** **Date** **8-29-49** **Scale** **1:40000**

Camera focal length estim. 152.4mm, DGS project, **Film** ☒ B&W ☐ Color

Photo # roll 5; photos 65 & 66

Job File 05-65-66

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks Blue River, South Fork

Raw ARC file prefix 5 A

Relative Orientation 0.022 millimeters

FLOW at Vida 1930 cfs

Absolute Orientation: X 5.1 meters

Absolute Orientation: Y 8.8 meters

Absolute Orientation: Z 3.2 meters

Notes Lots of gravel bars in South Fork. Can see terrace clearly. Clearcut extends up to terrace.
The road is very narrow upriver of Andrews Experimental Forest exit.
Below South Fork Confluence,it looks like a bridge got washed out.
Labor (timber) camp located by Quartz Creek bridge.
Timber has been cut on a number of steep slopes.
Logging left seed trees. Cutting extended up Blue River and Simmonds Creek.
I had problems with this model and had to redo the absori (final #s above).
When imported into ArcInfo, this file had to be rotated 0.8 degrees around in order for the channel ends to line up correctly with the adjoining files.

Year **1949** **Date** **8-26-49** **Scale** **1:40000**

Camera focal length estim. 152.4mm, DGS project, **Film** ☒ B&W ☐ Color

Photo # roll 3; photos 116 & 117

Job File 03-116-7

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks Delta, Dearborn

Raw ARC file prefix 6 A

Relative Orientation 0.02 millimeters

FLOW at Vida 1980 cfs

Absolute Orientation: X 3.1 meters

Absolute Orientation: Y 1.4 meters

Absolute Orientation: Z 3.6 meters

Notes Absori on 6 pts.
A bridge on the South Fork is under construction. The active channel is nearly identical to wetted channel. Lots of clearcuts are noted. Mill Creek comes in at the bottom of Dearborn Island. The tributary coming in from river right about in the middle of side channel at Dearborn might have had something to do with channel change at Dearborn. Lots of gravel bars are present on South Fork, perhaps an aftermath of the high flow event in 1945.
When imported into ArcInfo, this channel seemed to have a slight rotational problem.

Year 1949 **Date** 8-29-49 **Scale** 1:40000

Camera focal length estim. 152.4mm, DGS project, **Film** ☒ B&W ☐ Color

Photo # roll 5; photos 157 & 158

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos **Job File** 5-157-8

Landmarks McKenzie Bridge. **Raw ARC file prefix** 7 A

Relative Orientation 0.015 millimeters **FLOW at Vida** 1930 cfs

Absolute Orientation: X 6.6 meters

Absolute Orientation: Y 9 meters

Absolute Orientation: Z 6.5 meters

Notes Lots of logging roads are noted in these photos.
A bridge is located upriver of McKenzie Bridge, but is not present now. The channel is narrower than downriver.
Rechecked control on 4/27/93 due to problems with this file in ArcInfo (180 meters off!) Added control points and the control was much improved.

Year 1949 **Date** 8-26-49 **Scale** 1:40000

Camera focal length estim. 152.4mm, DGS project, **Film** ☒ B&W ☐ Color

Photo # roll 3; photos 103 & 104

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos **Job File** 3-103-4

Landmarks Belknap Hot Springs **Raw ARC file prefix** 8 A

Relative Orientation 0.017 millimeters **FLOW at Vida** 1980 cfs

Absolute Orientation: X 3.2 meters

Absolute Orientation: Y 3.8 meters

Absolute Orientation: Z 2.4 meters

Notes The channel is constrained in this area; wetted channel = active channel.
Due to the presence of large conifers in the riparian area, it was hard to see the channel.
Below Belknap on river right where "lake" is now was probably opened to channel during high water; perhaps susceptible due to clearcut.
The variation in channel position between this file and 9A was 15 to 20 meters, when imported into ArcInfo.

Year 1949 **Date** 8-26-49 **Scale** 1:40000

Camera focal length estim. 152.4mm, DGS project, **Film** ☒ B&W ☐ Color

Photo # roll 3; photos 102 & 103

Job File 3-102-3

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks Dear Creek, Twisty Creek, Frissell Creek **Raw ARC file prefix** 9 A

Relative Orientation 0.02 millimeters

FLOW at Vida 1980 cfs

Absolute Orientation: X 3.3 meters

Absolute Orientation: Y 1.9 meters

Absolute Orientation: Z 2.1 meters

Notes Absori on 5 pts.
Bridge (?) is hard to see. (May want to check on old map or 1939 photos.)
The channel is shaded by large trees.
No residential areas noted and few clearcuts or roads. No paved roads apparent. It is hard to see existing roads due to tall trees. This area was not logged at all on river right. Possible fire patterns are seen in the vegetation on river left.
The riparian area is completely forested. No hardwoods are seen.
When imported into ArcInfo, this channel varied from 8A by 15 to 20 meters in geographic location.

Year **1949** Date **8-26-49** Scale **1:40000**

Camera focal length estim. 152.4mm, DGS project, Film ☒ B&W ☐ Color

Photo # roll 3; photos 101 & 102

Job File 3-101-2

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Raw ARC file prefix 10 A

Landmarks Olallie Creek, Anderson Creek

FLOW at Vida 1980 cfs

Relative Orientation 0.024 millimeters

Absolute Orientation: X 1.7 meters

Absolute Orientation: Y 1.7 meters

Absolute Orientation: Z 1.3 meters

Notes Absori on 4 points.
Active channel = wetted channel.
Road is hard to see due to large trees.
No large gravel bars or LWD visible.
Entire riparian zone appears forested; no hardwood evident.
One clearcut present in upper Olallie Creek.
Can see bridge at confluence with Deer Creek. Appears to be a road up Deer Creek.

Summary Photo Orientation

1949	Mean Relori (mm)	0.02
	Mean Absori: X in meters	6.31
	Mean Absori: Y in meters	5.40
	Mean Absori: Z in meters	3.65

Year **1959** Date **7-8-59**

Camera Goers lens # 787649, 12" lens,

Photo # roll 31; photos 103 & 104

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks zoom of Dearborn

Relative Orientation 0.012 millimeters

Absolute Orientation: X 2.2 meters

Absolute Orientation: Y 5.5 meters

Absolute Orientation: Z 2.5 meters

Scale 1:12,000

Film ☒ B&W ☐ Color

Job File 31-103-4

Raw ARC file prefix 59DB

FLOW at Vida 2150 cfs

Notes Project EGI, Kargl Company, San Antonio, Texas
Camera collimation marker separation A to B = 222.34, C to D = 222.10mm
I did digitize vegetation on this zoom but no others because it took too much time.
It was not possible to do the 1967 Dearborn photos because line 1, photo 19 was missing from U of O. Observation from the June 14,1967 photos (ESF 1-18 and 1-20): main channel shifting with more flow going to river right. The golf course is under construction.
These photos are stored at the U of O Map Library.

Year **1959** Date **6-18-59** Scale **1:12,000**

Camera Goers lens # 787649, 12" lens, Film ☒ B&W ☐ Color

Photo # roll 15; photos 17 & 18

Job File 15-17-18

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Raw ARC file prefix 59DL

Landmarks Delta and South Fork Confluence

FLOW at Vida 3460 cfs

Relative Orientation 0.015 millimeters

Absolute Orientation: X 4.1 meters

Absolute Orientation: Y 2.3 meters

Absolute Orientation: Z 4.8 meters

Notes There is evidence of a wider active channel and more substrate storage on the South Fork prior to dam or perhaps as a result of the high flow event in 1945. Lots of wetlands are seen in these photos--also in Delta area with numerous secondary channels.

The terminal morraine of 50,000 year old glacier is visible near the junction with the South Fork. Clearcuts extend off the photo in all directions. Replanting was not apparently practiced; left seed trees instead. South facing slopes do not appear to be growing back

Hypothesis: deposits built up on inside bend, on river left above Delta, causing the channel to straighten and seek a different path such that it shifted into an existing secondary channel.

Year **1959** Date **5-13-59**

Camera Goers lens # 787649, 12" lens,

Photo # roll 4; photos 55 & 56

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks zoom of Blue River

Relative Orientation 0.013 millimeters

Absolute Orientation: X 5.9 meters

Absolute Orientation: Y 5.4 meters

Absolute Orientation: Z 3.9 meters

Scale 1:12,000

Film ☒ B&W ☐ Color

Job File 4-55-56

Raw ARC file prefix 59BLR

FLOW at Vida 6350 cfs

Notes Absori on 5 points. Flow was relatively high when this photo was taken as the annual mean was 3492 cfs.
No vegetation was digitized.
It is evident that large areas on river left were logged down to the river and dragged to landings, even from islands across the river. No riparian buffers were left.
Possible reason for channel shift: sediment-charged floodwaters entered the sinuous channel to river right where they lost energy and dropped sediment, severely decreasing the flow in this channel by the creation of a splay deposit. The river then occupied an existing, but much smaller side channel which had been destabilized by clearcutting and removal of riparian veg.

Summary Photo Orientation

1959	Mean Relori (mm)	0.01
	Mean Absori: X in meters	4.07
	Mean Absori: Y in meters	4.40
	Mean Absori: Z in meters	3.73

Year **1964** Date **4-8-64**

Camera VV WAC MCE NPP 285.91mm

Photo # roll #64, photos 593 & 594

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks zoom of Delta

Relative Orientation 0.063 millimeters

Absolute Orientation: X 23.6 meters

Absolute Orientation: Y 10.1 meters

Absolute Orientation: Z 4.7 meters

Scale 1:12400

Film ☒ B&W ☐ Color

Job File 64-593-594

Raw ARC file prefix 64DL

FLOW at Vida 4400 cfs

Notes I was not able to develop good control on this model; only 4 points were located. I will need to align roads or other features.
Other cautions on these photos include: large grain size, heavy shading on river left.
The camera file was constructed by measuring the fiducials.
These photos were borrowed from U of O Map Library.
Extensive logging is evident south of the South Fork. Only 2 or 3 blocks of mature forest left.

Summary Photo Orientation

1964	Mean Relori (mm)	0.06
	Mean Absori: X in meters	23.60
	Mean Absori: Y in meters	10.10
	Mean Absori: Z in meters	4.70

Year 1967 **Date** 6-15-67

Camera Goerz lens # 757831, 8 1/4 " lens,

Photo # roll 5; photos 168 & 169

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks zoom of Delta

Relative Orientation 0.02 millimeters

Absolute Orientation: X 2.3 meters

Absolute Orientation: Y 3.1 meters

Absolute Orientation: Z 1.9 meters

Scale 1:15,840

Film ☒ B&W ☐ Color

Job File 5-168-9

Raw ARC file prefix 67DL

FLOW at Vida 2830 cfs

Notes Project ESF. Shot by Western Aerial Contractors (WAC) in Eugene, Oregon. Camera collimation marker separation from A to B = 222.34mm and from C to D = 222.28mm.

I had problems with the green dots on this model (meaning either that there were control problems, the paper had heated up or the AP190 needed a cold start).

More vegetation is growing on gravel bars in South Fork and it has a smaller active channel, possibly due to dam influence on peak flows. There appears to be a change in the location of the tributary junction with McKenzie and South Fork. LWD is noted as evidence of 1964 flood. Blue River dam is new (unfilled) and transmission lines new (100 - 120 m wide swaths cut even across channel, for example at FishLadder Rapid upriver). Gravel is accumulating on river left above Delta.

Wasn't possible to use stereopair centered on Delta (5-17) as someone had written on it.

Year 1967	**Date** 6-16-67	**Scale**	1:15,840
Camera	Proj. ESF, lens # 757831, 8 1/4 " lens	**Film**	☒ B&W ☐ Color
Photo #	roll 6; photos 45 & 46	**Job File**	6-45-46
Control	☐ USGS Quad Map ☒ 1986 Aerial Photos	**Raw ARC file prefix**	67BLR
Landmarks	zoom Blue River	**FLOW at Vida**	2790 cfs

Relative Orientation 0.024 millimeters

Absolute Orientation: X 4.6 meters

Absolute Orientation: Y 3.0 meters

Absolute Orientation: Z 3.9 meters

Notes Green dot problems with this model.
Sediment deposited on river right at top of side channels appears to have prevented water from flowing into these channels. The cause may have been the 1964 flood, followed by salvage (?). Some LWD at head of islands is covered with substrate. River right side channel is apparently dry at junction from river. Probably getting subsurface flow through gravel bar as there is water in the channel further down.
Rock quarry and gravel machine present.

Summary Photo Orientation

1967	Mean Relori (mm)	0.02
	Mean Absori: X in meters	3.45
	Mean Absori: Y in meters	3.05
	Mean Absori: Z in meters	2.90

Year 1979 **Date** 7-24-79

Camera USDA79

Photo # roll 278; photos 83 & 84

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks zoom Dearborn

Relative Orientation 0.018 millimeters

Absolute Orientation: X 1.4 meters

Absolute Orientation: Y 2.4 meters

Absolute Orientation: Z 1.8 meters

Scale 1:12000

Film ☐ B&W ☒ Color

Job File 278-8384

Raw ARC file prefix 79DB

FLOW at Vida 2950 cfs

Notes These photos were borrowed from U of O Map Library. Calibrated focal length = 208.018mm. Camera file was constructed by measuring between fiducials. Photos were taken by Walker and Associates for Willamette National Forest, project # 616180.

Not all of the roads were digitized. Also did not do transmission lines. Looks like gravel was placed for a boat ramp above Dearborn Island bridge. A road is located right alongside the new channel. Could riprap have caused deepening of the new channel? Also, LWD which lined the channel on river right of right channel was later pulled out and might have exposed this channel to incision.

It is hard to see details in these photos due to large grain size.

Year 1979 **Date** 7-24-79

Camera USDA79

Photo # roll 178; photos 69 & 70

Control ☐ USGS Quad Map ☒ 1986 Aerial Photos

Landmarks zoom Delta

Relative Orientation 0.019 millimeters

Absolute Orientation: X 4.0 meters

Absolute Orientation: Y 2.5 meters

Absolute Orientation: Z 2.7 meters

Scale 1:12000

Film ☐ B&W ☒ Color

Job File 178-6970

Raw ARC file prefix 79DL

FLOW at Vida 2950 cfs

Notes Gravel bars on South Fork are getting overgrown.
Photos borrowed from U of O Map Library. Calibrated focal length = 208.018mm. Camera file was constructed by measuring between fiducials. Photos taken by Walker and Associates, for Willamette National Forest, project # 616180.

Summary Photo Orientation

1979	Mean Relori (mm)	0.02
	Mean Absori: X in meters	2.70
	Mean Absori: Y in meters	2.45
	Mean Absori: Z in meters	2.25

Year 1986 Date 7-19-86

Camera WAC

Photo # roll 23; photos 54 & 55

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks Vida, Gate Creek

Relative Orientation 0.014 millimeters

Absolute Orientation: X 6.4 meters

Absolute Orientation: Y 7.1 meters

Absolute Orientation: Z 3.1 meters

Scale 1:31000

Film ☒ B&W ☐ Color

Job File 23-54-5

Raw ARC file prefix 1B

FLOW at Vida 2570 cfs

Notes Had trouble w/ green dots on upstream section of these photos.
Digitized the 20 - 100 yr. conifers. Many residential areas are noted.
Redid relori (0.00) and redid absori (5.7/5.4/.522) but still had trouble w/ dots
The machine needed a cold start, according to Jim Kiser.
When this file was imported into ArcInfo, all the points were condensed into one spot. The photos had to be recontrolled on the AP190 and reimported, after which the file was useable.

Year 1986 Date 7-19-86

Camera WAC

Photo # roll 23; photos 145 & 146

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks Helfrich to Vida

Relative Orientation 0.005 millimeters

Absolute Orientation: X 5.5 meters

Absolute Orientation: Y 3.3 meters

Absolute Orientation: Z 1.6 meters

Scale 1:31000

Film ☒ B&W ☐ Color

Job File 23-145-6

Raw ARC file prefix 2B

FLOW at Vida 2570 cfs

Notes Some mixed hardwood/conifer single trees were apparent along river, but not digitized unless in patches. Also much devegetation can be seen, due to residential developments.
I had a few lines snapped wrong and fixed them in ArcInfo.

Year 1986 Date 7-19-86

Camera WAC

Photo # roll 24; photos 30 & 31

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks Browns's Hole, Ben and Kay Dorris

Relative Orientation 0.001 millimeters

Absolute Orientation: X 3.8 meters

Absolute Orientation: Y 9.5 meters

Absolute Orientation: Z 2.4 meters

Scale 1:31000

Film ☒ B&W ☐ Color

Job File 24-30-1

Raw ARC file prefix 3B

FLOW at Vida 2570 cfs

Notes One photo has lots of glare on water, making it harder to judge z dimension. Absori on 6 pts.

Year 1986 Date 7-19-86

Camera WAC

Photo # roll 24; photos 29 & 30

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks Mason Creek, Bear Creek, Brown's Hole

Relative Orientation 0.002 millimeters

Absolute Orientation: X 4.5 meters

Absolute Orientation: Y 10.8 meters

Absolute Orientation: Z 1.1 meters

Scale 1:31000

Film ☒ B&W ☐ Color

Job File 24-29-30

Raw ARC file prefix 4B

FLOW at Vida 2570 cfs

Notes I had trouble with these photos buckling and I also couldn't get downstream end of photos to line up properly. Therefore, I restricted the area digitized and used another photo pair to link up.

Year 1986 Date 7-19-86 Scale 1:31000

Camera WAC Film ☒ B&W ☐ Color

Photo # roll 24; photos 130 & 131 Job File 24-130-1

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks Quartz , Silver, Maple Creeks

Raw ARC file prefix 5B

Relative Orientation 0.006 millimeters

FLOW at Vida 2570 cfs

Absolute Orientation: X 7.1 meters

Absolute Orientation: Y 8.6 meters

Absolute Orientation: Z 1.8 meters

Notes Absori on 9 pts.
The matrix is 20 - 100 year conifer.
Additional large areas have been clearcut since these photos were taken.

Year 1986 Date 7-21-86 Scale 1:31000

Camera WAC Film ☒ B&W ☐ Color

Photo # roll 14; photos 174 & 175 Job File 14-174-5

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks Blue River to Finn Rock

Raw ARC file prefix 6B

Relative Orientation 0.013 millimeters

FLOW at Vida 2550 cfs

Absolute Orientation: X 5.9 meters

Absolute Orientation: Y 5.4 meters

Absolute Orientation: Z 4.8 meters

Notes These photos had substantial glare on the river, especially in downstream parts of photo.
Lots of hardwood trees
The old gravel pit is visible southwest of Blue River. Might have wetlands potential, judging from the vegetation and water.
2 fiducials were missing from photo 14-175; had to use corners instead.

Year 1986 Date 7-21-86

Scale 1:31000

Camera WAC

Film ☒ B&W ☐ Color

Photo # roll 25; photos 221 & 222

Job File 25-221-2

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Raw ARC file prefix 7B

Landmarks Blue River, South Fork

Relative Orientation 0.009 millimeters

FLOW at Vida 2550 cfs

Absolute Orientation: X 5.9 meters

Absolute Orientation: Y 5.5 meters

Absolute Orientation: Z 2.97 meters

Notes 20 - 100 yr conifer is matrix, and was not digitized separately.
Blue River Reservoir present.
When this file was imported into ArcInfo the upriver end of the channel had to be rotated about 2 degrees to get it to connect with file 8B (about 20 meters difference).

Year 1986 Date 7-21-86

Scale 1:31000

Camera WAC

Film ☒ B&W ☐ Color

Photo # roll 25, photos 121 & 122

Job File 25-121-2

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Raw ARC file prefix 8B

Landmarks Dearborn and Delta

Relative Orientation 0.005 millimeters

FLOW at Vida 2550 cfs

Absolute Orientation: X 7.3 meters

Absolute Orientation: Y 9.1 meters

Absolute Orientation: Z 1.2 meters

Notes Tokatee golf course is apparent in these photos.
I accidentally did 2 sets of gravel bars; edited in ArcInfo.

Year 1986 Date 7-21-86

Camera WAC

Photo # roll 25, photos 37 & 38

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks McKenzie Bridge

Relative Orientation 0.010 millimeters

Absolute Orientation: X 9.2 meters

Absolute Orientation: Y 4.2 meters

Absolute Orientation: Z 2.5 meters

Scale 1:31,000

Film ☒ B&W ☐ Color

Job File 25-37-38

Raw ARC file prefix 9B

FLOW at Vida 2550 cfs

Notes Landslide areas can be seen on steep slopes.
I might want to field check riparian area by the abbey.

Year 1986 Date 6-24-86

Camera WAC

Photo # roll 15; photos 73 & 74

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks Belknap Springs

Relative Orientation 0.002 millimeters

Absolute Orientation: X 7.2 meters

Absolute Orientation: Y 10.2 meters

Absolute Orientation: Z 2.1 meters

Scale 1:31000

Film ☒ B&W ☐ Color

Job File 15-73-4

Raw ARC file prefix 10B

FLOW at Vida 2250 cfs

Notes Some open water can be seen in an old side channel to river right, below Belknap Springs.

Year **1986** Date **8-9-86**

Camera WAC

Photo # roll 28; photos 155 & 156

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks Twisty Creek, Frissell Creek, above

Relative Orientation 0.001 millimeters

Absolute Orientation: X 9.8 meters

Absolute Orientation: Y 7.2 meters

Absolute Orientation: Z 1.6 meters

Scale 1:31000

Film ☒ B&W ☐ Color

Job File 28-155-6

Raw ARC file prefix 11B

FLOW at Vida 3010 cfs

Notes Many clearcut patches are present on hillslopes, especially to the north of these photos.

Year **1986** Date **8-9-86**

Camera WAC

Photo # roll 28; photos 157 & 158

Control ☒ USGS Quad Map ☐ 1986 Aerial Photos

Landmarks Tamolitch, Deer Creek, Olallie

Relative Orientation 0.006 millimeters

Absolute Orientation: X 6.7 meters

Absolute Orientation: Y 9.5 meters

Absolute Orientation: Z 0.75 meters

Scale 1:31000

Film ☒ B&W ☐ Color

Job File 28-157-8

Raw ARC file prefix 12B

FLOW at Vida 3010 cfs

Notes Absori on 5 pts.
No residential areas can be seen in these photos.
The wetted channel is equal to the active channel.
It is very difficult to discern patches of >100 conifer
No ponds were observed.

Year 1986	**Date** 8-9-86	**Scale**	1:31000
Camera	WAC	**Film**	☒ B&W ☐ Color
Photo #	roll 28; photos 158 & 159	**Job File**	28-158-9
Control	☒ USGS Quad Map ☐ 1986 Aerial Photos	**Raw ARC file prefix**	13B
Landmarks	Trailbridge Res., Olallie and Anderson	**FLOW at Vida**	3010 cfs

Relative Orientation 0.003 millimeters

Absolute Orientation: X 8.2 meters

Absolute Orientation: Y 8.5 meters

Absolute Orientation: Z 5.0 meters

Notes

Summary Photo Orientation

1986		
	Mean Relori (mm)	0.01
	Mean Absori: X in meters	6.73
	Mean Absori: Y in meters	7.61
	Mean Absori: Z in meters	2.38

Year 1990	**Date** 8-1-90	**Scale**	1:12,000
Camera	American Aerial Surveys 208.32 mm	**Film**	☐ B&W ☒ Color
Photo #	roll 1290; photos 103 & 104	**Job File**	90-103-4
Control	☐ USGS Quad Map ☒ 1986 Aerial Photos	**Raw ARC file prefix**	90DL
Landmarks	zoom of Delta	**FLOW at Vida**	2880 cfs

Relative Orientation 0.017 millimeters

Absolute Orientation: X 5.8 meters

Absolute Orientation: Y 3.1 meters

Absolute Orientation: Z 3.5 meters

Notes Project code 616180C, Willamette National Forest, 8-1-90
absori on 6 pts.
Did not digitize all roads.
Active side channel by Delta Campground follows the veg. fringe.
South Fork wetted channel is now similar to active channel. No unvegetated gravel bars are evident.
Interaction with the main stem: Suspect subsurface flow at top of island into old channel.

Summary Photo Orientation

1990		
	Mean Relori (mm)	0.02
	Mean Absori: X in meters	5.80
	Mean Absori: Y in meters	3.10
	Mean Absori: Z in meters	3.50

APPENDIX C: GIS Procedures and Analyses

Part 1. Arc/Info General Procedures

1. File Transfer Protocol (FTP) was used to transfer raw arc files to Sun workspace.
2. Line coverages were initially separated from future polygon coverages. In a couple of cases where the lines and polys were together in the same file, they were edited into separate files using the VI editor.
3. I generated all line coverages, using an aml to automate the process (gen.aml).
4. All coverages were initially built as lines.
4. Polygon coverages do not have label points when exported from the AP 190. Two options exist to make polygon coverages in this case. The gravel bar coverages were fairly simple so the process was to clean the coverage, createlabels, then put each arc label into the polygon as the polygon code using an aml named code.aml. For the vegetation covers, which were more complex with slivers from digitizing, the files were first run through a separate program called 'mkpoly', written by Barbara Marks, before generating in ArcInfo (step 3 above). This program averages the x values, then averages the y values, and places the label point at the location of the average x and y. Then each coverage is generated and edited to place labelpoints into irregularly shaped polygons.
5. All coverages were examined and edited in ArcEdit to eliminate messy overlaps and digitizing errors. Adjacent covers were used as backcoverages to check alignment and eliminate duplication.
6. An item, "code" was added to maintain the integrity of the unique codes given during digitizing. Photo numbers were added to the files containing the active channel and tribs.
7. Files were appended together, then built or cleaned.

Part 2. Arc/Info Analysis

ACTIVE CHANNEL

The active channel, as initially digitized, consisted of the wetted channel, plus unvegetated gravel bars within the high flow area, plus any lightly vegetated low areas that would be inundated during annual high flows. Side channels were not initially included.

Coverages:

ac4649	line coverage
ac4649poly	ends closed for polygon coverage
ac86	line coverage
ac86poly	ends closed for polygon coverage

To reflect the definition of active channel that includes side channels, two separate coverages were appended for each year to determine the extended active channel.

ac4649 + sc49_7 = exac49

ac86cl + sc86_7 = exac86

Both coverages were then converted to polygon coverages, exac49poly and exac86poly.

SIDE CHANNELS

To select only the side channels outside of the active (main) channel, an ERASE was done using the active channel coverage with no islands. To get it to work for both years, I had to use a fuzzy tolerance of 7 meters, due to problems with the 1940s coverage.

erase sc4649b ac4649polycl sc49_7 line 7

[operation - in cover - erase cover - out cover - type of cover - fuzzy tolerance]

Final Coverages:

sc49_7 and sc86_7

Table C1. Arc/Info statistical summary of side channel length and area, 1945/49 and 1986, McKenzie River, OR.

Year	Number	Sum (L)	Max. (L)	Min. (L)	Mean (L)	Std. Dev.
1945/49	53	17692	2025	9	334	443
1986	42	10639	1084	13.7	253	215

TRIBUTARIES

Final Coverages:

trib4649 line coverage with names

trib86 line coverage with names

GRAVEL BARS

I eliminated gravel bars less than 100 m^2 in area to compensate for differences in photoscale between 1945/49 and 1986. Gravel bars from the South Fork drainage were deleted for the main stem comparison.

Final Coverages:

lggb4649ed

lggb86ed

Table C2. Arc/Info statistical summary of gravel bar area, 1945/49 and 1986, McKenzie River, OR.

Year	Number	Sum Area	Max. Area	Min. Area	Mean Area	Std. Dev.
1945/49	53	207926	27728	103	3923	5606
1986	47	88512	9230	156	1883	2200

LARGE WOODY DEBRIS

Much more large woody debris was apparent in the 1945/49 aerial photos, despite the differing scale of the photos.

Final Coverages:

lwd4649ed deleted South Fork lwd

lwd86

1945/49: Approximately 23 aggregations or very large pieces can be counted on the coverage.

1986: Approx. 13 aggregations of very large pieces can be counted on the coverage..

Note: It is not appropriate to use the actual amount or length of LWD in these coverages, as this was digitized as a qualitative amount at specific locations, rather than a qualitative measure of each piece.

CHANNEL CHANGE

To determine the amount of change over time in the extended active channel, two different identity operations were conducted, to detect areas changing more than 30 meters and areas changing more than 60 meters:

identity exac86poly ac49bf30 acchg line

identity exac86poly ac49bf60 acchg60 line

Reselection of inside = 1 gives the length of channel change on either side of the channel.

To determine how much of the wetted channel (main flow, no side channels) has changed, I conducted similar identity operations using the wetted channel coverages.

identity wc86ext wc49buf30 wcchg30 line

identity wc86ext we49buf60 wcchg60 line

Reselection of inside = 1 gives the length of channel change on either side of the channel.

Table C3. Arc/Info statistical summary of change in channel position greater than 30 m and 60 m, 1945/49 and 1986, McKenzie River, OR.

Channel Change	Freq.	sum length	max. length	min length	mean length	std. dev.
chg. 30m+	51	9089	1441	8.08	178	291
not chgd. 30 m+	150	129024	7489	4.7	860	1521
chg 60m+	9	5342	1359	179	594	415
not chgd. 60 m +	40	132695	9387	5.7	3317	3133

VEGETATION

The vegetation categories were the most problematic to convert to useful ArcInfo polygon coverages. The main problem was that the AP190 exports these features not as polygons with a label point indicating type of vegetation (input during digitizing), but as arcs bent back on themselves with the unique identifier attached as the arc ID number. When displaying a complex coverage, a user would not be able to tell which polygon went with which label number. To solve this problem, Barbara Marks at the Forestry Sciences Lab wrote a computer program (mkpoly) that averaged all of the x values in each arc and all of the y values of that arc, then used the average x and y to assign the label point. Each coverage was then generated in ArcInfo, cleaned with a fuzzy tolerance of 10 meters, and edited in ArcEdit to remove overlaps, dangles, and to replace any label points that had fallen outside of irregularly shaped polygons. An item named code was added to maintain the vegetation codes, unique to each category of vegetation. All polygons with an area less than 200 m^2 were eliminated. Enclosed polys with no labels were given the code for 20-100 year conifer, as I defined that category as the forest matrix and did not digitize those polys. All individual vegetation coverages from the stereophotos were then appended together, polys less than 200 m^2 were eliminated, and the coverage was checked for label errors and dangles.

Final coverages:

veg49e
veg86e

<u>FEMA MAPS</u>

Flood Insurace Rate Maps used were panels 195. 215, 220, 405, 410, 430, and 435, borrowed from the State Land Conservation and Development Commission in Salem.

The condition of these maps was not conducive to accurate digitizing. They were wrinkled paper and because they were borrowed, I was not free to flatten them permanently, nor to mark on them. Aside from being wrinkled, the format of the maps is very crude. They appear to be hand-drawn with a wide pen. The only way to georeference them is with a few township/section lines. One map (#225) did not have the required 4 points for accurate location on the digitizer model and was not used.

When imported into ArcInfo, these maps did not join up and I had to use massive 'artistic license' to obtain a useful product. I used edgematching on the individual map coverages, then appended them, transformed them into UTM coordinates, then used rubbersheeting techniques with bridges, tributary junctions and some unique channel features to anchor the coverage.

Final coverages:

fp, fped, and fpedplus (most highly edited version)

RIPARIAN BUFFERS

The extended active channel coverages (exac49poly and exac86poly) were buffered as lines, so as not to exclude riparian areas on the larger islands between side channels and the main channel. The FEMA floodplain was used as a backcoverage in ArcEdit to determine how to edit slivers. If a sliver polygon was within the floodplain, it was deleted from the largest riparian buffer. If the sliver represented an island not designated as part of the floodplain, the entire island was left in the coverage, even if the shape did not correspond exactly to the FEMA coverage.

Table C4. Arc/Info statistical summary of area within riparian buffers of different set-backs from active channel, 1945/49 and 1986, McKenzie River, OR.

Cover	Area Inside	Perimeter	Island Freq.	Island Area	Island Perimeter
ac49bf30	9433716	150441	7	918730	13236
ac49bf60	13894432	147077	6	569262	9988
ac49bf90	18273118	142021	4	291164	5204
ac49bf90 fema	19024826	141978	4	291164	5204
ac86bf30	8227378	142638	3	280818	3949
ac86bf60	12483769	141132	2	178573	2612
ac86bf90	16697383	140361	2	108210	2096
ac86bf90 fema	18749744	139276	2	108210	2096

ROADS

Individual road files from the photopairs were edgematched, edited and appended, then built as lines. Highway 126 was moved sometimes 5 to 10 meters to accommodate edgematching. An item named 'type' was added in ArcEdit. Using 1:24,000 USGS quad maps, the type of road was assigned to each road in the 1986 coverage as designated on the map. Buffer distances were determined by type of road, in accordance with recommendations received from the Oregon Department of Transportation about typical road widths in the McKenzie area.

Table C5. Road widths used to determine buffer size of each type of road in 1986 Arc/Info coverage.

Type of Road	Probable Width
State Highway 126	12 ft. travel lanes (3 lanes in places)
	24 ft to 36 ft wide
	plus 2 to 8 ft. shoulders
Community streets (2 lane)	32 ft. wide, not curbed
	40 ft. wide, curbed
Driveways	12 ft. wide
	up to 16 ft. if leading to dble. garage
Forest roads (2 way paved)	20 ft. wide
Timber access (gravel)	one lane = 14 ft. wide
	two lanes = 24 - 26 ft. wide

Unfortunately, the road coverage became too complex to buffer in one piece using a lookup table, so the different roads types had to be selectively pulled into separate coverages, buffered, then reunited. DISSOLVE was used to create a less complicated buffered roads coverage, which did not delineate the original type of road.

Table C6. Buffer size used for each type of road in the 1986 Arc/Info coverage.

Road Type	Definition	Buffer Distance	New 1986 Cover
1	Highway 126	(both sides digitized)	hwy86fin
2	Community Streets	5 m	rds2_86bf
3	Forest Roads (paved)	4 m	rds3_86bf
4	Timber Access (gravel), Unimproved Rds. (USGS), and visible driveways	3 m	rds4_86bf
6	Bridges	0	bridg86
7	Transmission Lines	3 m	trans86bf

All roads from 1945/49 were given the same buffer width as any 1986 road in the same location, as a conservative measure, as 1945/49 road widths were not known but were, presumably less than current widths. If there were no corresponding 1986 road, the road was assigned to type 4 and buffered with 3 meters.

Final Buffered Road Coverages:

rds86finalbf

rds49bf

Table C7. Arc/Info statistical summary of area of roads inside each riparian buffer, 1945/49 and 1986, McKenzie River, OR.

1945/49 Buffer	Area in Roads	1986 Buffer	Area in Roads
30 m	175303	30 m	248190
60	335016	60	542225
90	446711	90	
90 m + FEMA	452768	90 m + FEMA	

Table C8. Arc/Info statistical summary of area within 30 m of roads, 1945/49 and 1986, McKenzie River, OR.

1945/49 Buffer	1940s Eco Edge Area	1986 Buffer	1986 Eco Edge Area
30 m	1249149	30 m	139910
60	2474911	60	2940592
90	3390395	90	4304778
90 m + FEMA	3428616	90 m + FEMA	4509113

LAND USE and VEGETATION

Roads were unioned with the active (main) channel polygon coverage to yield the following coverages:

acrds49

acrds86

Side channel polygons and tributaries were not included in this analysis to simplify the resulting coverages and interpretation.

The active channel plus roads coverage was then unioned with the vegetation coverage. When roads and vegetation overlapped, priority was given to the vegetation designation, as road areas were calculated separately in another analysis. In the 1945/49 coverage 58.6875 hectares overlapped veg and roads, equal to 3% of total area, possibly a reflection of the generous buffers given to old roads. Roads only made up 4.5% of the area. In the 1986 coverage 41.0871 hectares, or 2% of the total area was made up of veg and road polys which overlapped, with 268 hectares or 14% in roads only.

landuse49

landuse86

For FragStats, the landuse49 and landuse86 coverages were first unioned with their respective riparian buffers (ac49bf90fema and ac86bf90fema). All polygons formed from this union and without a landuse code were assigned #7700, the code for 20-100yr conifer, the forest matrix. Orchards were absorbed into the agriculture category. The unioned coverages were then clipped by the same riparian buffers to eliminate areas outside of the riparian area. Polygons less than 200 m^2 were eliminated.

Coverages : rip49 and rip86

The landuse code was simplified to a 2 digit number by dividing by 100 to calculate 'statcode'. The item 'statcode' was dissolved upon to simplify the coverages, resulting in coverages named frag49 and frag86.

To determine the percent of each land use in each riparian buffer, each different riparian buffer was used to clip the above coverages (rip49, rip86). Statistics were requested in ArcPlot and given an out-info file name, which was then sorted and unloaded in Tables to an ascii file. I used a file transfer process to transfer these files to MacIntosh Excel files.

nu49_30	nu86_30
nu49_60	nu86_60
nu49_90	nu86_90
rip49	rip86

To determine land use and vegetation by reach, the largest riparian buffer polygon coverages (ac49bf90fema and ac86bf90fema) and the active channel coverages (ac4649 and ac86) were divided at reach breaks, creating a polygon coverage with 7 reach polygons. An item was added, 'reach' and a single digit number entered to indicate the reach, beginning with reach 1 below Trailbridge Dam, and ending with reach 7 above Leaburg Dam.

Final coverages:

reachac49	1945/49 active (main) channel reaches
reachrip49	largest riparian buffer (1945/49), divided by reach
reachac86	1986 active (main) channel reaches
reachrip86	largest riparian buffer (1986), divided by reach

These coverages were then unioned with the landuse coverage for each year (landuse49 and landuse86) and then clipped with the largest riparian buffer. Polygons less than 200 m^2 were eliminated. All polygons without a landuse code were assigned #7700, the code for 20-100yr conifer, the forest matrix. Another item was added, called 'reachlu' and calculated equal to the lucode plus reach, so that the information about landuse category and reach number would be contained within one item. Hectares were calculated to simplify the statistical output. Coverages were named rchlu49e and rchlu86e.

Within ArcPlot, a statistical report was generated using the 'reachlu' item and yielding the sum of hectares, maximum, minimum, mean size of polygons, and standard deviation of area in each category and reach. This statistical report was sorted in Tables and unloaded to an ascii file for use in MacIntosh Excel program.

ZOOM AREAS

Three areas of the channel showed the most channel change over this time and extra photos were digitized to track the steps in channel change.

Blue River: 1959, 1967.

Categories digitized: active channel, wetted channel, tribs., large wood, roads, side channels, gravel bars.

Delta Campground: 1959, 1964, 1967, 1979, 1990.

Categories digitized: active channel, wetted channel, tribs., large wood, roads, side channels, gravel bars.

Three of these years were misregistered, probably due to a wrong entry in the AP190 software when it asked for the photo counter position of the control photos. As a result, the 1964, 1979 and 1990 photos are not in the correct geographical location, but instead are rotated 180°. To compensate for this error, plots can be transferred to transparencies and realigned over the original (correct) location or cut and pasted then photocopied.

Dearborn Island: 1959, 1979.

Categories digitized: active channel, wetted channel, large wood, roads, side channels, gravel bars.

Final coverages are too numerous to list here, but all follow the same naming convention. Zoom areas first have the abbreviation of the area, year, and category (e.g. blr59gb is the Blue River 1959 gravel bar coverage).

STUDYSHED BOUNDARIES

Beginning with the Oregon watershed boundary cover (orhuc_utm), I selected the outlines of the area drained by the section of the McKenzie River from Trailbridge Dam to Leaburg Dam. I deleted the drainage below Leaburg Dam and the Lost Lake subbasin.

Final Coverage:

studyshed

GEOLOGY

A coverage available at the Forestry Sciences Lab (or_geol) was clipped with the studyshed boundaries and again with the largest riparian buffer. Statistics were generated in ArcPlot and exported to an ascii file.

Final coverages:

geo	studyshed geology
acgeo	riparian geology (active channel + 90m + FEMA floodplain)

OWNERSHIP

An Oregon ownership coverage (orowners_utm), available at the Forestry Sciences Lab was clipped with the studyshed boundaries and again with the largest riparian buffer. Statistics were generated in ArcPlot and exported to an ascii file.

Final coverages:

owners	studyshed ownership
acowners	riparian ownership (active channel + 90m + FEMA floodplain)

Part 3. Naming Conventions of Arc/Info Coverages

All original 1945/49 coverage names included the letter 'a' plus a number, lower numbers downriver, and successive numbers upriver.

All original 1986 coverages names included the letter 'b' plus a number to indicate river position (as above).

After appending, the 1945/49 and 1986 coverages continued to carry the year, plus the code to indicate type of coverage.

FEMA maps are indicated in original coverage names by the letters 'fp' and their map number (e.g. fp_195). After appending and editing, they carry the designation FEMA or 'fp'.

Zoom areas first have the abbreviation of the area, year, and category (e.g. blr59gb is the 1959 Blue River gravel bar coverage).

List of abbreviations used in coverage names:

ac = active channel
blr = Blue River
cat = active channel + tribs.
db = Dearborn Island
dl = Delta Campground
exac = extended active channel (includes side channels)
gb = gravel bar
lu = land use
lw or lwd = large woody debris
rds = roads
sc = side channel
trib = tributary
v or veg = vegetation
wc = wetted channel

Part 4. List of Coverages

All digital coverages are currently stored at the Forestry Sciences Lab, workspace: /gis/sspace/minear or /users/minear

mac1946 (actually 1945)

a1a_20cn	a1a_sc	a1b_r	a2a_res	a2b_wc
a1a_20hw	a1a_wc	a1b_res	a2a_wc	cat46
a1a_act	a1b_20cn	a1b_wc	a2b_20cn	gb46
a1a_ag	a1b_20hw	a2a_20cn	a2b_20hw	
a1a_bare	a1b_act	a2a_20hw	a2b_act	
a1a_gb	a1b_ag	a2a_act	a2b_ag	rds46
a1a_lgcn	a1b_gb	a2a_ag	a2b_lgcn	
a1a_lghw	a1b_lgcn	a2a_lgcn	a2b_lghw	
a1a_r	a1b_lghw	a2a_lghw	a2b_r	
a1a_res	a1b_lwd	a2a_r	a2b_res	

mac1949

a10_c	a4_c	a5gb	a7_veg	a9_sc
a10_cat	a4_cat	a6_c	a7gb	a9_v
a10_r	a4_cw	a6_cat	a8_c	cat
a10_sc	a4_r	a6_cw	a8_cat	
a10_v	a4_sc	a6_r	a8_cw	
a3_c	a4gb	a6_sc	a8_r	
a3_cat	a5_c	a6_v	a8_sc	
a3_cw	a5_cat	a6gb	a8_v	
a3_r	a5_catpre	a7_cat	a8gb	
a3_sc	a5_cw	a7_cw	a9_c	
a3_v	a5_r	a7_dev	a9_cat	
a3gb	a5_sc	a7_r	a9_cw	
a4-v	a5_v	a7_sc	a9_r	

mac1986

b13rc	b13_r	b4_v	b8_cw
13b-r.arc	b1_cat	b4gb	b8_r
13b-v.arc	b1_cw	b5_c	b8_sc
b10_c	b1_dev	b5_cat	b8_v
b10_cat	b1_r	b5_cw	b8gb
b10_cw	b1_sc	b5_r	b9_c
b10_r	b1_veg	b5_sc	b9_cat
b10_sc	b1gb	b5_v	b9_cw
b10_v	b2_c	b5gb	b9_r
b10gb	b2_cat	b6_c	b9_sc
b11_c	b2_cw	b6_cat	b9_v
b11_cat	b2_r	b6_cw	b9gb
b11_cw	b2_v	b6_r	bb2_r
b11_r	b2gb	b6_sc	bl_r
b11_sc	b3_c	b6_v	
b11_v	b3_cat	b6gb	channel.cmp
b11gb	b3_cw	b7_c	
b12_c	b3_r	b7_cat	
b12_cat	b3_sc	b7_cw	rds86fin
b12_cw	b3_v	b7_r	
b12_r	b4_c	b7_sc	
b12_sc	b4_cat	b7_v	
b12_v	b4_cw	b7gb	
b12gb	b4_r	b8_c	
b13_c	b4_sc	b8_cat	

mckenzie

ac4649	lggb4649ed	rds86cl	ac49bf500
ac4649poly	lggb86	riprap91	ac86bf500
ac86	lggb86ed	sc4649	
ac86poly	line	sc49_7	
acchg		sc86	
acchg3	lwd4649	sc86_7	
acchg60	lwd4649ed	sc86ltd	
blrclip	lwd49	sclwd49	

mckenzie, cont'd.

cat4649	lwd86	sclwd86
cat86	lwdfield91	studyshed
dbclip	machuc	trbrclp
dlclip	mck86.cmp	trib4649
exac49poly	mck86.ps	trib86
exac86pcpy	paula.lin	wc49
exac86poly	portrait.eps	wc49buf30
fp	rds4649	wc49buf60
fped	rds4649cl	wc49ext
fpedplus	rds49bf10	wc86
gbopenrap86	rds49bf4	wc86ext
huc17090004	rds86	wcchg30
	rds86b	wcchg60
landmks	rds86bf4	
lggb4649	rds86bf4cl	

roads

bridg86		rds49bf	roads49
hwy86fin	rds2_86bf	rds4_86bf	roads86
rds3_86bf	rds86bf		trans86bf

macfema

fema	fp_435	fp_195	fp_215
fp_220	mcbr_fp	fp_405	fp_410
fp_430			

maczoom

blr49cat_clp	blr67lw_clp	db79gb	dl67ac
blr49gb_clp	blr67trib	db79gb_clp	dl67gb
blr49lw_clp	blr86cat_clp	db79r_clp	dl67trib
blr49sc_clp	blr86gb_clp	db79sc_clp	dl79_c
blr59_c	blr86lw_clp	dbclip	dl79_lw
blr59_lw	blr86sc_clp	dl59_c	dl79_r
blr59_r	blrclip	dl59_lw	dl79_sc
blr59_sc	db59_c	dl59_r	dl79ac

maczoom, cont'd.

blr59ac	db59_lw	dl59_sc	dl79gb
blr59ac_clp	db59_r	dl59ac	dl79trib
blr59gb	db59_sc	dl59gb	dl90_c
blr59gb_clp	db59ac	dl59trib	dl90_lw
blr59lw_clp	db59ac_clp	dl64_c	dl90_r
blr59sc_clp	db59gb	dl64_lw	dl90_sc
blr59trib	db59gb_clp	dl64_r	dl90ac
blr67_c	db59r_clp	dl64_sc	dl90gb
blr67_lw	db59sc_clp	dl64ac	dl90trib
blr67_r	db79_c	dl64gb	dlclip
blr67_sc	db79_lw	dl64trib	
blr67ac	db79_r	dl67_c	
blr67ac_clp	db79_sc	dl67_lw	misregdlclip
blr67gb	db79ac	dl67_r	
blr67gb_clp	db79ac_clp	dl67_sc	

veg

a10_v	a2b_20hw	a5veg	b11vc	b4_v
a10v	a2b_ag	a5vegc	b12_v	b4v
a10vc	a2b_lgcn	a6_v	b12v	b4vc
a1veg	a2b_lghw	a6v	b12vc	b4vcc
a1vege	a2b_res	a6vc	b13_v	b5_v
a2a20cn	a2bag	a7_res	b13v	b5v
a2a_20cn	a2blgcn	a7_veg	b13vc	b5vc
a2a_ag	a2blghw	a7res	b1_res	b5vcc
a2a_hw	a2bres	a7resc	b1_veg	b6_v
a2a_lgcn	a2bveg	a7v	b1res	b6v
a2a_lghw	a2bvege	a7vc	b1resc	b6vc
a2a_res	a2veg	a7veg	b1v	b6vcc
a2aag	a3_v	a7vegc	b1vc	b7_v
a2aage	a3v	a8_v	b1vce	b7v
a2ahw	a3vc	a8v	b1veg	b7vc
a2algcn	a4_v	a8vc	b1vegc	b8_v
a2algcne	a4v	a9_v	b2_v	b8v
a2alghw	a4vc	a9v	b2v	b8vc

veg, cont'd.

a2ares	a5_res	a9vc	b2vc	b9_v
a2aveg	a5_veg	b10_v	b2vce	b9v
a2avege	a5res	b10v	b2ve	b9vc
a2b20cn	a5resc	b10vc	b3_v	
a2b20hw	a5v	b11_v	b3v	
a2b_20cn	a5vc	b11v	b3vc	mkpoly

vegfinal

a10vc	acrds49	landuse86	reachlu86
a1vc	acrds86	landuse86b	reachrip49
a2vc	b10v		reachrip86
a3vc	b11v	lu49_30	reachriplu49
a4vc	b12v	lu49_60	reachriplu86
a5vc	b13v	lu49_90	ripfrag49
a6vc	b1v	lu86_30	ripfrag49e
a7vc	b2v	lu86_60	ripfrag86
a8vc	b3v	lu86_90	ripfrag86e
a9vc	b4v	nufrag49	veg49
ac49	b5v	nufrag86	veg49dis
ac49bf30	b6v	rchlu49e	veg49e
ac49bf60	b7v	rchlu86e	veg86
ac49bf90	b8v	rdpoly.aml	veg86dis
ac49bf90fema	b9v	rds49bf	veg86e
ac86	frag49	rds86bf	
ac86bf30	frag86	rds86combo	
ac86bf60		reachac49	
ac86bf90	landuse49	reachac86	
ac86bf90fema	landuse49b	reachlu49	

APPENDIX D: Hydrology and Climate

Table D1. Instantaneous peak flows at the outlet of Clear Lake, McKenzie River, OR, before and after dam construction and statistical analyses of variance and means. (U.S.G.S. gage #14158500, Wellman et al. 1993)

Before Dams		After Dams	
Water Year	Peak Flow (cms)	Water Year	Peak Flow (cms)
1948	65.70	1969	33.70
1949	44.75	1970	56.64
1950	39.65	1971	48.14
1951	52.39	1972	47.01
1952	30.87	1973	27.44
1953	73.63	1974	69.95
1954	46.44	1975	52.11
1955	38.52	1976	37.38
1956	84.11	1977	16.31
1957	45.31	1978	60.60
1958	40.21	1979	24.04
1959	32.85	1980	47.29
1960	43.90	1981	49.28
1961	63.15	1982	62.30
		1983	34.27
		1984	33.13
		1985	30.02
		1986	59.19
		1987	29.17
		1988	25.01
		1989	28.89
		1990	45.31

F-Test: Two-Sample for Variances

Instantaneous Peak Flows	*Before Dams*	*After Dams*
Mean	50.1061714	41.6909018
Variance	249.348323	214.09593
Observations	14	22
df	13	21
F	1.164657	
P(F<=f) one-tail	0.36618342	
F Critical one-tail	2.22215846	

t-Test: 2-Sample Assuming Equal Variances

Instantaneous Peak Flows	*Before Dams*	*After Dams*
Mean	50.1061714	41.6909018
Variance	249.348323	214.09593
Observations	14	22
Pooled Variance	227.574787	
Hypoth. Mean Diff.	0	
df	34	
t	1.63166152	
P(T<=t) one-tail	0.05599016	
t Critical one-tail	1.69092345	
P(T<=t) two-tail	0.11198031	
t Critical two-tail	2.03224317	

Table D2. Instantaneous peak flows at McKenzie Bridge, McKenzie River, OR, before and after dam construction, and statistical analyses of variance and means. (U.S.G.S. gage #14159000, Wellman et al. 1993)

Before Dams		After Dams	
Water Year	Peak Flow (cms)	Water Year	Peak Flow (cms)
1937	160.29	1969	158.88
1938	171.62	1970	184.36
1939	82.13	1971	241.00
1940	84.96	1972	288.86
1941	73.92	1973	115.83
1942	133.39	1974	221.18
1943	320.02	1975	178.13
1944	120.08	1976	190.59
1945	156.61	1977	54.66
1946	376.66	1978	281.22
1947	291.70	1979	143.87
1948	291.70	1980	202.77
1949	209.28	1981	252.33
1950	164.26	1982	278.10
1951	227.69	1983	160.86
1952	131.12	1984	201.36
1953	359.66	1985	154.06
1954	227.13	1986	356.83
1955	111.86	1987	125.74
1956	368.16	1988	191.73
1957	265.64	1989	152.64
1958	244.40	1990	205.89
1959	121.78		
1960	106.77		
1961	272.16		

Statistics

F-Test: Two-Sample for Variances

Instantaneous Annual Peak Flow	*Before Dams*	*After Dams*
Mean	202.918464	197.313164
Variance	8990.71869	4536.84351
Observations	25	22
df	24	21
F	1.98171232	
P(F<=f) one-tail	0.05883521	
F Critical one-tail	2.05400497	

t-Test: Two-Sample Assuming Unequal Variances

Instantaneous Annual Peak Flow	*Before Dams*	*After Dams*
Mean	202.918464	197.313164
Variance	8990.71869	4536.84351
Observations	25	22
Pearson Correlation	#N/A	
Pooled Variance	1703.38323	
df	43.1868184	
t	0.2356398	
P(T<=t) one-tail	0.40741545	
t Critical one-tail	1.68107135	
P(T<=t) two-tail	0.8148309	
t Critical two-tail	2.01669081	

D2, cont'd.

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	202.918464	197.313164
Variance	8990.71869	4536.84351
Observations	25	22
Pooled Variance	6912.24361	
Hypothesized Mean Difference	0	
df	45	
t	0.23063318	
P(T<=t) one-tail	0.40932256	
t Critical one-tail	1.67942744	
P(T<=t) two-tail	0.81864513	
t Critical two-tail	2.0141033	

Table D3. Instantaneous peak flows at Lookout Creek, tributary to Blue River, OR, and statistical analyses for the period before and after dams were constructed in other parts of the basin. (U.S.G.S. gage #14161500, Wellman et al. 1993)

Before Dams		After Dams	
Water Year	Peak Flow (cms)	Water Year	Peak Flow (cms)
1950	56.07	1969	61.17
1951	50.98	1970	54.37
1952	37.38	1971	66.84
1953	102.52	1972	118.52
1954	70.52	1973	23.28
1955	32.57	1974	37.10
		1975	37.38
		1976	46.16
		1977	8.30
		1978	86.38
		1979	32.85
		1980	44.18
		1981	62.87
		1982	49.56
		1983	41.63
		1984	59.47
		1985	32.00
		1986	76.46
		1987	27.47
		1988	30.87
		1989	47.58
		1990	55.51
		1991	28.60
		1992	31.44

Statistics

F-Test: Two-Sample for Variances

Instantaneous Peak Flows	*Before Dams*	*After Dams*
Mean	58.3392	48.3328
Variance	652.557506	546.187413
Observations	6	24
df	5	23
F	1.19475017	
P(F<=f) one-tail	0.34262156	
F Critical one-tail	2.64000022	

t-Test: 2-Sample Assuming Equal Variances

Instantaneous Peak Flows	*Before Dams*	*After Dams*
Mean	58.3392	48.3328
Variance	652.557506	546.187413
Observations	6	24
Pooled Variance	565.182073	
Hypoth. Mean Diff.	0	
df	28	
t	0.92215577	
P(T<=t) one-tail	0.18216276	
t Critical one-tail	1.70113026	
P(T<=t) two-tail	0.36432552	
t Critical two-tail	2.04840944	

Table D4. Instantaneous peak flows at gage near Vida, McKenzie River, OR, before and after dam construction and statistical analyses of variance and means. (U.S.G.S. gage #14162500, Wellman et al. 1993)

Before Dams		After Dams	
Water Year	Peak Flow (cms)	Water Year	Peak Flow (cms)
1937	716.50	1969	453.12
1938	792.96	1970	481.44
1939	416.30	1971	679.68
1940	317.18	1972	815.62
1941	303.02	1973	351.17
1942	682.51	1974	447.46
1943	1384.85	1975	441.79
1944	589.06	1976	529.58
1945	753.31	1977	125.74
1946	1823.81	1978	657.02
1947	1115.81	1979	472.94
1948	1110.14	1980	532.42
1949	1028.02	1981	484.27
1950	724.99	1982	617.38
1951	1008.19	1983	447.46
1952	625.87	1984	540.91
1953	1466.98	1985	390.82
1954	1115.81	1986	764.64
1955	523.92	1987	390.82
1956	1464.14	1988	467.28
1957	1302.72	1989	506.93
1958	954.38	1990	637.20
1959	662.69	1991	455.95
1960	404.98	1992	407.81
1961	1098.82		

Statistics

F-Test: Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	895.4784	504.1432
Variance	157791.892	20540.4748
Observations	25	24
df	24	23
F	7.68199828	
P(F<=f) one-tail	3.1414E-06	
F Critical one-tail	2.00500949	

t-Test: 2-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	895.4784	504.1432
Variance	157791.892	20540.4748
Observations	25	24
Pearson Correlation	#N/A	
Pooled Variance	3.5	
df	30.3673702	
t	4.62236451	
P(T<=t) one-tail	3.3764E-05	
t Critical one-tail	1.69726036	
P(T<=t) two-tail	6.7527E-05	
t Critical two-tail	2.04227035	

Table D5. Annual winter water year precipitation at the Andrews Experimental Forest, McKenzie River basin, OR (Greenland 1993), and statistical analyses of variance and means for the period before and after dam construction.

Before Dams		After Dams	
Winter Water Year	Precip. (cm)	Winter Water Year	Precip. (cm)
1937	156.41	1969	200.25
1938	237.69	1970	180.75
1939	155.35	1971	231.14
1940	164.06	1972	253.92
1941	128.22	1973	129.26
1942	161.24	1974	285.29
1943	272.47	1975	209.91
1944	132.77	1976	230.12
1945	162.76	1977	85.75
1946	225.55	1978	201.02
1947	193.73	1979	156.62
1948	207.72	1980	167.84
1949	190.17	1981	167.64
1950	195.61	1982	245.85
1951	239.70	1983	225.93
1952	208.84	1984	219.79
1953	195.20	1985	175.21
1954	216.66	1986	186.26
1955	170.87	1987	144.27
1956	272.31	1988	168.50
1957	182.55	1989	195.55
1958	217.30	1990	150.70
1959	191.16	1991	165.61
1960	168.40		
1961	209.50		

Statistics

F-Test: Two-Sample for Variances

Winter Water Yr. Precip.	*Before Dams*	*After Dams*
Mean	194.24904	190.312261
Variance	1427.66263	2004.16935
Observations	25	23
df	24	22
F	1.40381159	
P(F<=f) one-tail	0.20898601	
F Critical one-tail	1.71488423	

t-Test: Two-Sample Assuming Equal Variances

Winter Water Yr. Precip.	*Before Dams*	*After Dams*
Mean	194.24904	190.312261
Variance	1427.66263	2004.16935
Observations	25	23
Pooled Variance	1703.38323	
Hypothesized Mean Difference	0	
df	46	
t	0.33014002	
P(T<=t) one-tail	0.37139652	
t Critical one-tail	1.67865892	
P(T<=t) two-tail	0.74279304	
t Critical two-tail	2.01289367	

Table D6. Flood frequency curves before and after dam construction at gage near Vida, McKenzie River, OR. (U.S.G.S. gage #14162500, Wellman et al. 1993)

		Pre-Dams 1923-1962	Post-Dams 1963-1992
Recurrence Interval (yrs)	Exceedance Probability (%)	Discharge (cms)	Discharge (cms)
1.25	80	574.9	405.3
2	50	826.9	504.8
5	20	1175.3	661.7
10	10	1401.8	778.8
25	4	1685.0	942.6
50	2	1891.8	1076.5
100	1	2098.5	1221.2

APPENDIX E: Landscape and Class Indices, FragStats Analysis

Table E1. Comparison of landscape indices from FragStats analysis of riparian area (90 m on either side of active channel, plus floodplain), Trailbridge Dam to Leaburg Dam, McKenzie River, OR, from aerial photos taken in 1945/49 and 1986.

	1945/49	**1986**
Total Area (ha):	1,931.471	1,885.707
Largest Patch Index(%):	3.618	5.119
Number of patches:	895	1,202
Patch Density (#/100 ha):	46.338	63.743
Mean Patch Size (ha):	2.158	1.569
Patch Size Standard Dev (ha):	6.229	5.250
Patch Size Coeff of Variation (%):	288.658	334.618
Total Edge (m):	383,908.812	452,693.438
Edge Density (m/ha):	198.765	240.066
Landscape Shape Index:	33.426	38.326
Mean Shape Index:	2.242	2.241
Area-Weighted Mean Shape Index:	3.755	3.890
Double Log Fractal Dimension:	1.385	1.438
Mean Patch Fractal Dimension:	1.472	1.489
Area-Weighted Mean Fractal Dimension:	1.424	1.442
Total Core Area (ha):	1,931.471	44.090
Number of Core Areas:	895	9
Core Area Density (#/100 ha):	46.338	0.477
Mean Core Area 1 (ha):	2.158	0.037
Core Area Standard Dev 1 (ha):	32.238	1.160
Core Area Coeff of Variation 1 (%):	1,493.844	3,161.711
Mean Core Area 2 (ha):	2.158	4.899
Core Area Standard Dev 2 (ha):	32.238	12.483
Core Area Coeff of Variation 2 (%):	1,493.844	254.800
Total Core Area Index (%):	100.000	2.338
Mean Core Area Index (%):	100.000	0.059
Shannon's Diversity Index:	1.665	1.646
Simpson's Diversity Index:	0.750	0.726
Modified Simpson's Diversity Index:	1.384	1.294
Patch Richness:	10	10
Patch Richness Density (#/100 ha):	0.518	0.530
Relative Patch Richness (%):	NA	NA
Shannon's Evenness Index:	0.723	0.715
Simpson's Evenness Index:	0.833	0.806
Modified Simpson's Evenness Index:	0.601	0.562
Interspersion/Juxtaposition Index (%):	58.212	61.077

Table E2. Metrics by vegetation or land-use category from FragStats analysis of riparian area in 1945/49, (90 m on either side of active channel, plus floodplain), Trailbridge Dam to Leaburg Dam, McKenzie River, OR, in 1945/49.

Date: 29 Nov 93 08:52:40 Monday Coverage: frag49

Basename for Output Files: frag49

Patch Type Attribute: statcode Edge Dist: 100

Background Class: NONE

Max Patch Types Possible: NONE Weight File: NONE

Patch ID Attribute: frag49# Class Names Attribute: NONE

Input Landscape Does Not Contain a Landscape Border

Use Landscape Boundary/Background Edges: NO

Write Patch Indices: YES Write Class Indices: YES

AML/Program Directory: /tmp_mnt/gis/giswork/barbara/vector/

Total Area (ha): 1931.471

Roads, Transmission Lines

Patch Type:	60	Class Area (ha):	32.885
Landscape Similarity (%):	1.703		
Largest Patch Index (%):	0.109	Number Patches:	97
Patch Density (#/100 ha):	5.022	Mean Patch Size (ha):	0.339
Patch Size SD (ha):	0.452	Patch Size CV (%):	133.426
Total Edge (m):	75600.078		
Edge Den (m/ha):	39.141		
Landscape Shape Index:	13.637	Mean Shape Index:	3.553
Area-Weighted Mean Shape:	5.796	Double Log Fractal Index:	1.764
Mean Patch Fractal:	1.654	Area-Weighted Mean Fractal:	1.669
Core Area Similarity (%):	1.703	Total Core Area (ha):	32.885
Number Core Areas:	97	Core Area Den (#/100 ha):	5.022
Mean Core Area 1 (ha):	0.339	Core Area SD 1 (ha):	0.452
Core Area CV 1 (%):	133.426	Mean Core Area 2 (ha):	0.339
Core Area SD 2 (ha):	0.452	Core Area CV 2 (%):	133.426
Total Core Area Index (%):	100.000	Mean Core Area Index (%):	100.000
Intersper/Juxtapos (%):	20.277		

Table E2, cont'd.

Residential/ Developed

Patch Type:	70	Class Area (ha):	52.127
Landscape Similarity (%):	2.699		
Largest Patch Index (%):	0.233	Number Patches:	66
Patch Density (#/100 ha):	3.417	Mean Patch Size (ha):	0.790
Patch Size SD (ha):	0.873	Patch Size CV (%):	110.530
Total Edge (m):	19698.613	Edge Den (m/ha):	10.199
Landscape Shape Index:	10.049	Mean Shape Index:	1.409
Area-Weighted Mean Shape:	1.499	Double Log Fractal Index:	1.119
Mean Patch Fractal:	1.386	Area-Weighted Mean Fractal:	1.350
Core Area Similarity (%):	2.699	Total Core Area (ha):	52.127
Number Core Areas:	66	Core Area Den (#/100 ha):	3.417
Mean Core Area 1 (ha):	0.790	Core Area SD 1 (ha):	0.873
Core Area CV 1 (%):	110.530	Mean Core Area 2 (ha):	0.790
Core Area SD 2 (ha):	0.873	Core Area CV 2 (%):	110.530
Total Core Area Index (%):	100.000	Mean Core Area Index (%):	100.000
Intersper/Juxtapos (%):	56.477		

Bare Rock or Soil

Patch Type:	72	Class Area (ha):	3.374
Landscape Similarity (%):	0.175		
Largest Patch Index (%):	0.052	Number Patches:	6
Patch Density (#/100 ha):	0.311	Mean Patch Size (ha):	0.562
Patch Size SD (ha):	0.335	Patch Size CV (%):	59.639
Total Edge (m):	1867.856	Edge Den (m/ha):	0.967
Landscape Shape Index:	8.904	Mean Shape Index:	1.570
Area-Weighted Mean Shape:	1.571	Double Log Fractal Index:	1.198
Mean Patch Fractal:	1.411	Area-Weighted Mean Fractal:	1.386
Core Area Similarity (%):	0.175	Total Core Area (ha):	3.374
Number Core Areas:	6	Core Area Den (#/100 ha):	0.311
Mean Core Area 1 (ha):	0.562	Core Area SD 1 (ha):	0.335
Core Area CV 1 (%):	59.639	Mean Core Area 2 (ha):	0.562
Core Area SD 2 (ha):	0.335	Core Area CV 2 (%):	59.639
Total Core Area Index (%):	100.000	Mean Core Area Index (%):	100.000
Intersper/Juxtapos (%):	40.172		

Table E2, cont'd.

Agriculture, Orchards

Patch Type:	73	Class Area (ha):	43.297
Landscape Similarity (%):	2.242		
Largest Patch Index (%):	0.368	Number Patches:	27
Patch Density (#/100 ha):	1.398	Mean Patch Size (ha):	1.604
Patch Size SD (ha):	1.596	Patch Size CV (%):	99.517
Total Edge (m):	10977.744	Edge Den (m/ha):	5.684
Landscape Shape Index:	9.489	Mean Shape Index:	1.567
Area-Weighted Mean Shape:	1.593	Double Log Fractal Index:	1.056
Mean Patch Fractal:	1.383	Area-Weighted Mean Fractal:	1.339
Core Area Similarity (%):	2.242	Total Core Area (ha):	43.297
Number Core Areas:	27	Core Area Den (#/100 ha):	1.398
Mean Core Area 1 (ha):	1.604	Core Area SD 1 (ha):	1.596
Core Area CV 1 (%):	99.517	Mean Core Area 2 (ha):	1.604
Core Area SD 2 (ha):	1.596	Core Area CV 2 (%):	99.517
Total Core Area Index (%):	100	Mean Core Area Index (%):	100.000
Intersper/Juxtapos (%):	46.680		

<20yr Hardwoods

Patch Type:	74	Class Area (ha):	56.146
Landscape Similarity (%):	2.907		
Largest Patch Index (%):	0.664	Number Patches:	69
Patch Density (#/100 ha):	3.572	Mean Patch Size (ha):	0.814
Patch Size SD (ha):	1.605	Patch Size CV (%):	197.244
Total Edge (m):	27102.916		
Edge Den (m/ha):	14.032		
Landscape Shape Index:	10.524	Mean Shape Index:	1.658
Area-Weighted Mean Shape:	1.622	Double Log Fractal Index:	1.216
Mean Patch Fractal:	1.426	Area-Weighted Mean Fractal:	1.361
Core Area Similarity (%):	2.907	Total Core Area (ha):	56.146
Number Core Areas:	69	Core Area Den (#/100 ha):	3.572
Mean Core Area 1 (ha):	0.814	Core Area SD 1 (ha):	1.605
Core Area CV 1 (%):	197.244	Mean Core Area 2 (ha):	0.814
Core Area SD 2 (ha):	1.605	Core Area CV 2 (%):	197.244
Total Core Area Index (%):	100.	Mean Core Area Index (%):	100.000
Intersper/Juxtapos (%):	51.273		

Table E2, cont'd.

<20yr Conifers

Patch Type:	75	Class Area (ha):	69.609
Landscape Similarity (%):	3.604		
Largest Patch Index (%):	0.463	Number Patches:	37
Patch Density (#/100 ha):	1.916	Mean Patch Size (ha):	1.881
Patch Size SD (ha):	1.744	Patch Size CV (%):	92.703
Total Edge (m):	16134.062	Edge Den (m/ha):	8.353
Landscape Shape Index:	9.820	Mean Shape Index:	1.651
Area-Weighted Mean Shape:	1.817	Double Log Fractal Index:	1.124
Mean Patch Fractal:	1.381	Area-Weighted Mean Fractal:	1.358
Core Area Similarity (%):	3.604	Total Core Area (ha):	69.609
Number Core Areas:	37	Core Area Den (#/100 ha):	1.916
Mean Core Area 1 (ha):	1.881	Core Area SD 1 (ha):	1.744
Core Area CV 1 (%):	92.703	Mean Core Area 2 (ha):	1.881
Core Area SD 2 (ha):	1.744	Core Area CV 2 (%):	92.703
Total Core Area Index (%):	100.	Mean Core Area Index (%):	100.000
Intersper/Juxtapos (%):	32.357		

20-100yr Hardwoods

Patch Type:	76	Class Area (ha):	108.148
Landscape Similarity (%):	5.599		
Largest Patch Index (%):	0.779	Number Patches:	82
Patch Density (#/100 ha):	4.245	Mean Patch Size (ha):	1.319
Patch Size SD (ha):	2.595	Patch Size CV (%):	196.732
Total Edge (m):	38668.652	Edge Den (m/ha):	20.020
Landscape Shape Index:	11.266	Mean Shape Index:	1.517
Area-Weighted Mean Shape:	1.769	Double Log Fractal Index:	1.210
Mean Patch Fractal:	1.396	Area-Weighted Mean Fractal:	1.350
Core Area Similarity (%):	5.599	Total Core Area (ha):	108.148
Number Core Areas:	82	Core Area Den (#/100 ha):	4.245
Mean Core Area 1 (ha):	1.319	Core Area SD 1 (ha):	2.595
Core Area CV 1 (%):	196.732	Mean Core Area 2 (ha):	1.319
Core Area SD 2 (ha):	2.595	Core Area CV 2 (%):	196.732
Total Core Area Index (%):	100.	Mean Core Area Index (%):	100.000
Intersper/Juxtapos (%):	51.267		

Table E2, cont'd.

20-100yr Conifers

Patch Type:	77	Class Area (ha):	767.861
Landscape Similarity (%):	39.755		
Largest Patch Index (%):	2.019	Number Patches:	317
Patch Density (#/100 ha):	16.412	Mean Patch Size (ha):	2.422
Patch Size SD (ha):	5.318	Patch Size CV (%):	219.545
Total Edge (m):	334774.750	Edge Den (m/ha):	173.326
Landscape Shape Index:	30.273	Mean Shape Index:	2.693
Area-Weighted Mean Shape:	3.834	Double Log Fractal Index:	1.310
Mean Patch Fractal:	1.526	Area-Weighted Mean Fractal:	1.448
Core Area Similarity (%):	39.755	Total Core Area (ha):	767.861
Number Core Areas:	317	ore Area Den (#/100 ha):	16.412
Mean Core Area 1 (ha):	2.422	Core Area SD 1 (ha):	5.318
Core Area CV 1 (%):	219.545	Mean Core Area 2 (ha):	2.422
Core Area SD 2 (ha):	5.318	Core Area CV 2 (%):	219.545
Total Core Area Index (%):	100.	Mean Core Area Index (%):	100.000
Intersper/Juxtapos (%):	78.825		

>100yr Conifer

Patch Type:	79	Class Area (ha):	420.589
Landscape Similarity (%):	21.776		
Largest Patch Index (%):	3.618	Number Patches:	183
Patch Density (#/100 ha):	9.475	Mean Patch Size (ha):	2.298
Patch Size SD (ha):	6.607	Patch Size CV (%):	287.472
Total Edge (m):	99141.578	Edge Den (m/ha):	51.330
Landscape Shape Index:	15.148	Mean Shape Index:	1.598
Area-Weighted Mean Shape:	2.313	Double Log Fractal Index:	1.217
Mean Patch Fractal:	1.395	Area-Weighted Mean Fractal:	1.359
Core Area Similarity (%):	21.776	Total Core Area (ha):	420.589
Number Core Areas:	183	Core Area Den (#/100 ha):	9.475
Mean Core Area 1 (ha):	2.298	Core Area SD 1 (ha):	6.607
Core Area CV 1 (%):	287.472	Mean Core Area 2 (ha):	2.298
Core Area SD 2 (ha):	6.607	Core Area CV 2 (%):	287.472
Total Core Area Index (%):	100.	Mean Core Area Index (%):	100.000
Intersper/Juxtapos (%):	36.937		

Table E3. Metrics by vegetation or land-use category from FragStats analysis of riparian area in 1986 (90 m on either side of active channel, plus floodplain), Trailbridge Dam to Leaburg Dam, McKenzie River, OR, in 1986.

Date: 29 Nov 93 14:09:15 Monday

Coverage: frag86

Basename for Output Files: frag86

Patch Type Attribute: statcode   Edge Dist: 100

Background Class: NONE

Max Patch Types Possible: NONE

Weight File: NONE

Patch ID Attribute: frag86#   Class Names Attribute: NONE

Input Landscape Does Not Contain a Landscape Border

Use Landscape Boundary/Background Edges: NO

Write Patch Indices: YES   Write Class Indices: YES

AML/Program Directory: /tmp_mnt/gis/giswork/barbara/vector/

Total Area (ha): 1885.707

Roads, Transmission Lines

Patch Type:	60	Class Area (ha):	69.102
Landscape Similarity (%):	3.664		
Largest Patch Index (%):	0.238	Number Patches:	107
Patch Density (#/100 ha):	5.674	Mean Patch Size (ha):	0.646
Patch Size SD (ha):	0.938	Patch Size CV (%):	145.246
Total Edge (m):	114899.414		
Edge Den (m/ha):	60.932		
Landscape Shape Index:	16.382	Mean Shape Index:	3.910
Area-Weighted Mean Shape:	5.609	Double Log Fractal Index:	1.594
Mean Patch Fractal:	1.651	Area-Weighted Mean Fractal	1.618
Intersper/Juxtapos (%):	25.472		

Table E3, cont'd.

Residential/ Developed

Patch Type:	**70**	Class Area (ha):	92.626
Landscape Similarity (%):	4.912		
Largest Patch Index (%):	0.380	Number Patches:	202
Patch Density (#/100 ha):	10.712	Mean Patch Size (ha):	0.459
Patch Size SD (ha):	0.814	Patch Size CV (%):	177.423
Total Edge (m):	45763.578		
Edge Den (m/ha):	24.269		
Landscape Shape Index:	11.891	Mean Shape Index:	1.356
Area-Weighted Mean Shape:	1.554	Double Log Fractal Index:	1.180
Mean Patch Fractal:	1.416	Area-Weighted Mean Fractal:	1.368
Intersper/Juxtapos (%):	48.286		

Bare

Patch Type:	72	Class Area (ha):	5.036
Landscape Similarity (%):	0.267		
Largest Patch Index (%):	0.077	Number Patches:	6
Patch Density (#/100 ha):	0.318	Mean Patch Size (ha):	0.839
Patch Size SD (ha):	0.439	Patch Size CV (%):	52.320
Total Edge (m):	2397.086		
Edge Den (m/ha):	1.271		
Landscape Shape Index:	9.074	Mean Shape Index:	1.479
Area-Weighted Mean Shape:	1.508	Double Log Fractal Index:	1.231
Mean Patch Fractal:	1.376	Area-Weighted Mean Fractal:	1.363
Intersper/Juxtapos (%):	42.633		

Table E3, cont'd.

Agriculture, Orchards

Patch Type:	73	Class Area (ha):	27.254
Landscape Similarity (%):	1.445		
Largest Patch Index (%):	0.230	Number Patches:	23
Patch Density (#/100 ha):	1.220	Mean Patch Size (ha):	1.185
Patch Size SD (ha):	1.079	Patch Size CV (%):	91.049
Total Edge (m):	9346.580		
Edge Den (m/ha):	4.957		
Landscape Shape Index:	9.525	Mean Shape Index:	1.722
Area-Weighted Mean Shape:	1.888	Double Log Fractal Index:	1.284
Mean Patch Fractal:	1.404	Area-Weighted Mean Fractal:	1.383
Intersper/Juxtapos (%):	58.103		

<20yr Hardwoods

Patch Type:	74	Class Area (ha):	101.646
Landscape Similarity (%):	5.390		
Largest Patch Index (%):	1.517	Number Patches:	111
Patch Density (#/100 ha):	5.886	Mean Patch Size (ha):	0.916
Patch Size SD (ha):	2.894	Patch Size CV (%):	316.037
Total Edge (m):	56441.406		
Edge Den (m/ha):	29.931		
Landscape Shape Index:	12.585	Mean Shape Index:	1.795
Area-Weighted Mean Shape:	2.825	Double Log Fractal Index:	1.311
Mean Patch Fractal:	1.456	Area-Weighted Mean Fractal:	1.424
Intersper/Juxtapos (%):	55.422		

Table E3, cont'd.

<20yr Conifers

Patch Type:	75	Class Area (ha):	11.072
Landscape Similarity (%):	0.587		
Largest Patch Index (%):	0.138	Number Patches:	10
Patch Density (#/100 ha):	0.530	Mean Patch Size (ha):	1.107
Patch Size SD (ha):	0.780	Patch Size CV (%):	70.412
Total Edge (m):	3898.850		
Edge Den (m/ha):	2.068		
Landscape Shape Index:	9.171	Mean Shape Index:	1.975
Area-Weighted Mean Shape:	2.123	Double Log Fractal Index:	1.226
Mean Patch Fractal:	1.440	Area-Weighted Mean Fractal:	1.414
Intersper/Juxtapos (%):	50.650		

20-100yr Hardwoods

Patch Type:	76	Class Area (ha):	140.140
Landscape Similarity (%):	7.432		
Largest Patch Index (%):	0.531	Number Patches:	175
Patch Density (#/100 ha):	9.280	Mean Patch Size (ha):	0.801
Patch Size SD (ha):	1.344	Patch Size CV (%):	167.863
Total Edge (m):	70942.500		
Edge Den (m/ha):	37.621		
Landscape Shape Index:	13.527	Mean Shape Index:	1.615
Area-Weighted Mean Shape:	1.744	Double Log Fractal Index:	1.240
Mean Patch Fractal:	1.419	Area-Weighted Mean Fractal:	1.374
Core Area Similarity (%):	0.003	Total Core Area (ha):	0.051
Number Core Areas:	2	Core Area Den (#/100 ha):	0.106
Mean Core Area 1 (ha):	0.000	Core Area SD 1 (ha):	0.003
Core Area CV 1 (%):	1044.242		
Mean Core Area 2 (ha):	0.025		
Core Area SD 2 (ha):	0.013	Core Area CV 2 (%):	50.759
Total Core Area Index (%):	0.036	Mean Core Area Index (%):	0.004
Intersper/Juxtapos (%):	58.075		

Table E3, cont'd.

20-100yr Conifers

Patch Type:	77	Class Area (ha):	875.378
Landscape Similarity (%):	46.422		
Largest Patch Index (%):	5.119	Number Patches:	402
Patch Density (#/100 ha):	21.318	Mean Patch Size (ha):	2.178
Patch Size SD (ha):	6.665	Patch Size CV (%):	306.054
Total Edge (m):	384452.125		
Edge Den (m/ha):	203.877		
Landscape Shape Index:	33.893	Mean Shape Index:	2.786
Area-Weighted Mean Shape:	3.876	Double Log Fractal Index:	1.267
Mean Patch Fractal:	1.557	Area-Weighted Mean Fractal:	1.449
Core Area Similarity (%):	2.123	Total Core Area (ha):	40.035
Number Core Areas:	5	Core Area Den (#/100 ha):	0.265
Mean Core Area 1 (ha):	0.100	Core Area SD 1 (ha):	1.556
Core Area CV 1 (%):	1561.943	Mean Core Area 2 (ha):	8.007
Core Area SD 2 (ha):	11.455	Core Area CV 2 (%):	143.068
Total Core Area Index (%):	4.573	Mean Core Area Index (%):	0.138
Intersper/Juxtapos (%):	80.196		

>100yr Conifers

Patch Type:	79	Class Area (ha):	227.686
Landscape Similarity (%):	12.074		
Largest Patch Index (%):	1.399	Number Patches:	151
Patch Density (#/100 ha):	8.008	Mean Patch Size (ha):	1.508
Patch Size SD (ha):	3.211	Patch Size CV (%):	212.936
Total Edge (m):	71653.344		
Edge Den (m/ha):	37.998		
Landscape Shape Index:	13.573	Mean Shape Index:	1.646
Area-Weighted Mean Shape:	2.061	Double Log Fractal Index:	1.243
Mean Patch Fractal:	1.414	Area-Weighted Mean Fractal:	1.367
Core Area Similarity (%):	0.209	Total Core Area (ha):	3.943
Number Core Areas:	1	Core Area Den (#/100 ha):	0.053
Mean Core Area 1 (ha):	0.026	Core Area SD 1 (ha):	0.320
Core Area CV 1 (%):	1224.745	Mean Core Area 2 (ha):	3.943
Total Core Area Index (%):	1.732	Mean Core Area Index (%):	0.099
Intersper/Juxtapos (%):	43.439		

Table E4. Comparison of vegetation and land-use types by FragStats analysis for riparian area (90 m plus floodplain), Trailbridge Dam to Leaburg Dam. McKenzie River, OR.

Year	Land Use or Veg. Type	Class Area	Total Area	%of Landscape	Largest Patch Index (%)	Number of Patches	Patch Density (#/ 100ha)	Mean Patch Size (ha)	Patch Size Std. Dev.	Patch Size Coeff. of Variation (%)	Total Class Edge (m)	Class Edge Density (m/ha)
1949	Active	377.44	1931.47	19.54	3.36	11	0.6	34.3	20.8	61	143,851	74
1986	channel	335.77	1885.71	17.81	3.8	15	0.8	22.4	18.4	82	145,592	77
1949	Roads	32.88	1931.47	1.7	0.11	97	5.0	0.3	0.5	133	75,600	39
1986		69.1	1885.71	3.66	0.24	107	5.7	0.7	0.9	145	114,899	61
1949	Residential	52.13	1931.47	2.7	0.23	66	3.4	0.8	0.9	111	19,699	10
1986	or Dev.	92.63	1885.71	4.91	0.38	202	10.7	0.5	0.8	177	45,764	24
1949	Bare	3.37	1931.47	0.17	0.05	6	0.3	0.6	0.3	60	1,868	1
1986		5.04	1885.71	0.27	0.08	6	0.3	0.8	0.4	52	2,397	1
1949	Agri-	43.3	1931.47	2.24	0.37	27	1.4	1.6	1.6	100	10,978	6
1986	cultural	27.25	1885.71	1.45	0.23	23	1.2	1.2	1.1	91	9,347	5
1949	<20 yr	56.15	1931.47	2.91	0.66	69	3.6	0.8	1.6	197	27,103	14
1986	Hardwood	101.65	1885.71	5.39	1.52	111	5.9	0.9	2.9	316	56,441	30
1949	<20 yr	69.61	1931.47	3.6	0.46	37	1.9	1.9	1.7	93	16,134	8
1986	Conifer	11.07	1885.71	0.59	0.14	10	0.5	1.1	0.8	70	3,899	2
1949	20-100	108.15	1931.47	5.6	0.78	82	4.3	1.3	2.6	197	38,669	20
1986	yr Hardwd	140.14	1885.71	7.43	0.53	175	9.3	0.8	1.3	168	70,943	38
1949	20-100 yr	767.86	1931.47	39.76	2.02	317	16.4	2.4	5.3	220	334,775	173
1986	Conifer	875.38	1885.71	46.42	5.12	402	21.3	2.2	6.7	306	384,452	204
1949	>100 yr	420.59	1931.47	21.78	3.62	183	9.5	2.3	6.6	287	99,142	51
1986	Conifer	227.69	1885.71	12.07	1.4	151	8.0	1.5	3.2	213	71,653	38

Table E4, cont'd.

Year	Land Use or Veg. Type	Land-scape Shape Index	Mean Shape Index	Area Wtd. Mean Shape	Dble. Log Fractal Index	Mean Patch Fractal	Area Wtd. Mean Patch Fractal	Core Area Similarity (%)	Total Core Area (ha)	# of Core Areas	Core Area Density (#/ 100ha)	Mean Core Area (ha)	Core Area Std. Dev. (ha)
1949	Active	18.02	6.43	6.84	1.31	1.52	1.49	19.54	377.44	11	0.57	34.31	20.77
1986	channel	18.38	5.52	6.93	1.55	1.5	1.5	0	0.06	1	0.05	0	0.02
1949	Roads	13.64	3.55	5.8	1.76	1.65	1.67	1.7	32.88	97	5.02	0.34	0.45
1986		16.38	3.91	5.61	1.59	1.65	1.62	0	0	0	0	0	0
1949	Resid.	10.05	1.41	1.5	1.12	1.39	1.35	2.7	52.13	66	3.42	0.79	0.87
1986	or Dev.	11.89	1.36	1.55	1.18	1.42	1.37	0	0	0	0	0	0
1949	Bare	8.9	1.57	1.57	1.2	1.41	1.39	0.17	3.37	6	0.31	0.56	0.34
1986		9.07	1.48	1.51	1.23	1.38	1.36	0	0	0	0	0	0
1949	Agric.	9.49	1.57	1.59	1.06	1.38	1.34	2.24	43.3	27	1.4	1.6	1.6
1986		9.53	1.72	1.89	1.28	1.4	1.38	0	0	0	0	0	0
1949	<20 yr	10.52	1.66	1.62	1.22	1.43	1.36	2.91	56.15	69	3.57	0.81	1.6
1986	Hardwd	12.58	1.79	2.82	1.31	1.46	1.42	0	0	0	0	0	0
1949	<20 yr	9.82	1.65	1.82	1.12	1.38	1.36	3.6	69.61	37	1.92	1.88	1.74
1986	Conifer	9.17	1.98	2.12	1.23	1.44	1.41	0	0	0	0	0	0
1949	20-100	11.27	1.52	1.77	1.21	1.4	1.35	5.6	108.15	82	4.25	1.32	2.59
1986	yr Hdwd	13.53	1.61	1.74	1.24	1.42	1.37	0	0.05	2	0.11	0	0
1949	20-100	30.27	2.69	3.83	1.31	1.53	1.45	39.76	767.86	317	16.41	2.42	5.32
1986	Conifer	33.89	2.79	3.88	1.27	1.56	1.45	2.12	40.03	5	0.27	0.1	1.56
1949	>100 yr	15.15	1.6	2.31	1.22	1.4	1.36	21.78	420.59	183	9.47	2.3	6.61
1986	Conifer	13.57	1.65	2.06	1.24	1.41	1.37	0.21	3.94	1	0.05	0.03	0.32