AN ABSTRACT OF THE THESIS OF

Pamela J. Lombard for the degree of Master of Science in Forest Engineering presented on May 12, 1997. Title: The Effect of the Size and Orientation of Large Wood on Pool Volume in Two Oregon Coast Range Streams.

Abstract approved: ______________________________

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This study was conducted to determine how the size and orientation of large wood placed in streams in combination with peak flows, substrate and channel gradient affect pool volume, surface area and maximum depth in two coastal Oregon streams. Eighteen Douglas-fir (*Pseudotsuga menziesii*) logs were placed in each of two streams, J-Line Creek and Preacher Creek, in the summer of 1989. Surveys were conducted annually from 1989-1996 at summer low flow using a total station electronic theodolite. The orientation of the introduced wood and the parameters of residual pools associated with the wood were determined from high resolution topographic maps made from the surveys.

Residual pool volume associated with the introduced wood increased 2,500 percent over the seven years for J-Line Creek and 30 percent for Preacher Creek. Large spanners, logs placed perpendicular to the stream flow and flush with the stream bottom, had the greatest pool volume associated with them, however horizontal orientations shifted downstream over time. Large ramps, logs placed at a downstream orientation and angled up onto the bank, were the most stable treatment.

Differences between the two watersheds and an interaction variable between the diameter of the introduced wood and the horizontal orientation of the introduced wood were the significant variables which entered the multiple linear regression model for residual pool volume. These variables, as well as the vertical orientation of the introduced wood, were significantly correlated to both residual pool surface area and maximum depth. The recurrence interval of the annual maximum instantaneous peak flow was not significantly associated with residual pool volume, surface area nor maximum depth. Multiple regression models explained, at most, twenty-eight percent of the variability in residual pool volume, maximum depth and surface area.

Estimates of pool volume obtained with aquatic habitat inventories (Bisson et al., 1982) were compared with residual pool calculations determined from the topographic maps. Pool volume in a reach determined by aquatic habitat inventories explained 96 percent of the variability of residual pool volume in a reach, however estimates of individual pool volume explained only 40 percent of the variability in residual pool volume.

The Effect of the Size and Orientation of Large Wood on Pool Volume in Two Oregon Coast Range Streams

by

Pamela J. Lombard

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Pamela J. Lombard, Author

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

The Effect of the Size and Orientation of Large Wood on Pool Volume in Two Oregon Coast Range Streams

INTRODUCTION

Large wood plays a major role in channel morphology and sediment routing in small and intermediate-sized streams in the Pacific Northwest (PNW) (Swanson and Lienkaemper, 1978; Harmon et al., 1986). Although it is difficult to predict how stream discharge, local substrate size, and local channel gradient will interact with large wood in the formation and enhancement of pools, a diversity of large roughness elements, such as large wood stemming from a healthy riparian plant community is generally associated with high quality fish habitat (Beschta, 1991). Fish populations are related to the amount of large wood in streams (Bisson et al., 1982; Sedell et al., 1982), thus large wood is necessary if high quality habitat for fish and other aquatic organisms is to be maintained (Franklin et al., 1981; Sedell et al., 1982; Maser et Trappe, 1984; Harmon et al., 1986).

In unmanaged , pristine forest ecosystems, riparian areas play an important role in supplying many species and sizes of wood to stream channels. Debris torrents also deliver large wood to stream channels from conifer stands upslope in the watershed (Kaufmann, 1988). Many coastal streams in the PNW lack significant inputs of Douglas-fir *(Pseudotsuga menziesii*) or western red cedar (*Thuja plicata*) because of disturbances to riparian areas and the resulting regeneration of red alder (*Alnus rubra*) (Heimann, 1987; Hayes et al., 1996). Douglas-fir and western red cedar wood can be an integral part of stream structure for over a century while red alder deteriorates in years to decades (Hayes et al., 1996). Stream channels with alder dominated riparian areas generally have less complex structure than streams with a mix of species including conifers in the riparian areas (McMahon and Reeves, 1989).

Management activities can affect the amount, size and species of wood in stream channels and riparian areas. Historically, logging expedited the processes that delivered wood to stream channels by mass movements or by direct inputs of logging slash into the stream channels after logging (Swanson and Lienkaemper, 1978). In the 1970s, the loading of large wood in stream channels decreased because the forest practice rules mandated that logging slash be removed from stream channels (State of Oregon, 1972). Large jams of woody debris were considered a barrier to the passage of anadromous salmonids (Harmon et al., 1986). Low loading of large wood in stream channels can be exacerbated by low stocking of conifers in riparian areas resulting from logging, fire or debris torrents.

There is growing awareness among both public and private landowners regarding the role of large wood in the structure and function of forested, headwater streams in the PNW. This awareness has been communicated to policymakers and is reflected in the Oregon Forest Practices Act (FPA) (Lorensen et al., 1994). The FPA provides incentives for landowners to place large wood in streams to enhance fish habitat by allowing a lower basal area of conifers to be retained in the Riparian Management Area (RMA). RMAs can extend from six to thirty meters (twenty to one hundred feet) from the stream channel depending on the classification of the stream. The FPA also prohibits removal of all snags or downed wood within the RMA (Lorensen et al., 1994).

The importance of large wood for structure in stream channels is widely accepted, however the role of individual pieces or groups of wood is poorly understood. How long must wood stay in the stream to alter morphology? What size, orientation and species of large wood are most effective in improving or maintaining aquatic habitat in streams? Is one piece of wood or an entire woody debris jam required?

Much large wood has been added to streams in the PNW during the last decade to enhance aquatic habitat (Kaufmann, 1988; Beschta et al., 1991; Crispin et al., 1993; Gregory and Wildman, unpublished). Large conifer wood has been placed or cabled into stream channels to remedy the lack of naturally occurring conifer wood. The goal of this study is to examine the relationship between the size and orientation of individual pieces of large wood and residual pool volume as an indicator of aquatic habitat, and to determine how that relationship is affected by discharge, channel gradient, and substrate.

OBJECTIVES

The overall goal of this project is to investigate how the size and orientation of large wood placed in streams affects the formation and size of residual pools, as a measure of aquatic habitat, in small, coastal, gravel-bedded streams. Results from flume studies that predict local scour will be tested with the first five years of data from a field trial in which individual pieces of wood of various size and orientation were placed in two streams. Specific objectives include:

1) To determine how the size and orientation of large wood affects the creation and volume of residual pools.

2) To determine the effect that maximum annual peak discharge, local gradient and local substrate have on the association between the size and orientation of large wood and residual pool volume.

3) To determine the degree to which aquatic habitat inventories (Bisson et al., 1982) estimate residual pool volume.

REVIEW OF THE LITERATURE

The necessity of pool habitat for fish

Pools are an important component of aquatic habitat and are necessary for fish. Fish need pools because of the low velocities and large depths found in pools (Fausch, 1984). Optimum coho salmon (*Oncorhynchus kisutch*) habitat consists of large, deep pools with instream cover and off-channel pools (Bustard and Narver, 1975). Fish densities are higher in pools than in riffles or glides in Quartz Creek in the McKenzie River Drainage (Gregory and Wildman, unpublished). Coho salmon less than one year old and one to two year old cutthroat trout (*Salmo clarki*) selectively use pool habitat, including backwater pools, trench pools, lateral scour pools and plunge pools, especially during summer lowflow (Bisson et al., 1982; Sullivan et al., 1987). Use of riffles, rapids and cascades is mostly by steelhead trout (*Salmo gairdneri*) and cutthroat trout less than one year old (Bisson et al., 1982; Bachman, 1984).

Large wood and pools

Most pools form around elements of large roughness, such as boulders, bedrock, roots of live vegetation or large, downed trees. More than sixty percent of the pools in streams in the PNW are associated with large wood (Keller and Tally, 1979; Andrus et al., 1988; Robison and Beschta, 1989; Fausch and Northcote, 1992). Scour associated with large wood is the dominant mechanism that forms pools in southeast Alaska and Washington, forming seventy-three percent of the pools inventoried (Montgomery et al., 1995). Large wood causes the formation of plunge pools, dammed pools, and lateral scour pools (Bisson et al., 1982). In thirteen second and third order (Strahler, 1957) streams in undisturbed, eastern Oregon forests, ninety-one percent of the plunge pools, seventy-six percent of the dammed pools, and forty-six percent of the scour pools were formed in association with large wood (Cordova, 1995). Scour associated with large wood is primarily below falls, below vertical flow constrictions, and near lateral flow deflections or constrictions. The largest pools are plunge pools formed downstream of sill logs (Kaufmann, 1988).

Forty to eighty percent of the large wood in streams in southeast Alaska and Washington is associated with pools (Montgomery et al., 1995). Pool spacing can be reduced from five to thirteen times the channel width to one to four times the channel width if there are elements of large roughness such as large wood or boulders in the channel (Nakamura and Swanson, 1993; Montgomery et al., 1995). In eastern Oregon, the best predictor of the number of pools per 100 m of stream is the amount of wood per 100 m of stream (Cordova, 1995). Eleven percent of the large wood formed sixty-three percent of the pools in constrained reaches and eighty percent of the pools in unconstrained reaches.

Large wood has been removed from streams in the PNW with varied results. Some studies have found a reduction in the spacing, area or volume of pools (Bilby, 1984; Fausch and Northcote, 1992) while other studies have found that stream cleaning had no immediate effect on pool spacing, depth or volume (Lisle, 1986b; Smith et al., 1993). In studies where the removal of wood did not initially affect average pool spacing, volume or depth, the response was more complex, affecting local pool and bar morphology (Smith et al., 1993) or channel aggradation or degradation (Beschta, 1979; Bilby, 1984; Lisle, 1986b; Smith et al., 1993).

Variables that correlate with pool attributes

Large wood influences the formation and size of pools through ponding, flow convergence, flow deflection, and the creation of a stepped longitudinal profile. These processes have been described as a result of visual observation (Beschta, 1983; Kaufmann, 1988; Bilby and Ward, 1989). Wood forms scour pools by concentrating streamflow and eroding the stream bed or banks (Bilby and Ward, 1989). Wood pieces that span the width of the channel (spanners) create rolling turbulent eddies beneath them. Depth of scour is proportional to the diameter of the wood at a constant discharge and is maximum when the log is positioned to obstruct, but not be overtopped, by flows. This constricts the flow and causes high-velocities that scour the channel bottom (Beschta, 1983). If the logs are placed at a horizontal angle of forty-five degrees with the downstream bank, the creation of eddies resembles a vortex spiral down the length of the log. Deflection and convergence of lateral flow creates long, smooth-edged scour areas with rapid velocities.

The majority of studies concerning large wood quantified wood present in streams, and the associated pools. A common conclusion was that large wood should be used only as an indicator of complexity and that many other variables are part of the equation to predict the spacing, volume, and depth of pools (Ralph et al., 1994).

<u>Orientation of wood</u>

Pieces of large wood projecting out from the streambank are oriented downstream more frequently than they are oriented upstream in streams draining unmanaged, pristine watersheds (Long, 1987; Robison, 1987; Bilby and Ward, 1989). In studies carried out in western Oregon and southeastern Alaska, forty-one percent of the pieces of large wood had horizontal orientations between zero and eighty degrees relative to the downstream banks, thirty percent had horizontal orientations between eighty degrees and one hundred and twenty degrees (perpendicular to the channel) and twenty-eight percent had horizontal orientations between one hundred and twenty degrees and one hundred and eighty degrees (an upstream orientation). The average vertical orientation of the wood relative to the channel bed in these two studies was twenty degrees. In the Queen Charlotte Islands, large wood tended to be oriented diagonally across the stream with the larger end found downstream (Hogan, 1985). Hogan (1985) also found that most wood was oriented diagonally across the stream in unlogged areas and parallel with the flow in streams of logged areas.

The horizontal orientation of large wood often depends on whether or not the wood has been moved by streamflow. In a fifth order stream in the Oregon Cascade Range, the horizontal orientations of pieces of large wood that had not been transported by streamflow were clustered around ninety degrees or perpendicular to the channel. Large wood that had been transported by streamflow tended to have a horizontal orientation parallel to the streambanks (Nakamura and Swanson, 1994).

The majority of wood in streams associated with pools is either perpendicular to flow or angled downstream (Bilby and Ward, 1989; Fausch and Northcote, 1992; Cordova, 1995). Plunge pools and dammed pools are associated with wood at an orientation perpendicular to streamflow while scour pools and backwater pools occur independently of large wood orientation (Bilby and Ward, 1989).

Gradient of the bed of the stream

Channel gradient is a useful indicator of a stream's potential morphologic response to large wood (Keller and Tally, 1979; Andrus et al., 1988; Stack and Beschta, 1989; Nakamura and Swanson, 1993; Montgomery et al., 1995). As channel gradient increases, the percentage of plunge pools increases and the percentage of deflection pools decreases (Stack and Beschta, 1989). Keller and Tally (1979), found that the influence of wood on pools is greatest in streams with gradients between 0.03-0.05, and most of the drop in elevation occurs at woody debris jams in these steep channels, especially in soft sandstone and shale sections. An inverse relationship between pool spacing and the frequency of large wood is found in pool-riffle, plane-bed and forced pool-riffle reaches with gradients between 0.002 and 0.035. Large wood can decrease pool spacing in step-pool channels with gradients greater than or equal to 0.035 (Montgomery et al., 1995).

Drainage area and stream width

Drainage area is positively correlated with pool volume (Bilby and Ward, 1989; Stack and Beschta, 1989; Nakamura and Swanson, 1993). In the central Oregon Coast Range, drainage area is statistically the most significant variable associated with the volume, maximum depth, area, and spacing of pools. Pools get larger and farther apart as drainage area increases. Pool spacing per channel width is not correlated with drainage area (Stack and Beschta, 1989).

In unmanaged old-growth streams in western Washington, the size of the wood is associated with the surface area of the pool when the stream is greater than seven meters wide. The type of pool associated with large wood also changes as stream size increases. The frequency of plunge pools associated with large wood decreases with increasing stream width, but the frequency of scour pools associated with large wood increases (Bilby and Ward, 1989).

Other variables

In a 6.5 km^2, coastal Oregon watershed, pools formed by large wood are more numerous in higher order streams low in the watershed (as opposed to the lower order streams high in the watershed) because streambed material is finer (Andrus et al., 1988). Streambed scour increases as wood size increases in both vertical and lateral scour pools because large wood causes greater turbulence and resistance to streamflow (Kaufmann, 1988). The distance between the piece of wood and the streambed (Montgomery et al., 1995), channel constraint (Cordova, 1995, Montgomery et al., 1995), channel type (Montgomery et al, 1995), time since a debris torrent (Kaufmann, 1988), sinuosity (Nakamura and Swanson, 1994) and a stream power index (Stack and Beschta, 1989) all are correlated with pool attributes. Bilby and Ward (1989),.found depth of flow to be the primary variable that correlated with pool surface area in streams less than seven meters wide.

Habitat improvement projects

As early as the 1930s, land managers believed that stream habitat improvement structures could help restore depleted fish populations (Ehlers, 1954). The effects of stream habitat improvement structures were evaluated eighteen years after the installation of fifteen log dams, five log deflectors, and several other types of structures. Streamflow had washed out eight of the log dams, but those remaining had created pools. The results were qualitatively reported: "even though most of the flow goes under the dam, the structure does seem to maintain a good pool" (Ehlers, 1954).

In Elk Creek, in coastal Oregon, 106 full-spanning and 94 partial-spanning structures were created with wood boles and root wads cabled to boulders or bedrock between 1986 to 1989 (Crispin et al., 1993). A 0.5 km long reach of stream, upstream of the structures, was left as a control. An inventory of the structures in 1990 showed that ninety-eight percent had remained in place. The surface area of summer pool habitat increased five-fold in the treated reach while it decreased over the same time period in the untreated reach (Crispin et al., 1993). The total number of pools in the study reach increased from 155 (out of 340 aquatic habitat units) to 209 (out of 339 aquatic habitat units) between 1985 to 1990. Full-spanning logs were the most successful in creating new pools. Average maximum pool depth increased similarly in both treated and untreated reaches (Crispin et al. 1993).

Kaufmann (1988) observed the addition of large wood into Gwynn Creek in the Oregon Coast Range by the United States Forest Service (U.S.F.S.) in clumps of two to three pieces. Increases in pool volume were weakly related to the amount of wood in the treatment. The addition of wood explained 34 to 44 percent of the variation in pool volume.

During 1988, 186 pieces of large wood were added to Quartz Creek in the McKenzie River drainage as both individual pieces and as accumulations of pieces with various degrees of cabling (Gregory and Wildman, unpublished). The average maximum depth of pools increased from 0.76 m to 1.04 m between 1988 and 1993. The length of stream in pools increased from ten to twenty-one percent over this same period. Only eight of the forty-eight structures moved more than ten meters downstream between 1988 and 1993. Structures that moved less than ten meters still functioned as intended.

In both Quartz Creek and Elk Creek, a positive result of the installation of wood structures was the recruitment of other wood. After a storm at Elk Creek, the treated reach had twice as much wood as the untreated reach despite the fact that the untreated reach was upstream of the treated reach. The average diameter and length of wood were greater in the treated reach (Crispin et al., 1993). Five years after structures were installed in Quartz Creek, size class distributions of wood were equal to size class distributions found in old-growth forests in the McKenzie basin (Gregory and Wildman, unpublished).

Local scour around spur dikes and weirs

To determine the effect individual pieces of large wood have on scour and the formation of pools, it is useful to examine hydraulic processes which have been observed with spur dikes (structures extending from the bank of an alluvial channel in order to protect the stream bank from erosion and improve depth for navigation), and weirs, which have been used extensively for channel scour manipulation (Klingeman et al., 1984). Dikes and groins cause scour that deepens the local channel. Weirs placed across streams cause plunging flow that creates pools (Klingeman et al., 1984).

Depth of scour is affected by the size of the bed material and the depth of uniform flow upstream of the spur location (Gill, 1972; Klingeman et al., 1984). The surface area of scour increases with spur-dike length and horizontal orientation up to 90 degrees (Klingeman et al., 1984). More specifically, upstream-oriented structures and structures oriented perpendicular to flow cause more scour than do downstream-oriented structures (Klingeman et al., 1984).

Scour around dowels in a flume

Scour around spur-dikes in flumes is affected by sediment size, the Froude number, the angle of inclination and the opening ratio between the projected spur-dike and the bank (Garde et al., 1961). Maximum scour occurred at the nose of a spurdike positioned perpendicular to flow. A coarse substrate eroded less than a fine substrate.

The effects of large wood on local channel morphology has also been simulated in flumes (Beschta, 1983; Cherry and Beschta, 1989). The interactions between local scour, large wood size and orientation and discharge were simulated with dowels of constant diameter in a flume with gradient, bed material size and channel width held constant. Scour around the dowels was positively correlated with flow as flow was increased from 1.1 L/s to 2.8 L/s (held constant throughout a trial), but the response was not linear. Maximum depth of scour was positively correlated with channel opening ratio and negatively correlated with the vertical orientation of the dowels. The surface area of scour was positively correlated with flow depth and negatively correlated with the vertical orientation of the wood. Dowels with horizontal orientations of ninety degrees and vertical orientations of zero degrees (spanners) resulted in scour with the largest surface area (Cherry and Beschta, 1989).

STUDY AREA

The location for this study is the central Oregon Coast Range. Two streams, J-Line Creek and Preacher Creek (Figure 1), were chosen for treatment due to similarities in geology, topography, vegetation, climate, hydrology and land use. Both streams had low pool to riffle ratios and had small amounts of large wood when the study was initiated in 1989. J-Line Creek and Preacher Creek are second order (Strahler, 1957) tributaries to the East Fork of Lobster Creek. They support populations of cutthroat trout (*Salmo clarki*) , coho salmon (*Oncorhynchus kisutch*) and two species of sculpin (*Cottus perplexus* and *Cottus gulosus*).

J-Line Creek is on the Salem district of the Bureau of Land Management and Preacher Creek is on the Alsea Ranger District of the Siuslaw National Forest. They experience similar climate. Preacher Creek drains an area twice that of J-Line Creek, (7.8 km^2 (3.0 mi^2) and 2.9 km^2 (1.1 mi^2), respectively). The average radient of the two streams is two to three percent.

Geology

The geology of the two study streams is dominated by the Tyee formation which consists primarily of tuffaceous and micaceous sandstone. This formation has resulted in steep slopes and stream channels which are subject to debris flows and scouring (Badura et al., 1974). Scattered igneous intrusions occurred during the Oligocene, followed by local depositions of sedimentary and volcanic rock during the Miocene (Franklin and Dyrness, 1973).

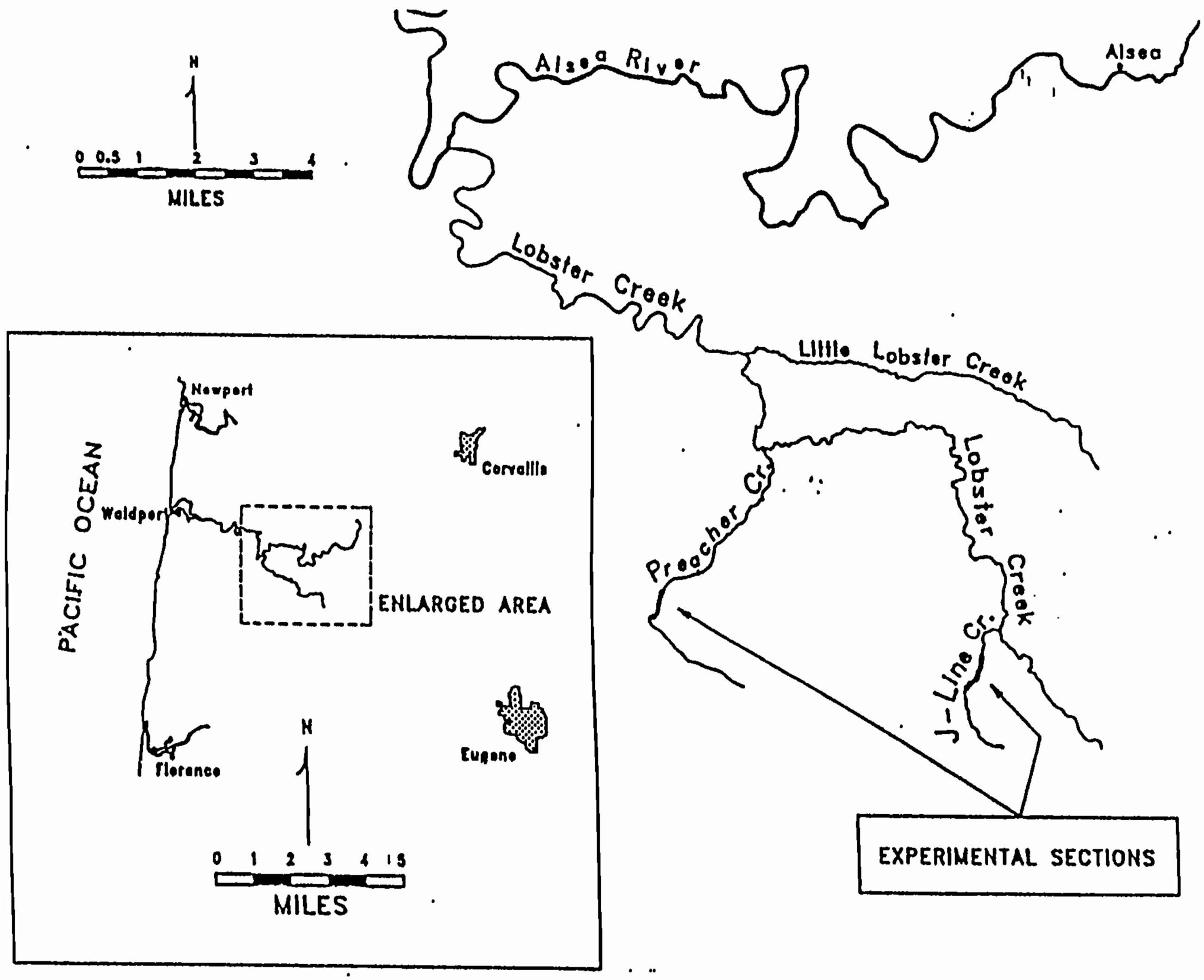

Figure 1. Location of study area and study streams in Oregon.

Soils are derived from sandstone and basalt in this region and are mostly Haplumbrepts (Western brown forest soils). These soils range from shallow, brownish yellow, stony loams to deep, well-developed, reddish-brown clay loams (Franklin and Dyrness, 1973). The landscape is highly dissected and slope angles range from forty to one hundred and ten percent (Marston, 1980).

Climate

Mean annual precipitation in the Oregon Coast Range is 2500-3000 mm. Precipitation results from moist, marine frontal systems moving inland from the Pacific Coast and falls almost exclusively as rain during mild, wet winters (Froyd, 1992). These air masses result in long duration, low intensity storms. Rainfall is enhanced by orographic lifting over the Coast Range. Average annual snowfall is 25 mm. Average daily temperatures range from -6 to 31 degrees Celsius (Franklin et Dyrness, 1973).

Vegetation

Riparian areas in Oregon Coast Range forests vary in vegetation and can include Douglas-fir, sitka spruce, (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*) western red cedar, red alder, salmonberry (*Rubus spectabilis*), vine maple *(Acer circinatum*) and red elderberry (*Sambucus racemosa*) (Froyd, 1992). Species make-up and density are often a function of natural and anthropogenic disturbances, including fire, logging, and landslides. Disturbances in the riparian zone often result in the regeneration of red alder in the overstory and salmonberry in the understory (Hayes et al., 1996). The riparian areas of both Creeks are dominated by red alder and salmonberry. Hillslopes are predominately conifer.

METHODS

The interaction of large wood and channel morphology can be studied at many scales. This study examines how a single piece of wood interacts with peak flows, local gradients and local substrates of the streambed to affect channel morphology in a single aquatic habitat unit. Objective measures of channel morphology are used to determine how the size and orientation of an individual piece of large wood affects a single aquatic habitat unit by forming or enhancing residual pools. Measures of residual pool volume are compared quantitatively with more subjective measures of pool volume obtained using aquatic habitat inventories.

Installation of tagged wood

The treatment for this study consisted of placing thirty-six Douglas-fir logs in two streams of the Oregon Coast Range. A hydraulic excavator was used to place eighteen, bucked, limbed and tagged logs in, each of two creeks, J-Line and Preacher, in study reaches approximately 7.6 km (2,500 ft) long. Each log was 6-7 m (20-23 ft) long, (twice the length of the active channel width), and was assigned a diameter class of 20 cm (8 inch), 40 cm (16 inch) or 60 cm (24 inch) based on the diameter at midpoint. These diameter classifications are treatment classes and refer to the approximate diameters of the thirty-six logs. Each log received a metal tag with a number from one to eighteen, thus treatment logs will be referred to as tagged wood, differentiating them from other large wood within the experimental reaches of the study streams (Appendix A).

When the tagged wood was installed in 1989, each piece was oriented as either a ramp or a spanner (Figure 2). Ramps were placed with the upstream end of the log on the bank, resulting in a vertical angle between the tagged wood and the streambed of ten degrees. The horizontal angle between the tagged wood and the downstream bank was forty-five degrees. Spanners were placed perpendicular to flow, and flush with the streambed. None of the tagged wood pieces were secured, however spanners were placed in excavated troughs in the streambanks so that they could lie flat on the streambed. Placement allowed free movement of tagged wood in response to flows.

Habitat units where the tagged wood was placed were chosen subjectively based on accessibility and lack of existing wood. Treatments were randomly assigned to habitat units. Each combination of tagged wood diameter and orientation was replicated three times in each stream.

Measurements

Independent variables which were measures of the orientation of the wood were determined from high-resolution topographic maps of the stream channels. Maps were constructed from topographic surveys using either an optical theodolite and stadia rod or a total station electronic theodolite (Leica T 1010, Heerbrugg, Switzerland). The location of survey points as determined by changes in slope of the channel, including the deepest point in each pool. Lines representing a constant break in slope, called breaklines, were shown on the maps at the first continuous break in slope outside the main channel to delineate the active channel (Figure 3). The endpoints of the tagged wood and topographic masspoints used to create the terrain model were also located

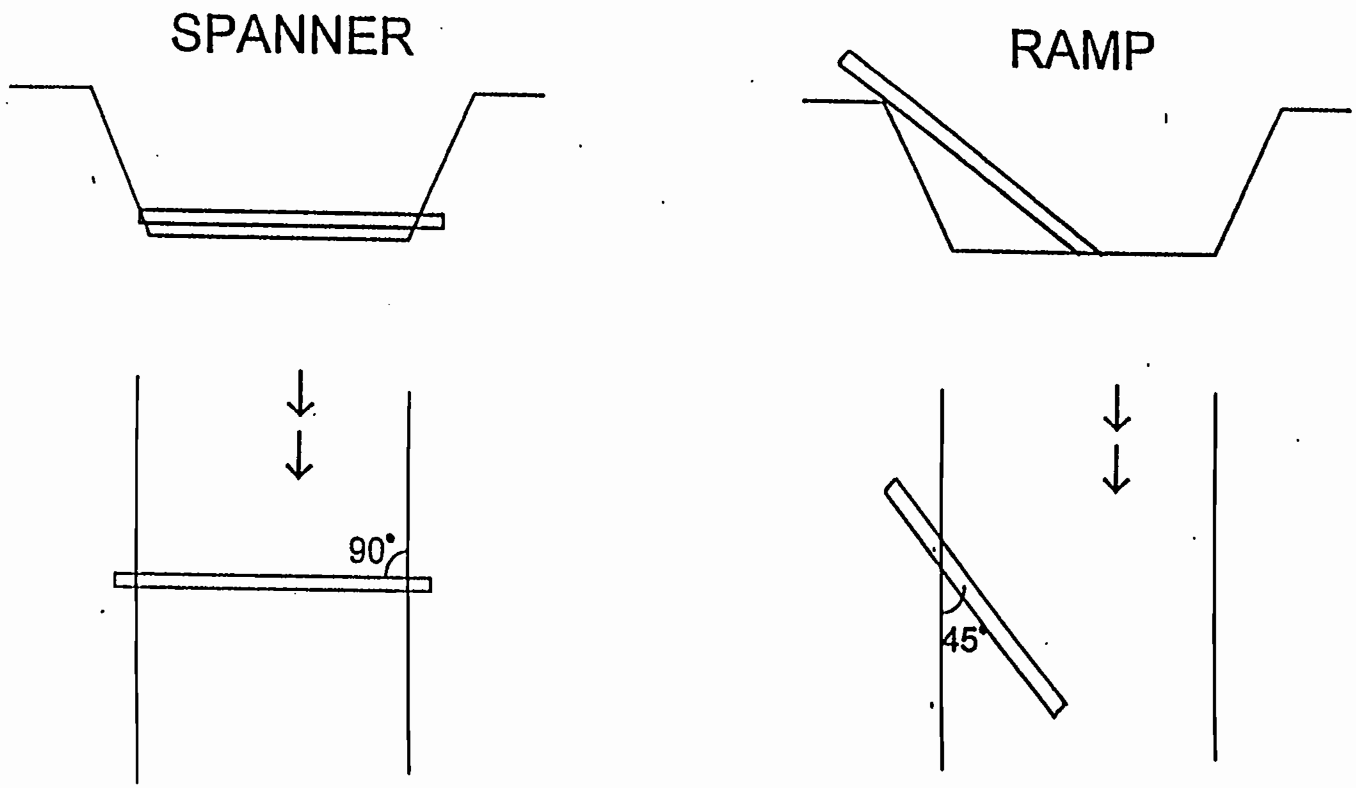

Figure 2. Original horizontal and vertical orientations of large wood placed in J-Line Creek and Preacher Creek as ramps and spanners in 1989.

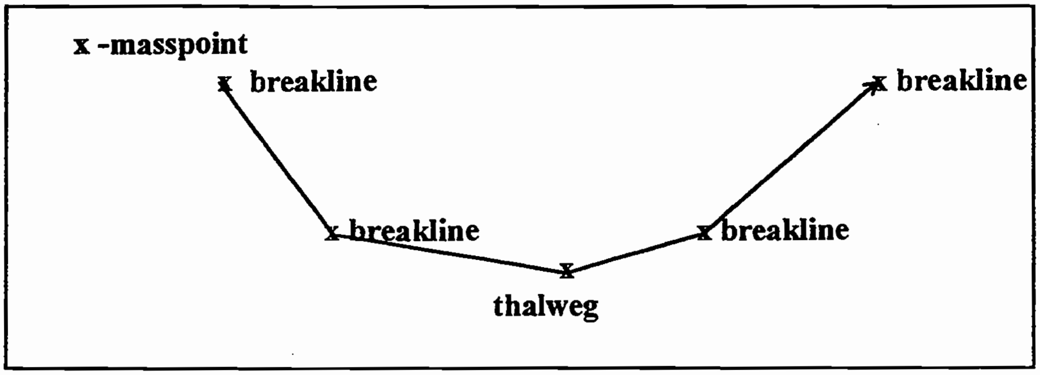

Figure 3. Example cross-section of stream channel surveyed for topographic maps including: thalweg points, breaklines and masspoints.

In 1989, 1990 and 1991, surveys were carried out using an optical theodolite and a stadia rod primarily in the area of influence around the tagged wood. Breaklines were formed at the first break in slope outside the active channel on the topographic maps. In 1993, 1995 and 1996, a total station electronic theodolite was used and surveys were carried out uniformly throughout the entire study reach. Breaklines were created at the first two continuous breaks in slope outside the active channel on the topographic maps (Figure 3). Over the five years in which the flow had a chance to interact with the tagged wood, a data point was established for each piece for each water year, resulting in 180 “piece years”of data.

The surveys of the stream channels were used to make high resolution topographic maps with software packages WILDSOFT, LISCAD and AUTOCAD (Leica, Heerbrugg, Switzerland) (Figure 4). These maps were used to obtain information on wood orientation and movement and the existence and size of residual pools observed in conjunction with tagged wood. Tagged wood that moved less than 0.6m (two feet) per year was considered stable.

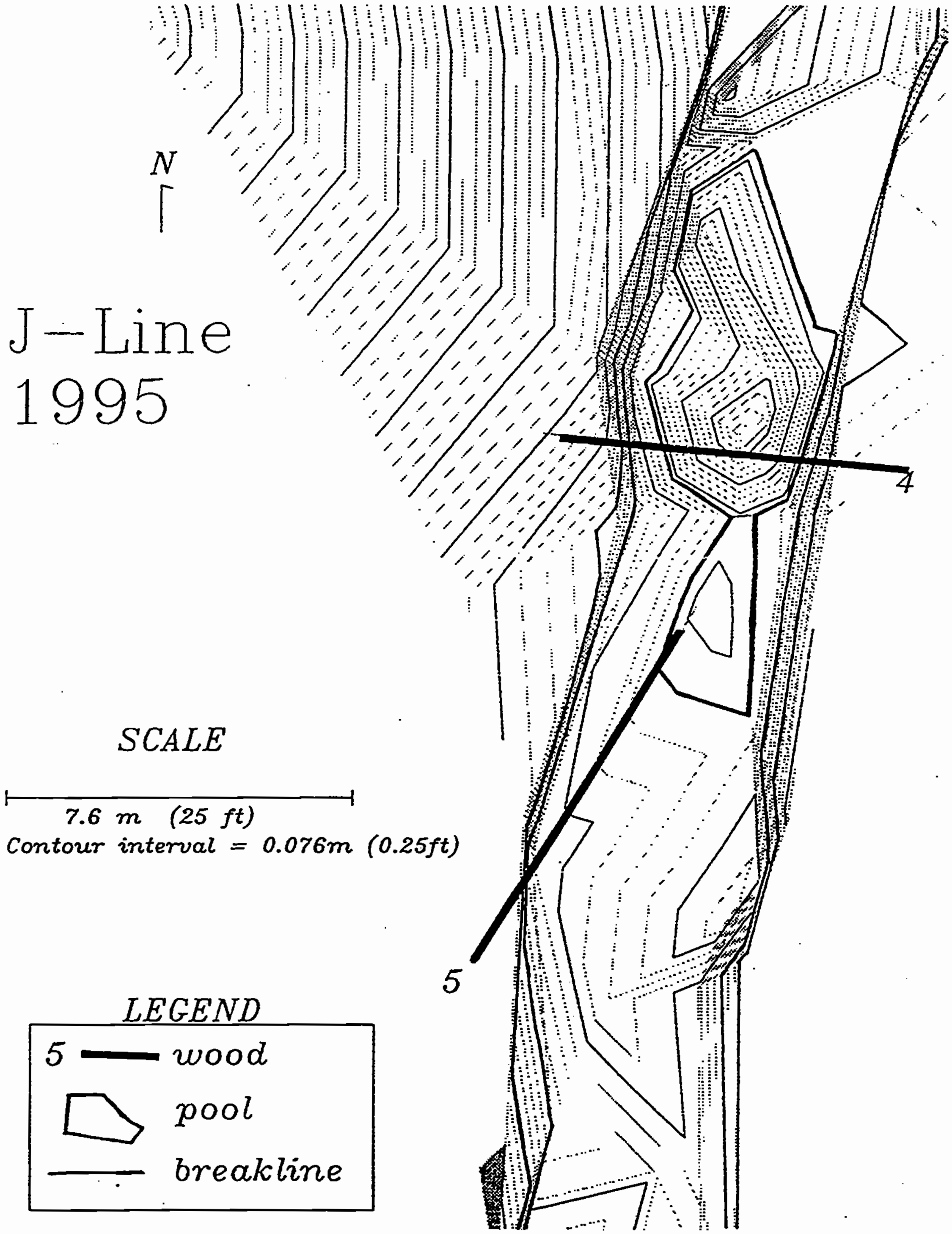

Figure 4. Topographic map of J-Line Creek in 1995, including tagged wood numbers four and five, top of bank and bankfull breaklines, and a residual pool.

Aquatic habitat inventories (Bisson et al., 1982) were conducted each year from 1989 to 1996 during summer low flow. These inventories included estimates of the type, length, average width, and average and maximum depths of each aquatic habitat unit. They also included estimates of the dominant substrate and riparian vegetative cover. In 1991, the boundaries between aquatic habitat units were included in the topographic survey and in the resulting topographic maps. If a pool unit was associated with a piece of tagged wood, this information was recorded. These aquatic habitat inventories were used to estimate the volume of individual pools and total pool volume in a reach. In aquatic habitat inventories parameters of *pools* were estimated as opposed to parameters of *residual pools*.

Residual pools

In the search for a pool identification method which was not dependent on stream stage, O'Neill and Abrahams (1984) developed a method which differentiated pools based on the elevation change since the last bedform. Residual pools are objective features of stream habitat which are not dependent on flow and can be defined as a longitudinal section of stream that contains water at zero discharge due to the damming effect of the riffle crest (Stack, 1989; Lisle 1986a, 1987). Residual pools as defined in this study, had to have a minimum depth of 0.15 m (0.5 ft), which meant they had to consist of at least two complete concentric contour lines (contour intervals of 0.076 m (0.25 ft)) on the topographic map made from the topographic surveys (Figure 4).

Dependent and independent variables

Residual pools were identified and delineated on topographic maps made using commercial software, LISCAD (Leica, Heerbrugg, Switzerland). Dependent variables included the volume, surface area and maximum depth of each residual pool and these parameters were also calculated using software, LISCAD (Table 1).

Many of the independent variables related to the orientation of the wood (Table 1). Collectively, they are referred to as wood orientation variables. Horizontal orientation (HOR) is the angle between the end of the piece of tagged wood projecting into the stream and the downstream bank. This is nominally 90 degrees for spanners and 45 degrees for ramps directly after placement of the tagged wood (Figure 5a). Vertical orientation (VOR) is the angle between the piece of tagged wood and the bottom of the streambed (Figure 5b). Spanners placed flush with the bottom of the bed have a vertical orientation close to zero if they have not been moved by high flows. Ramps have a vertical orientation of between five and fifteen degrees. Opening ratio (RATIO) is a ratio between the projected length of the piece of tagged wood and the channel width (Figure 5c). This ratio is one for spanners the first year directly after placement.

Table 1. Description, abbreviation and method of determination for all independent and dependent variables measured.

VARIABLE	ABBREV.	UNITS	METHOD OF DETERMINATION
Treatment Variables			
Diameter of wood	DIAM	cm	Measured midpoint
Horizontal orientation or angle between the tagged wood and downstream bank.	HOR	degrees	Measured angle off of topographic maps developed with LISCAD
Vertical orientation or angle between the tagged wood and the streambed	VOR	degrees	Determined angle from elevations of endpoints of tagged wood
Opening ratio or ratio of the opening between the tagged wood and opposite bank over stream width	RATIO	---	Distance between projected wood and opposite bank divided by stream width
Horizontal and vertical orientations and opening ratio of previous summer	HOR1 VOR1 RATIO1	degrees degrees -----	Same as above, but taken from previous summer's data
Site Index Variables			
Recurrence interval of the maximum instantaneous peak flow for the water year	Q	years	Frequency analysis of 13 years of record from U.S.G.S. gauging station at E. F. of Lobster Cr.
Local Substrate	SUB	---	Taken from aquatic habitat inventories.
Local Gradient	GRAD	percent	Calculated off longitudinal profiles developed from thalweg points.
Basin or Watershed	BASIN	----	J-Line vs. Preacher Cr.
Dependent Variables			
Residual pool volume	VOL	cubic meters	Defined by minimum depth of (0.5 ft)
Residual pool surface area	AREA	square meters	Volume surface area and depth calculated with
Residual pool maximum depth	DEP	meters	software LISCAD

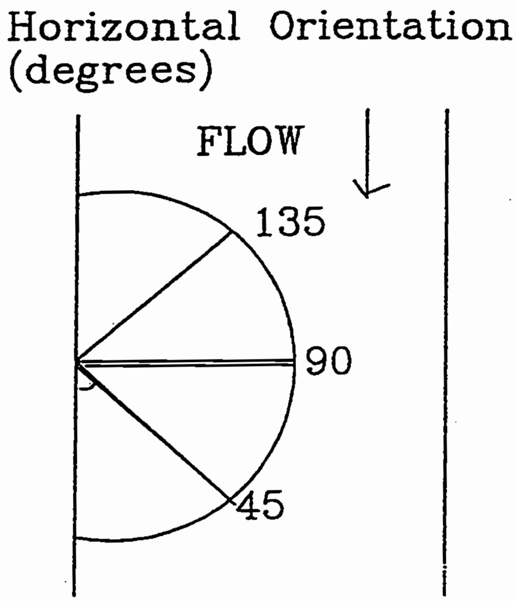

Figure 5a.

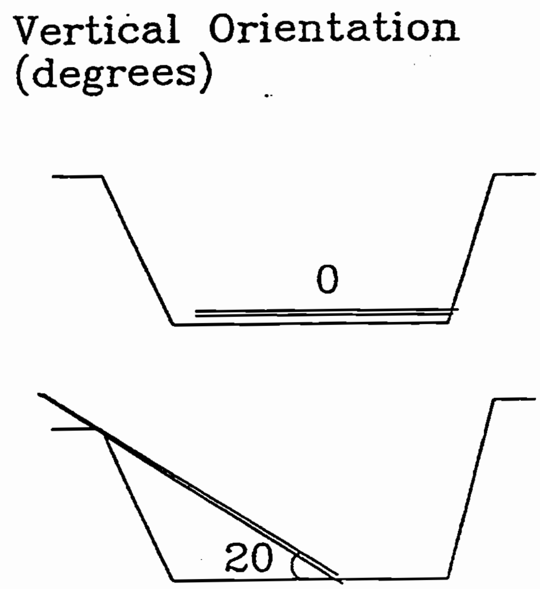

Figure 5b.

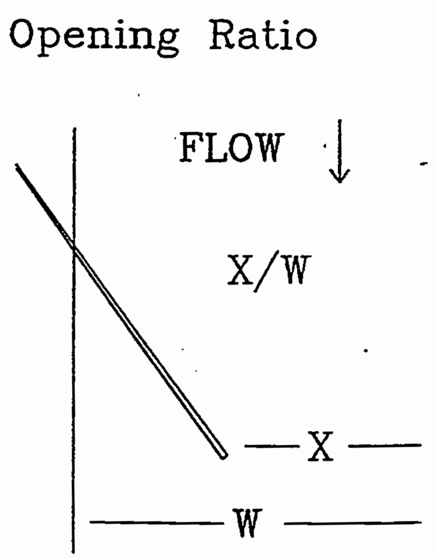

Figure 5c.

Figures 5a-5c. Measured orientations of tagged wood including horizontal orientation, vertical orientation, and opening ratio.

When the tagged wood moved as a result of winter high flows, it was unclear whether the orientation of the tagged wood previous to the winter flows or the orientation of the tagged wood after the winter flows would have a higher correlation with residual pool parameters during the following summer low flow. For this reason, tests for correlation between wood orientation variables and residual pool parameters collected at the same time were conducted as well as tests for correlation between residual pool parameters collected one summer and wood orientation variables collected the previous summer. Independent variables tested from the previous summer (as designated by a "1" attached to each variable name) include: horizontal opening ratio of the wood (RATIO1), horizontal orientation (HOR1), and vertical orientation (VOR1).

Local gradient of the streambed was determined from longitudinal profiles of the streambed. These profiles were created using thalweg points from the topographic maps. Aquatic habitat inventories gave the dominant substrate associated with each habitat unit with a piece of tagged wood.

Discharge was taken from data for the U.S.G.S. gauging station at the East Fork of Lobster Creek near Alsea, Oregon. At this station, discharge is measured from a 14.8 km^2 (5.7 mi^2) watershed. A peak flow frequency analysis was carried out on data from 1983 (when the gauging station was constructed) until 1996 (Appendix C). The return period of the maximum instantaneous peak flow for the water year was used in the analysis of residual pools during the same water year (the summer following the winter peak flow). The return period of the maximum instantaneous peak flows were assumed to be proportional for the gauging station and for both Preacher Creek and J-Line Creek.

RESULTS

Data inclusion

The data for this project is composed of 180 individual observations (i.e. 180 piece-years) of large, tagged wood pieces. Twelve of the initial 180 observations are not included in the analysis. High flow carried one piece of tagged wood downstream beyond the study reach in each stream. Piece number four in Preacher Creek (Appendix A) moved 58.8 m (193 ft) downstream of the experimental reach in Water Year (WY) 1996. Piece number one in J-Line Creek moved 16.2 m (53 ft) downstream of the experimental reach during WY 1995 and thus was removed from the data set in the summers of 1995 and 1996. Preacher Creek's piece number eighteen in 1989, and pieces numbered sixteen and eighteen in 1996 and J-Line's piece number fourteen in 1990 and piece number seventeen in 1996 were not included in the data set because they were outside of the stream channel established by the breaklines on the topographic map and thus were not associated with any aquatic habitat unit.

J-Line Creek had an active beaver dam in the summer of 1995. Piece numbers ten, eleven, twelve and thirteen were removed from the data set for that year because they were observed to be floating in a beaver pond and did not have fixed locations. Piece number ten in J-Line Creek was buried in 1996 and thus its location could not be obtained. The remaining 168 data points were used in the analysis.

Residual pools associated with tagged wood

Residual pool volume associated with the tagged wood increased and spacing decreased for both streams from 1989 to 1996. Spacing of residual pools, expressed as the average number of bankfull channel widths per pool (Stack and Beschta, 1989), decreased in J-Line Creek from 35 channel widths per pool in 1989 to 9.5 channel widths per pool in 1996. In Preacher Creek, the relative spacing of residual pools remained essentially unchanged at 14 channel widths per pool in 1989 and 13 channel widths per pool in 1996.

J-Line Creek's total residual pool volume increased by 2,500 percent, from 0.76 m^3 (26.8 ft^3) to 19.5 m^3 (690 ft^3) during the seven years while Preacher Creek's residual pool volume increased by 30 percent, from 6.45 m^3 (228 ft^3) to 8.38 m^3 (296 ft^3). The change in residual pool volume for both streams was the greatest between 1989 and 1990, the year directly following the placement of the tagged wood (Figure 6). Residual pool volume declined in both streams in WY 1990 and increased from WY 1991 to WY 1995. The only difference in trends between the two streams occurred in WY 1996, following a peak flow with a sixty-eight year recurrence interval (Appendix C). Residual pool volume in Preacher Creek increased from 6.72 m^3 to 8.38 m^3 (237 ft^2 to 296 ft^2), but decreased in J-Line Creek from 26.9 m^3 to 19.5m^3 (950 ft^2 to 689 ft^2). J-Line Creek had more than twice the residual pool volume associated with the tagged wood than Preacher Creek did during the summer of 1996. Average residual pool volume associated with the original treatments of 60 cm spanner, 40 cm spanner and 60 cm ramp were greater than average residual pool volume associated with the original treatments of 40 cm ramp, 20 cm ramp and 20 cm spanner (Figure 7).

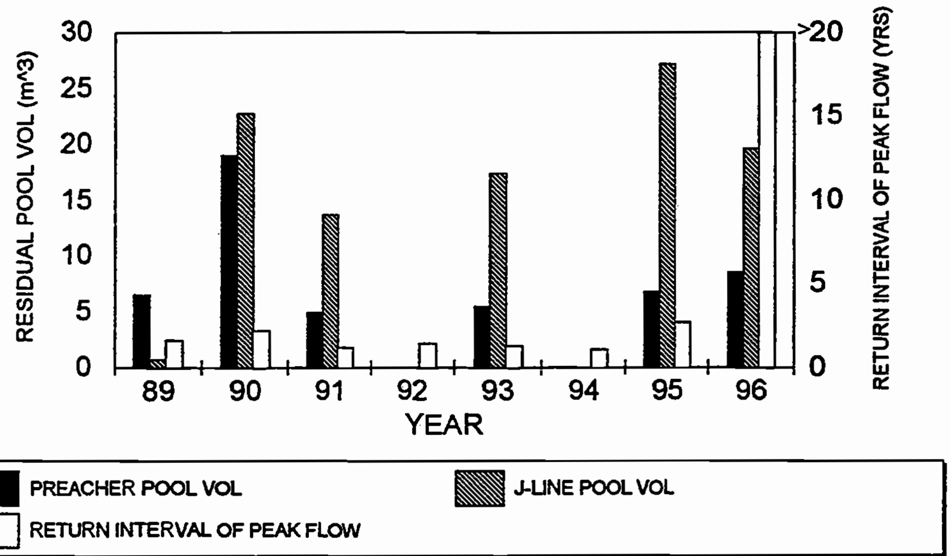

Figure 6. Residual pool volume associated with tagged wood in J-Line Creek and Preacher Creek with corresponding recurrence intervals of annual peak flows from 1989-1996 (residual pool volume not measured in 1992 and 1994).

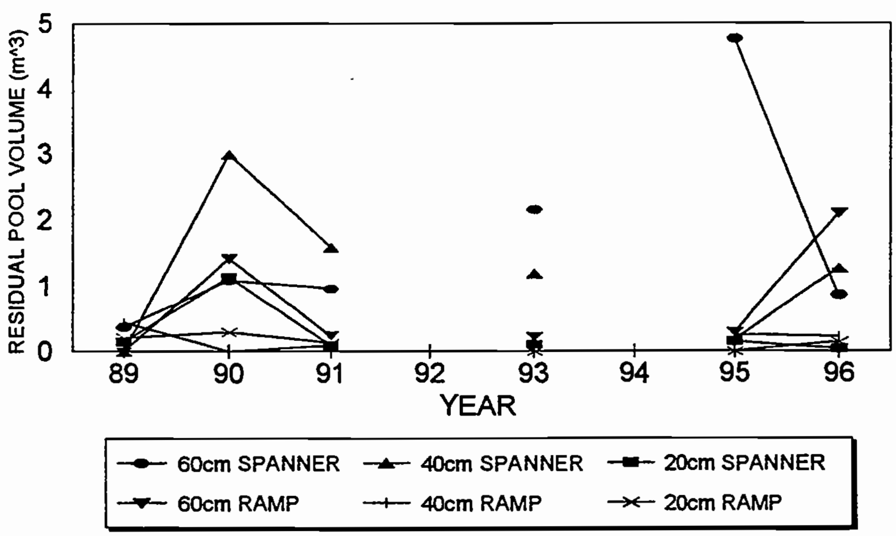

Figure 7. Average residual pool volume associated with diameter class and original orientation of tagged wood in Preacher Creek and J-Line Creek from 1989-1996 (residual pool volumes not measured in 1992 and 1994.)

The averages and standard deviations of the change in residual pool volume from 1989 to 1996 associated with each treatment are also compared (Figure 8). The greatest average increase in residual pool volume is associated with 60 cm ramps which also have the greatest standard deviation. An average decrease in residual pool volume from 1989-1996 occurred with the original treatments of 40 cm ramps, 20 cm ramps and 20 cm spanners.

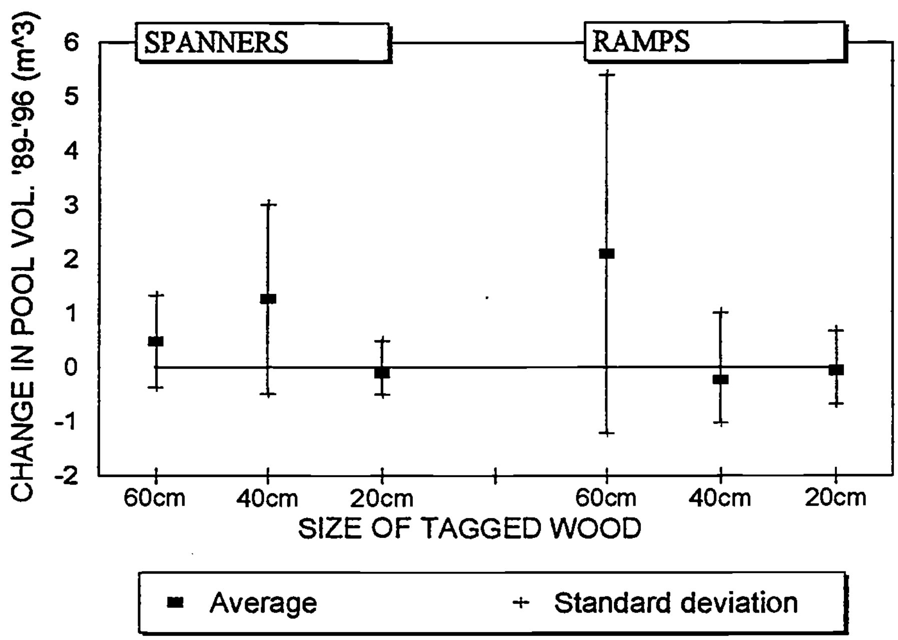

Figure 8. Average change in residual pool volume from 1989 to 1996 associated with each of the treatment classes of tagged wood in J-Line Creek and Preacher Creek.

Longitudinal profiles

Longitudinal profiles of the channel thalwegs were developed for both streams each year they were surveyed (Figures 9 and 10). Profile points are indicated at each break in slope rather than at fixed distances. The profiles from 1989-1991 are most accurate directly adjacent to the pieces of tagged wood because topographic survey points were not collected as intensively in habitat units without tagged wood during these years. Longitudinal profiles from 1993-1996 represent the entire channel because topographic survey points were collected evenly throughout the stream reach. These differences should be kept in mind when examining changes in the profiles from 1989-1996 (Figures 9 and 10). The profiles in 1996 are more varied and are longer over the entire reach which indicates there is more meandering of the thalweg in both streams six years after the treatment than there was in 1989. Longitudinal profiles were used to determine local gradient of the streambed around each piece of tagged wood.

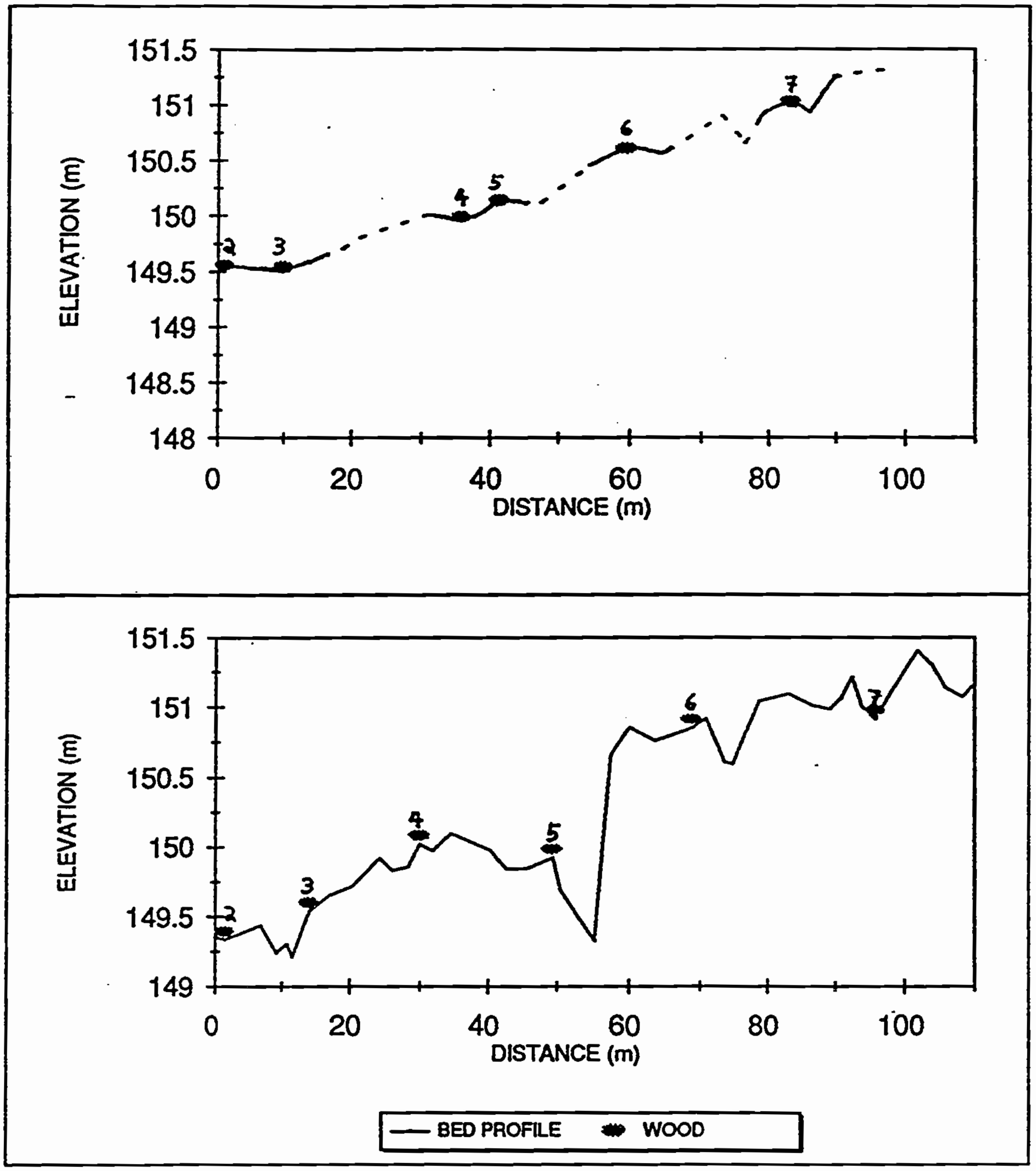

Figure 9. Longitudinal profiles of thalweg elevations on the lower section of J-Line Creek in 1989 (upper) and in 1996 (lower). Sections of the channel which were not surveyed in 1989 are indicated by a dotted line.

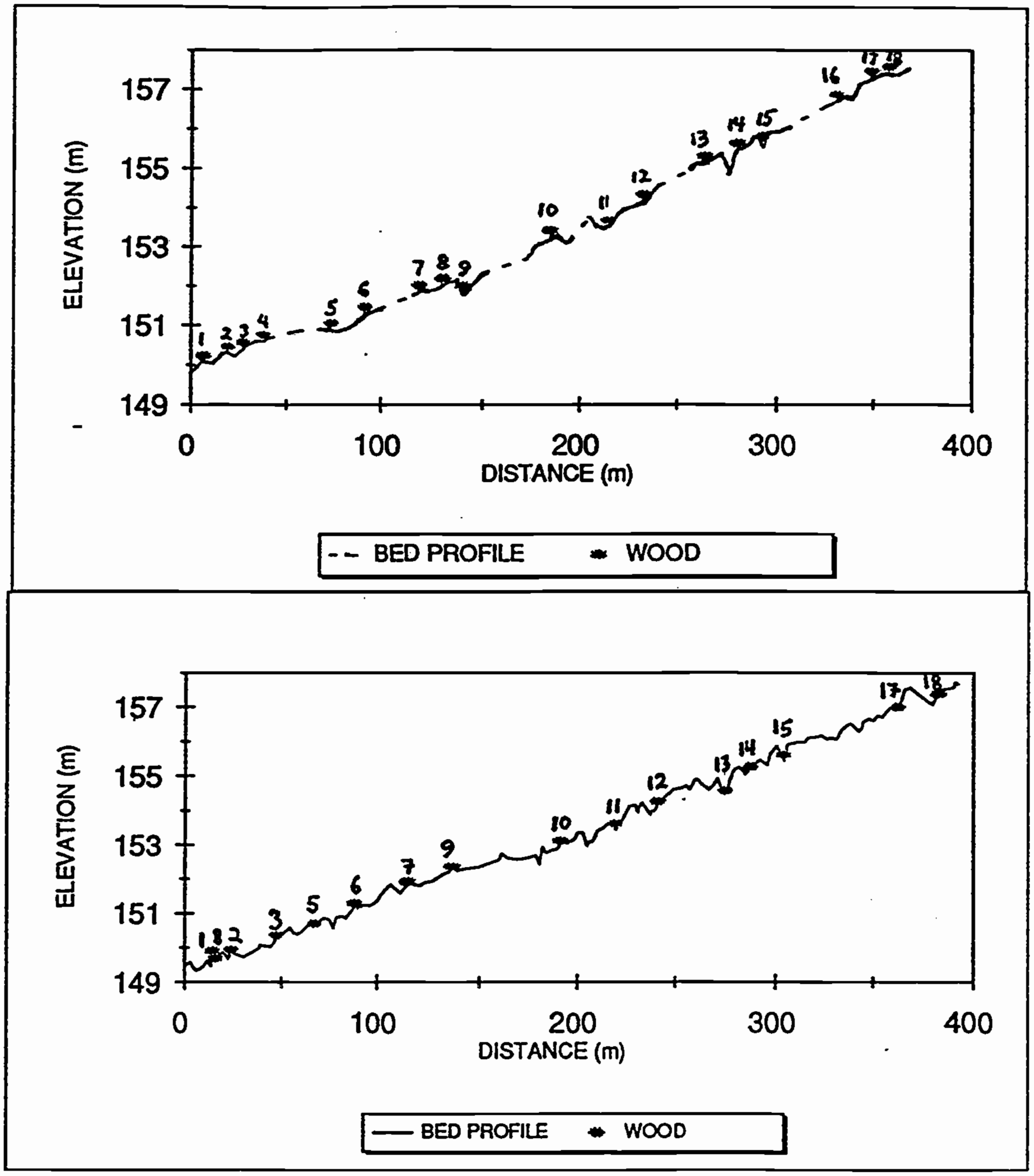

Figure 10. Longitudinal profiles of the thalweg elevations on Preacher Creek in 1989 (upper) and 1996 (lower). Sections of the channel which were not surveyed in 1989 are indicated with a dotted line.

Wood movement

The existence and volume of residual pools did not depend on whether a piece of tagged wood was stable or had moved during the previous winter. There was not a statistically significant difference in the means of residual pool volumes associated with stable pieces of tagged wood versus residual pool volumes associated with unstable pieces of tagged wood ($p < .05$, Standard Error = 2.1, $n = 168$).

Tagged wood movement was more closely associated with the recurrence interval of the maximum instantaneous peak flow from the previous winter than with the diameter classification and original orientation of the tagged wood (Figure 11). One exception to this is in WY 1990 in which the maximum instantaneous peak flow had a recurrence interval of 2.18 years, but tagged wood moved relatively far because of adjustment after initial placement. Although 60 cm diameter wood was more stable than 40 cm diameter wood and 20 cm diameter wood in WY 1990, this does not hold true for all years. The original orientations of ramp versus spanner does not predict tagged wood movement because orientation classifications only accurately describe tagged wood in 1989.

From 1989 to 1996, 20 cm diameter wood moved farther than 60 cm diameter wood (Figure 12). The most stable combination of size and orientation was the 60 cm ramp. The flow did not move 60 cm pieces as much as it did 20 cm and 40 cm pieces because they are larger. Ramps moved less than spanners because they were already oriented downstream. Forty-six percent of the tagged wood pieces moved less than 0.61 m (2 ft) per year and were considered stable (Figure 13).

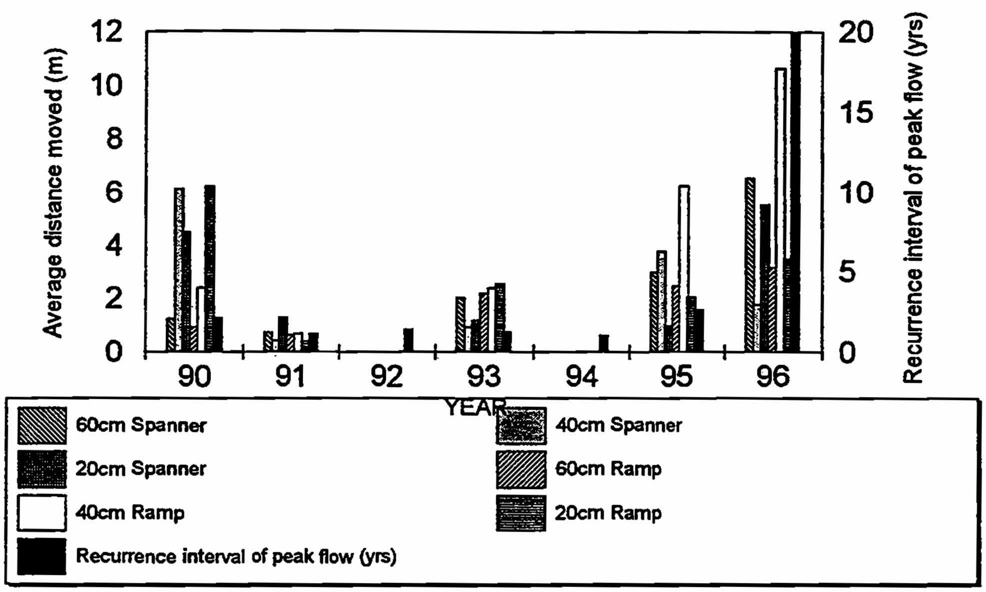

Figure 11. Annual movement of tagged wood and recurrence intervals of peak flows in J-Line Creek and Preacher Creek averaged by treatment from WY 1990 through WY 1996 (measurements not taken in 1992 and 1994).

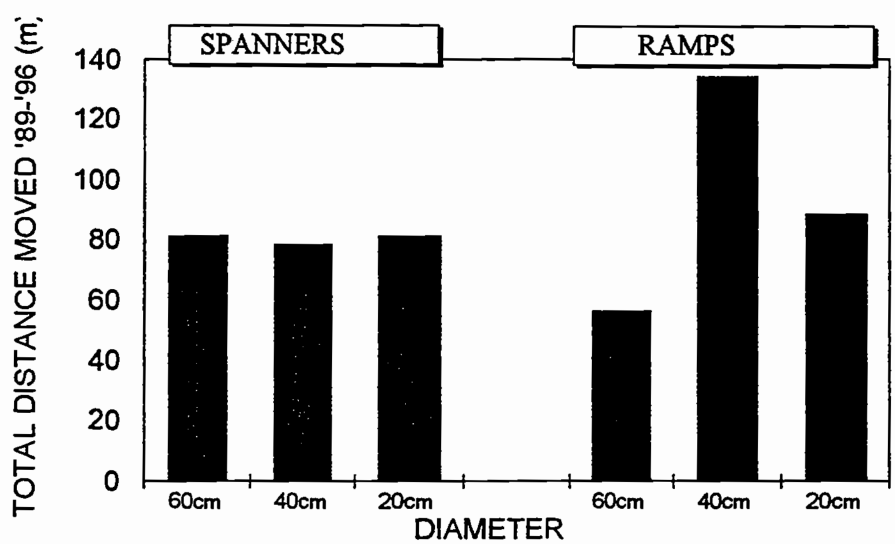

Figure 12. Total distance moved by tagged wood in J-Line Creek and Preacher Creek from 1989-1996 based on diameter and original orientation of wood.

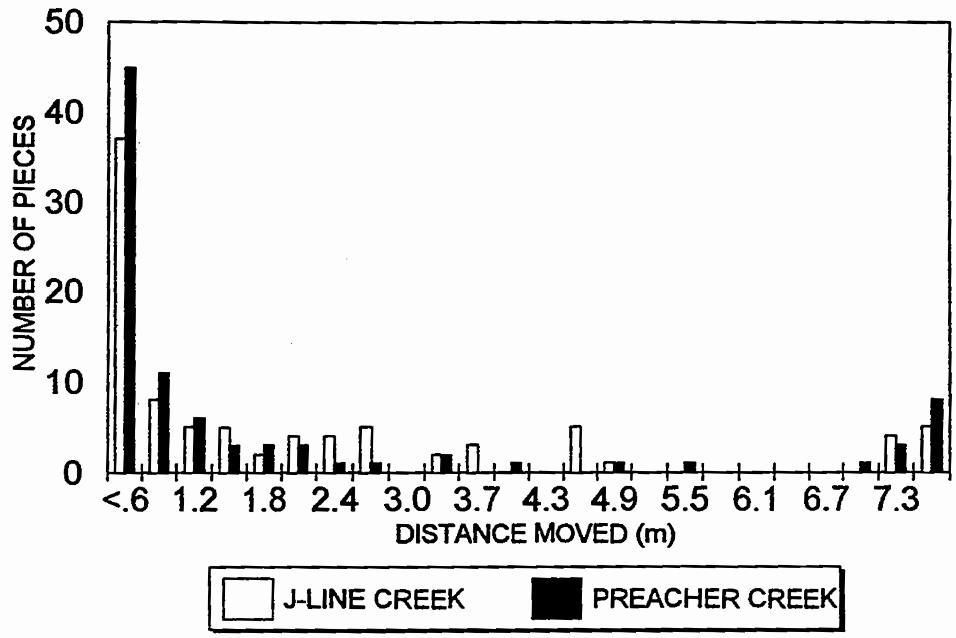

Figure 13. Frequency distribution of annual movement of tagged wood in J-Line Creek and Preacher Creek from 1989-1996 showing high percentage of stable pieces of tagged wood (movement is less than 0.61 m (2 ft)).

In 1989, half of the horizontal orientations were clustered around 30 degrees and were ramps and half were clustered around 90 degrees and were spanners as a result of project design. The tagged wood shifted away from a horizontal orientation of 90 degrees over time (Figure 14). Twenty-five to thirty-five percent of the tagged wood remained at a horizontal orientation of 90 degrees from 1990-1995, but only thirteen percent of the tagged wood remained at 90 degrees after the sixty-eight year recurrence interval peak flow of 1996.

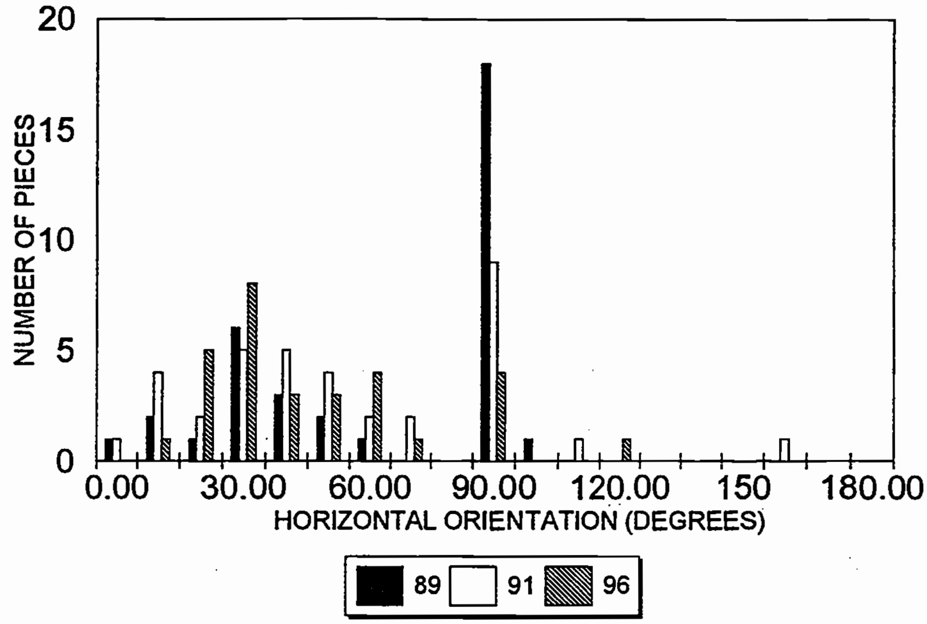

Figure 14. Frequency distribution of horizontal orientation of tagged wood in J-Line Creek and Preacher Creek in 1989, 1991 and 1996.

Analysis

Analysis of the volume, surface area and maximum depth of residual pools was carried out for years in which the tagged wood was in place, and had interacted with at least one winter high flow (1990, 1991, 1993, 1995 and 1996). One-way analysis of variance and simple and multiple regression were used to evaluate the factors which influence the dependent variables, residual pool volume, maximum depth, and surface area. Independent variables tested in multiple linear regressions include vertical and horizontal orientations of the tagged wood, horizontal opening ratio, tagged wood diameter, the difference between response in residual pool volume in J-Line Creek versus the response in Preacher Creek, the return period of the maximum instantaneous peak flow for the water year, local substrate, and the local gradient of the streambed.

Interaction terms between the diameter class of the tagged wood and wood orientation variables and between the return period of the maximum instantaneous peak flow and wood orientation variables also entered the multiple regression analysis. All analyses were carried out using Statgraphics 5.0 and differences in variables were considered to be significant at $p < 0.05$.

None of the dependent variables have normal distributions (Figure 15). This is due to the fact that each year about half of the tagged wood pieces were not associated with a residual pool. This problem can be partially explained by the resolution of the topographic maps used and the definition of a residual pool. It is also due, however, to the many tagged wood pieces which did not form residual pools. When a log transformation of the dependent variables is undertaken, there is no value assigned to the log of zero. This technique was not used because only about half of the values of the dependent variables would have been available for analysis.

If a small number (0.1), is substituted for all of the dependent variables which are equal to zero and a log transformation of these values is taken, the result is two distinct groups of data, one group of data representing aquatic habitat units where residual pools did form and one group of data representing aquatic habitat units where residual pools did not form. Neither group of data is represented by the line of best fit (Figure 16). The analysis which best explained the data set left values of the dependent variables untransformed and acknowledged the assumptions which were violated in the statistical analysis (nonnormality and non-constant variance). Thus, the statistical results must be examined critically.

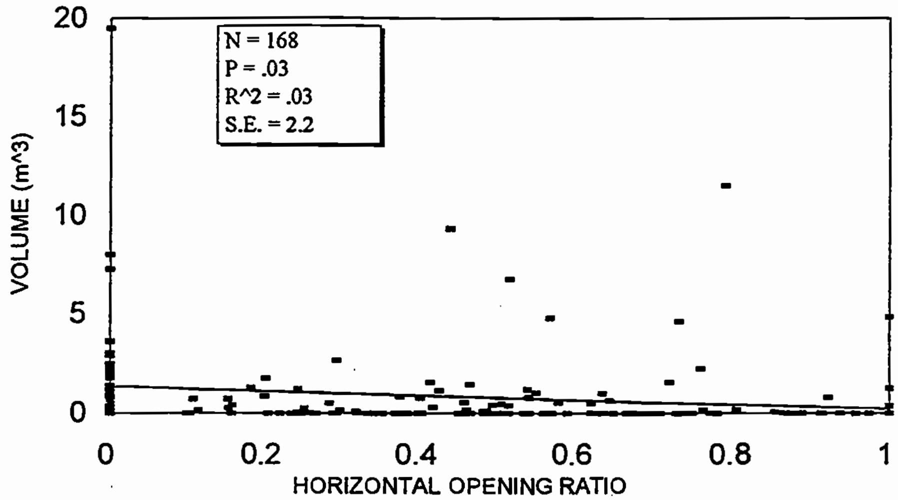

Figure 15. Regression of residual pool volume on the horizontal opening ratio of the tagged wood in J-Line Creek and Preacher Creek showing nonnormality of the dependent variable.

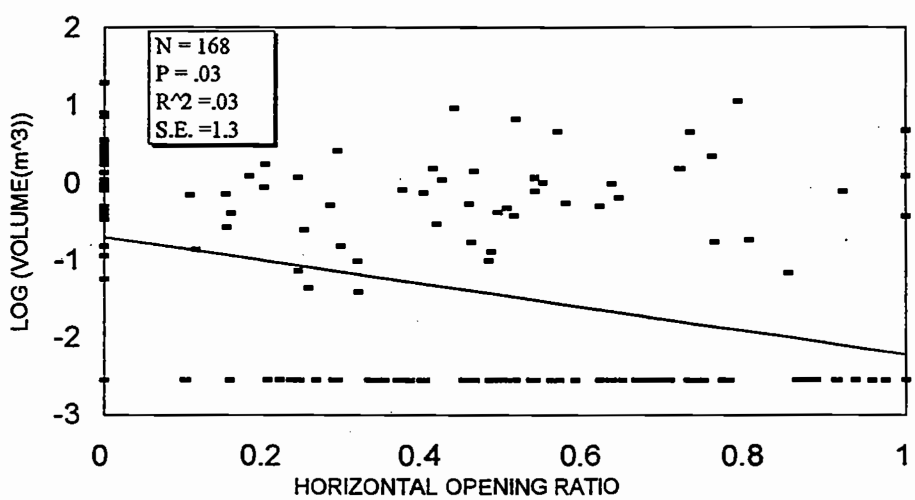

Figure 16. Regression of the natural logarithm of residual pool volume on the horizontal opening ratio of the tagged wood in J-Line Creek and Preacher Creek.

Initial analysis of the data set consisted of a multiple linear regression for each stream, each year to determine if there was a trend over time with regards to the association of residual pool volume with any of the independent variables. There was not a trend in the significance of any of the independent variables in predicting residual pool parameters in either creek over the five years of study. In J-Line Creek, none of the independent variables correlated with residual pool volume during any of the years. In Preacher Creek, none of the variables correlated with residual pool volume in 1990 and 1991, but the diameter classification was positively correlated with residual pool volume in 1993 ($n = 18$, $p < 0.05$ and $R^2 = 0.15$). The opening ratio was negatively correlated with residual pool volume in 1995 ($n = 16$, $p < 0.05$ and $R^2 = 0.32$) and the diameter classification was positively correlated with residual pool volume in 1996 ($n = 18$, $p < 0.05$ and $R^2 = 0.47$).

Because data sets composed of data from only one stream and water year were small ($n = 18$) and there was no clear trend in the significance of the independent variables during the five years of study, data was combined for all years in the rest of the analyses. Analysis of variance tests were performed on diameter, basin, substrate and the recurrence interval of the peak flow. Diameter was positively correlated with residual pool volume, pool depth and pool surface area (Table 2). Significantly greater residual pool volumes, surface areas and maximum depths were associated with 60 cm pieces than with 20 cm pieces as hypothesized (Figure 17).

Table 2. Analysis of Variance for independent variables including: local substrate associated with tagged wood, basin, diameter of tagged wood and recurrence interval of maximum instantaneous peak flow on dependent variables: residual pool volume, maximum depth and surface area. Bold letters indicate statistical significance.

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	P-VALUE	SIGNIFICANT DIFFERENCE BETWEEN
VOLUME	**DIAMETER**	**0.02**	**20 cm and 60 cm diameters**
VOLUME	**BASIN**	**0.03**	**J-Line and Preacher**
VOLUME	Q	>0.1	
VOLUME	SUBSTRATE	>0.1	
MAX DEPTH	**DIAMETER**	**<0.01**	**20 cm and 60 cm diameters**
MAX DEPTH	**SUBSTRATE**	**<0.01**	**cobble and gravel cobble and large gravel**
MAX DEPTH	BASIN	0.09	
MAX DEPTH	Q	>0.1	
AREA	**DIAMETER**	**<0.01**	**20 cm and 60 cm diameters**
AREA	**SUBSTRATE**	**0.05**	**cobble and gravel cobble and large gravel**
AREA	BASIN	0.09	
AREA	Q	>0.1	

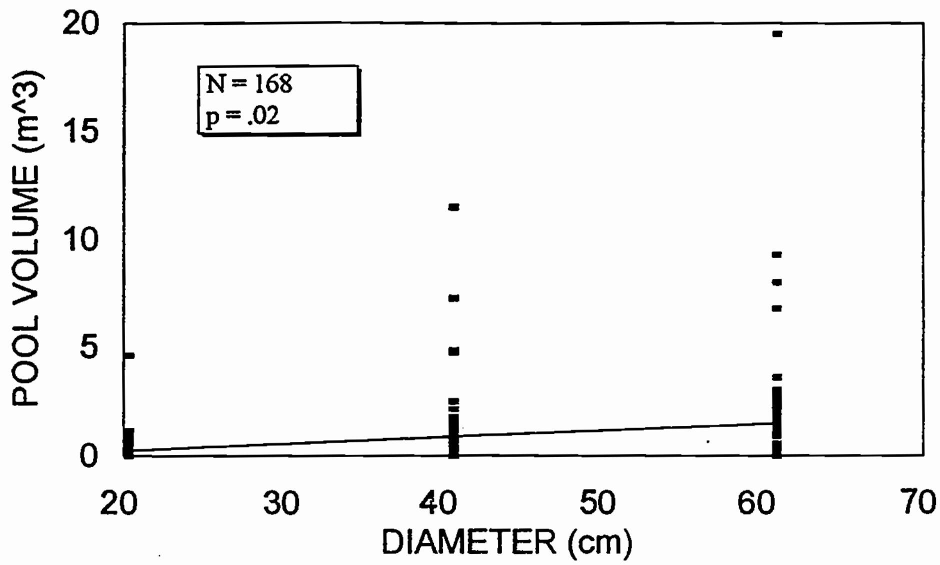

Figure 17. Diameter classification of tagged wood placed in two streams in the Oregon Coast Range as a predictor of residual pool volume due to scour.

Substrate type was tested for correlation with residual pool parameters. Aquatic habitat units which had a cobble bed had significantly smaller residual pool maximum depths and smaller residual pool surface areas than aquatic habitat units which had either gravel or large gravel substrate (Table 2). The size of the substrate during the previous summer did not correlate with residual pool volume, maximum depth or surface area. Local gradient was not statistically significant in predicting residual pool parameters in any of the tests.

The recurrence interval of the maximum instantaneous peak flow did not correlate with residual pool volumes, maximum depths or surface areas (Figure 18). This is contrary to the hypothesis that residual pool parameters will increase with larger peak flows.

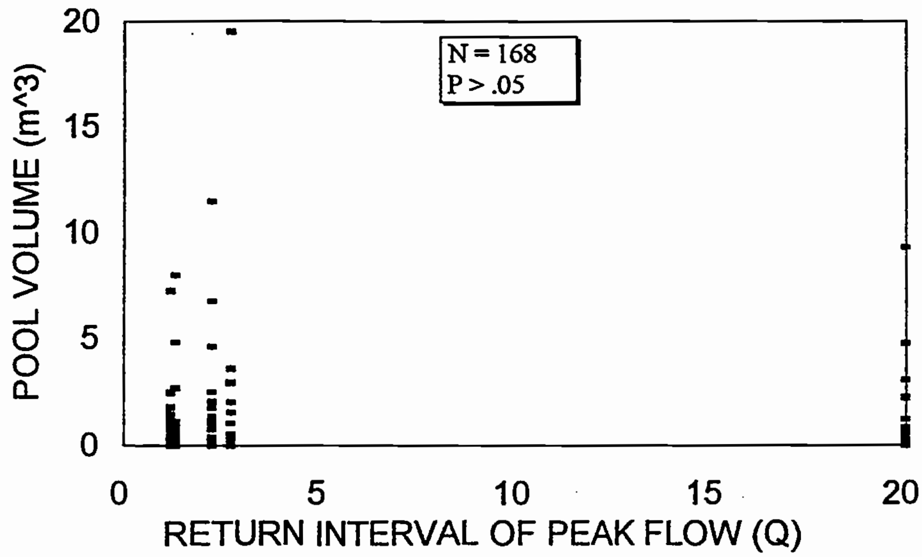

Figure 18. Recurrence interval of the peak flow as a predictor of residual pool volume associated with tagged wood in two coastal Oregon streams.

An analysis of variance was conducted to determine if the two streams had significantly different residual pool volumes. Residual pool volume was significantly greater in J-Line Creek than in Preacher Creek ($p = 0.03$) (Table 2). Because of this difference, analysis of variance and regression tests were performed on the streams as separate data sets as well as on the combined data set.

Although many of the wood orientation variables in the data sets for both the individual streams and combined data were significantly correlated with residual pool parameters ($p < 0.05$) in linear regression tests, only a small amount of the variance in residual pool volume, surface area, or maximum depth was explained. In J-Line Creek, the wood diameter classification and the horizontal orientation of the tagged wood during the previous summer were positively correlated with residual pool volume while vertical orientation, vertical orientation during the previous summer, and opening ratio of the tagged wood during the previous summer were all negatively correlated with residual pool volume ($P < 0.05$ in all cases) (Table 3).

In Preacher Creek, the horizontal orientation of the tagged wood during the previous summer was positively correlated with residual pool volume and explained fifteen percent of the variance, the most for any one, single variable in the analyses (Figure 19). The horizontal orientation of the tagged wood, the opening ratio, the opening ratio of the tagged wood during the previous summer, diameter class and local substrate were also significantly correlated with residual pool volume in Preacher Creek ($p < 0.01$) (Table 3).

In analyses of the data of both streams combined, all wood orientation variables, except the horizontal orientation of the tagged wood correlated with residual pool volume (Table 3). An example showing the amount of scatter around the line of best fit is the vertical orientation of the tagged wood (Figure 20) as a predictor of residual pool volume.

Table 3. Wood orientation variables significantly associated with residual pool volume in individual tests of linear regression.

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	P-VALUE	STANDARD ERROR	R^2	n
J-Line Creek					
VOLUME	**VOR1**	**<.01**	**2.9**	**.11**	**81**
VOLUME	**VOR**	**.02**	**2.9**	**.06**	**81**
VOLUME	**HOR1**	**.03**	**3.0**	**.06**	**81**
VOLUME	**RATIO1**	**.03**	**3.0**	**.06**	**81**
VOLUME	RATIO	>.05	3.0	.03	81
VOLUME	HOR	>.05	3.0	.004	81
Preacher Creek					
VOLUME	**HOR1**	**<.01**	**.89**	**.15**	**87**
VOLUME	**HOR**	**<.01**	**.92**	**.09**	**87**
VOLUME	**RATIO**	**.02**	**.95**	**.06**	**87**
VOLUME	**RATIO1**	**.03**	**.95**	**.05**	**87**
VOLUME	VOR	<.05	.95	.03	87
VOLUME	VOR1	<.05	.95	.02	87
J-Line Creek and Preacher Creek					
VOLUME	**HOR1**	**<.01**	**2.2**	**.05**	**168**
VOLUME	**VOR1**	**<.01**	**2.2**	**.05**	**168**
VOLUME	**RATIO1**	**<.01**	**2.2**	**.04**	**168**
VOLUME	**VOR**	**.02**	**2.2**	**.03**	**168**
VOLUME	**RATIO**	**.03**	**2.2**	**.03**	**168**
VOLUME	HOR	.2	2.2	.01	168

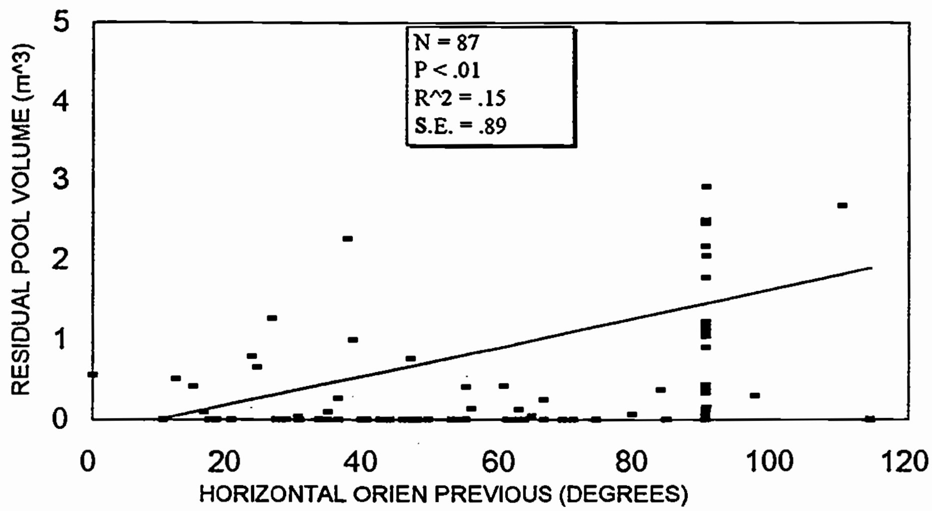

Figure 19. The horizontal orientation of the tagged wood the summer previous to the summer the residual pools were measured as a predictor of residual pool volume in Preacher Creek from 1989-1996.

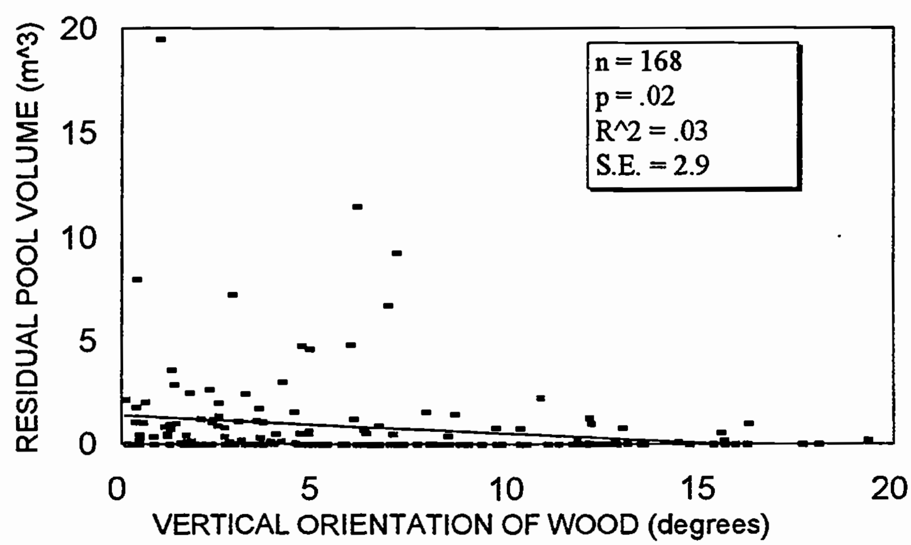

Figure 20. The vertical orientation of the tagged wood as a predictor of residual pool volume in Preacher Creek and J-Line Creek from 1989-1996

Multiple linear regression tests were also run on the combined data set with residual pool maximum depth and surface area (Table 4) as the dependent variables. Very similar results were found as with residual pool volume. Horizontal orientation was the only wood orientation variable which was not significantly associated with residual pool parameters in any of the tests ($p > 0.05$), but none of the variables explained more than ten percent of the variance in residual pool surface area or maximum depth. Horizontal orientation of the tagged wood during the previous summer explained more of the variance in residual pool surface area than any other independent variable (Figure 21).

Table 4. Wood orientation variables as predictors of residual pool characteristics for J-Line Creek and Preacher Creek combined data set.

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	P-VALUE	STANDARD ERROR	R^2
Residual pool depth				
DEPTH	**RATIO1**	**<.01**	**.24**	**.1**
DEPTH	**VOR1**	**<.01**	**.24**	**.1**
DEPTH	**RATIO**	**<.01**	**.24**	**.1**
DEPTH	**HOR1**	**<.01**	**.25**	**.09**
DEPTH	**VOR**	**<.01**	**.25**	**.07**
DEPTH	HOR	.05	.25	.02
Residual pool surface area				
AREA	**HOR1**	**<.01**	**6.0**	**.09**
AREA	**VOR1**	**<.01**	**6.0**	**.08**
AREA	**RATIO1**	**<.01**	**6.1**	**.08**
AREA	**RATIO**	**<.01**	**6.3**	**.07**
AREA	**VOR**	**<.01**	**6.3**	**.05**
AREA	HOR	.05	6.5	.02

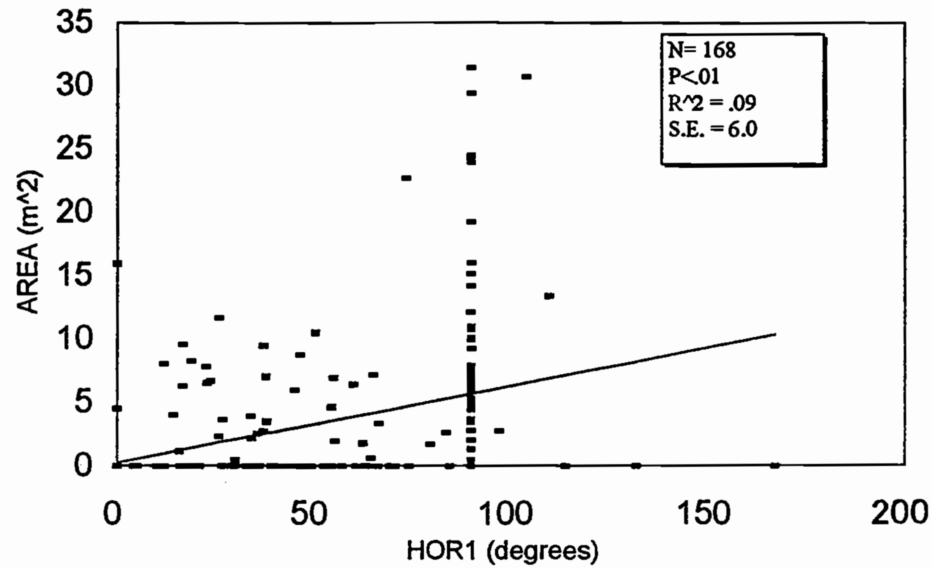

Figure 21. The horizontal orientation of the tagged wood during the previous summer as a predictor of the surface area of residual pools in J-Line Creek and Preacher Creek

Multiple stepwise regression was performed on the streams separately as well as with the combined data. An interaction term between the diameter classification and the horizontal orientation of the tagged wood during the previous summer was the significant variable to enter the combined streams regression model explaining residual pool volume (Table 5). Diameter times the horizontal orientation of the tagged piece during the previous summer explained twelve percent of the variability. The significance of diameter times the horizontal orientation of the previous summer supports the hypothesis that as piece size and horizontal orientation increase, residual pool volume will also increase. Because of the significant difference between J-Line Creek and Preacher Creek in predicting residual pool parameters, models were also created of the two streams separately (Table 5).

Table 5. Models to predict residual pool volume, surface area and maximum depth chosen with stepwise forward multiple regression.

DEP VAR	MODEL	P-VALUE	STAN ERROR	R^2
Data from both streams combined				
VOLUME	**-.19+(.0005*DIAM*HOR1)**	**<0.01**	**2.1**	**.12**
AREA	**2.2+(.001*DIAM*HOR1)**	**<0.01**	**5.7**	**.19**
DEPTH	**.039+(.0003*DIAM*HOR1)-(.02*VOR1)**	**<0.01**	**.13**	**.22**
J-Line Creek				
VOLUME	**-.46+(.0007*DIAM*HOR1)**	**<0.01**	**2.7**	**.16**
AREA	**3.5-(.37*VOR1)+(.002*DIAM*HOR1)**	**<0.01**	**6.3**	**.26**
DEPTH	**0.11-(.01*VOR1)+(.00004*DIAM*HOR1)**	**<0.01**	**.16**	**.26**
Preacher Creek				
VOLUME	**-.25+(.0003*DIAM*HOR1)**	**<0.01**	**.84**	**.28**
AREA	**-.23+(.0014*DIAM*HOR1)**	**<0.01**	**4.5**	**.23**
DEPTH	**-.09+(.0002*DIAM*HOR)**	**<0.01**	**12**	**.04**

Individual models predicted residual pool volume better ($R^2 = 0.28$ and 0.16 for Preacher Creek and J-line Creek, respectively) than the combined model ($R^2 = 0.12$) (Table 5).

Multiple regressions were also performed with residual pool surface area and depth as dependent variables. The resulting models were similar to those for residual pool volume (Table 5). The interaction between the diameter classification of the tagged wood and the horizontal orientation of the tagged wood during the previous summer significantly predicted residual pool maximum depth and surface area. The watersheds showed significantly different values for residual pool surface areas and maximum depths as they did for residual pool volumes.

Matching habitat unit pools with topographic map residual pools

A regression was performed between aquatic habitat inventory pool volume and residual pool volume to determine if aquatic habitat inventories could be used as an index of residual pool volume. These regressions were performed with total reach level information (giving six data points, from two streams and three years of data) and with individual pool information. Only pools and residual pools which were found in units with tagged wood were used for the regression because these were the only units which could be matched between the two types of surveys. Since aquatic habitat unit boundaries had been surveyed and included in the topographic maps in 1991, data from 1991 was used to check if the pools in the two types of surveys were matched correctly

There was a statistically significant relationship between the pools estimated with the aquatic habitat inventories and the actual residual pool volume ($p < 0.01$). The pools in the habitat unit inventories explained forty percent of the variance in residual pool volume (Figure 22). At the individual unit level, the aquatic habitat inventories underpredicted pool volume. At the reach level, there was also a significant relationship between total aquatic habitat inventory estimations of pool volume and calculations of residual pool volume from topographic maps (Figure 23). Aquatic habitat inventory pool volume predicted ninety-six percent of the variance in residual pool volume.

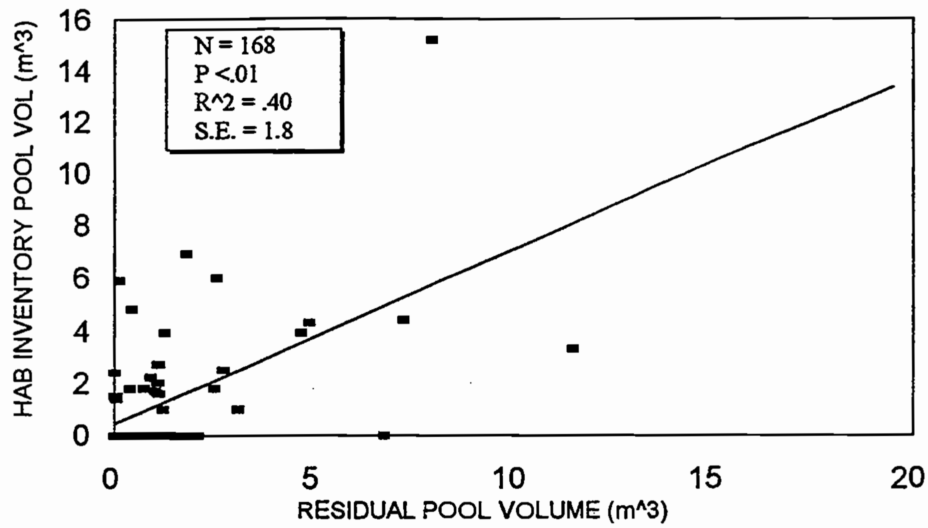

Figure 22. Individual residual pool volumes as predictors of individual pool volumes estimated with aquatic habitat inventories.

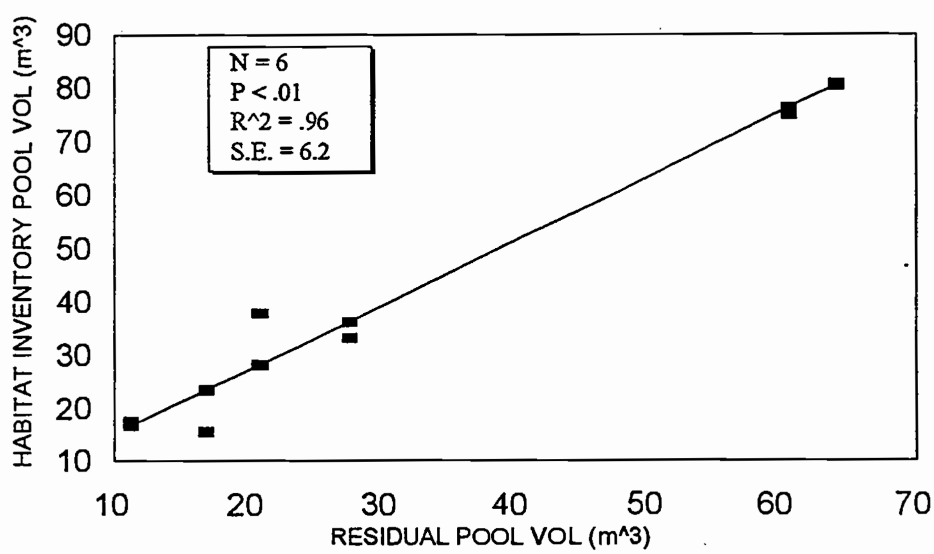

Figure 23. The sum of the residual pool volumes in a reach as a predictor of the sum of the pool volumes estimated in a reach with aquatic habitat inventories.

Average depth as a function of maximum depth

A common method of calculating average pool depth is to divide the pool volume by the pool surface area. Volume, surface area and average depth are all difficult to estimate accurately in the field so it would be useful to determine average depth as a function of maximum depth.

The regression analysis of dependent variable average depth (volume divided by surface area as measured off of topographic maps) on independent variable maximum depth (also determined from topographic maps) showed the two to be highly correlated (p <0.01) (Figure 24). The model is; **AVERAGE DEPTH (m) = .002 + (MAX DEPTH (m) * .66).** It has an $R^2 = 0.98$, an n=168, and a standard error of 0.09. This model could easily be used to estimate average depth when only maximum depth is measured. Individual models may have to be developed for each stream.

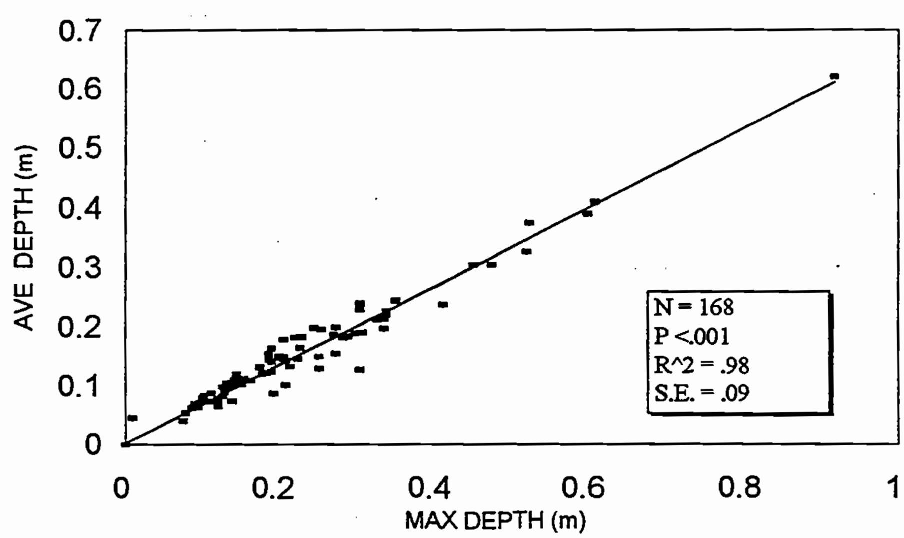

Figure 24. Average pool depth as a function of maximum pool depth.

DISCUSSION AND CONCLUSIONS

Large wood placed in streams can increase local scour in the short term, but the ability to predict when and where this scour occurs is limited. In two, second-order streams in the Oregon Coast Range, J-Line Creek and Preacher Creek, only twelve percent of the variability in residual pool volume, twenty-two percent of the variability in residual pool maximum depth and nineteen percent of the variability in residual pool surface area associated with tagged wood placed in streams was explained by the size and orientation of the tagged wood. Models developed in this study are meant to identify hydraulically important variables rather than be predictive equations.

An interaction between the diameter and horizontal orientation of the tagged wood was positively correlated with residual pool volume. Pieces of tagged wood with midpoint diameters of 60 cm and oriented horizontally at ninety degrees to the streambank were associated with residual pools with the largest volume. The horizontal and vertical orientations of the tagged wood the summer prior to the measurement of residual pools and the horizontal and vertical orientations of the tagged wood the same summer as the measurement of residual pools both correlate with residual pool parameters. This is due, in part, to the fact that most pieces of tagged wood did not move most years, thus their horizontal and vertical orientations remained similar from year to year.

The recurrence interval of the maximum instantaneous peak flow and the local gradient of the steambed did not correlate with residual pool parameters. This indicates that the relationship between peak flows, local gradient, large wood, and local scour deserves further study. Local substrate correlated with the surface area and maximum depth of residual pools. Aquatic habitat units with gravel are more likely to experience scour in the presence of large wood than aquatic habitat units with cobble.

Wood interaction

A confounding factor in associating a piece of tagged wood with a given residual pool is that pieces of tagged wood can affect each other. Each piece of tagged wood was originally placed to be physically independent from each other piece of tagged wood. However some pieces of tagged wood were physically close enough to interact with the next piece of tagged wood downstream because of errors made during placement.

Tagged wood also interacted with untagged wood in the stream to affect scour. Pieces of large, untagged wood were not surveyed every year, but were noted if they were associated with a residual pool. If tagged wood was found in a residual pool, but was not the dominant element of the formation of the residual pool, the residual pool was not attributed to that piece of tagged wood. This was the case for beaver dams or residual pools formed by large, nontagged wood or boulders.

In some cases, the tagged wood was the key piece in a debris jam. If the tagged wood piece recruited woody debris, or acted synergistically with another large, nontagged pieces of wood in creating a residual pool, it was analyzed in association with the residual pool. Thus a smaller diameter piece of tagged wood at an orientation that would not normally cause scour could be associated with a large residual pool because of the interaction between pieces of tagged wood or the interaction between tagged wood and nontagged wood. The largest residual pool associated with tagged wood was the result of two tagged wood pieces acting together in J-Line Creek (pieces four and five) from 1990-1996. Although the interaction between pieces of large wood was not studied as a part of this project, it appears to be an important variable and deserves to be considered in future research on this subject.

Wood movement

Average movement of tagged wood was greatest during WY 1996, which had a maximum peak flow with a recurrence interval of sixty-eight years. This could explain why residual pool volume decreased during WY 1996 for J-Line Creek and showed only a slight increase for Preacher Creek. However both average tagged wood movement and average residual pool volume were large in WY 1990, the year after the tagged wood was installed. Tagged wood movement would be expected to be high the first year after installation because the tagged wood must adjust to the channel. Residual pool volumes were also large in the summer of 1990 compared to small preexisting residual pool volumes in the summer of 1989.

Differences in residual pools between J-Line Creek and Preacher Creek

Residual pool volume, surface area and maximum depth were significantly different in Preacher Creek and J-Line Creek after treatment. These two “paired” streams acted differently, thus extrapolation of these results to other “similar” streams should be made cautiously. There are many possible explanations for the difference in average residual pool volume in the two stream channels, including sediment sources, land management, inputs of wood, the differences in drainage area and beaver activity. While Preacher Creek might be expected to have greater residual pool volume than J-Line Creek because its’ drainage area is twice as large (Stack and Beschta, 1989), this was not the case.

The lack of association between peak flows and residual pool attributes

Some measure of water depth or discharge has been found to be significantly associated with scour around structures in a channel in hydraulic studies and in flumes (Ahmad, 1953; Garde et al., 1961; Gill, 1972; Beschta, 1983; Cherry and Beschta, 1989). The recurrence intervals of the maximum instantaneous annual peak flows may not have correlated with the volumes of residual pools in the field because of a nonlinear relationship between discharge and the volume of residual pools. The wood orientation variables which predicted residual pool volume in a flume (Cherry and Beschta, 1989) also predicted residual pool volume in the field. Although discharge predicted residual pool volume in a flume, it did not predict residual pool volume in the field. Flumes may be better suited for the study of wood orientation variables than they are for the investigation of variables such as discharge.

Unlike most field studies, flumes are able to test a range of flows which differ by orders of magnitude. An important difference between the flow depth variable in flume studies and the recurrence interval of the maximum instantaneous peak flow variable used in this study is that storm hydrographs vary with time. Furthermore, the recurrence interval of the maximum instantaneous peak flow may have occurred at an instant or for a short time while a given flow depth in a flume occurred over the entire trial in the laboratory (seven to eight hours) (Cherry and Beschta, 1989).

Another reason why discharge or depth of flow significantly predicted local scour in a flume, but not in the field is because dowels in fixed positions are used in flume studies, however wood rises and falls with streamflow in the field (Gregory and Wildman, unpublished), so local bed scour may be less pronounced than scour which is associated with a fixed structure. Streambanks can erode locally because of high shear stresses (Cherry and Beschta, 1989), while the sides of a flume do not erode.

Aquatic habitat inventory pools versus residual pools

The total volume of residual pools in a stream reach were estimated better than the volume of individual residual pools within a stream reach with aquatic habitat inventories. In simple regression tests, ninety-six percent of the variability in the total volume of residual pools, and forty percent of the variability in the volume of individual residual pools were explained by pools estimated with aquatic habitat inventories.

The difficulties in quantifying how wood affects aquatic habitat are compounded by the difficulties in assessing the amount and quality of aquatic habitat in a stream at any given time. Aquatic habitat in small streams is characterized to determine patterns of fish use and identify and assess environmental change (Bisson et al., 1982). Although aquatic habitat inventories are valuable as a way to determine the number and type of habitat units, aquatic habitat inventories include subjective estimates of pool parameters. Aquatic habitat inventories do not include the habitat potential of a stream over a range of flows or allow for clear comparisons between streams (Kaufmann, 1988). Pools are often defined qualitatively, and channel unit characterizations are dependent on stage (Lisle, 1987).

An objective measure which evaluates aquatic habitat quantitatively is residual pool volume. The fact that residual pool volume is determined by the elevation of a riffle crest makes it repeatable at a range of flows by different individuals. Measures of residual pool volume, surface area or maximum depth, especially when obtained with an electronic theodolite, could be used to calibrate other quicker methods, such as aquatic habitat inventories.

It might be expected that aquatic habitat inventories overestimate the volume of residual pools because the pools measured during aquatic habitat inventories include both the water laying on top of the residual pool, and the residual pool. However, this is apparently not the case. Aquatic habitat inventories underpredict the volume of individual residual pools at the individual habitat unit level because of the large number habitat units in which a pool was not found during the aquatic habitat inventory, but a residual pool was found on the topographic map. This results from the arbitrary definition of a residual pool with a minimum depth of 0.15 m. This resulted in some residual pools with volume as small as 0.06 m^3. When the minimum residual pool volume was increased to a volume identified as a pool by stream surveyors, 0.45 m^3 (Kaufmann, 1988), only forty percent of the variance in individual residual pool volume was estimated by individual pools measured in aquatic habitat inventories.

Thus, it appears to be difficult to predict the volume of individual residual pools using aquatic habitat inventories, even in the best circumstances, where the person performing the inventory is the same from year to year and individual pools are matched in the field and on the topographic map. Aquatic habitat inventories do, however, give a good estimate of the volume of residual pools in a reach.

The two methods, estimating pool volume with aquatic habitat inventories and calculating residual pool volume off of topographic maps, were not designed with similar goals. Aquatic habitat inventories were designed to assess stream conditions and suitability for fish. The type of pool (trench, backwater, secondary, etc.) as well as the cover associated with the pool unit are as important as the actual pool volume in determining whether or not a fish will use the pool (Bisson et al., 1982). Although subjective estimates are a necessary part of the process of identifying and evaluating important components of aquatic habitat, it is worthwhile to calibrate these subjective estimates with residual pool volume wherever possible. Ninety-eight percent of the variability in the average depth of individual residual pools (calculated by dividing the residual pool volume by the residual pool surface area) could be estimated with the maximum depth of the residual pool taken from topographic maps.

RECOMMENDATIONS FOR FUTURE WORK

Research

The next step in future research is to integrate fish density data with physical data for J-Line Creek and Preacher Creek to see if the addition of large wood, and its size and orientation are positively correlated with fish densities. The greatest population of fish was found in a large beaver pond in J-Line Creek in 1995. In future studies it will be important to research the role that beaver play.

It is necessary to reexamine the hypothesis that peak discharge is associated with residual pool volume. Studies designed to test this hypothesis should have more than five years of data. If further studies are initiated to examine the interaction between structures that alter habitat and channel morphology, the interaction between natural wood and introduced wood should be an integral part of the analysis. This interaction is critical for understanding the relationship between large wood added to streams and residual pools. It would also be useful to determine the historical sources of large conifer wood found in coastal Oregon streams. This would involve examining the amount of large wood contributed to the stream in pulses by landslides and debris flows versus blowdown in conifer riparian areas.

Management

Although the existence of large wood in stream channels was associated with increases in residual pool volume in J-Line Creek and Preacher Creek, from 1990-1996, aquatic habitat manipulation projects should consider the addition of large wood to a channel as short term rehabilitation, enhancement or mitigation (Beschta et al., 1994) and should use this technique for increasing local scour only when protection or restoration are not possible or desirable. Before expending the resources necessary for fish habitat rehabilitation, the long-term goals for the system should be assessed.

If long-term fish habitat improvement is the goal of the project, the identification and removal of causes of habitat degradation should occur before adding log structures to the stream (Beschta et al., 1992, Kauffman et al., 1993; National Research Council, 1996). The restoration of native riparian vegetation and natural succession of plant communities is a vital part of this process (White and Brynildson, 1967, Beschta et al., 1992; National Research Council, 1996).

If fish habitat does not increase after these first two steps have been taken, the pros and cons of adding large wood to the channel may be considered. An assessment of the differences between added large wood and natural wood might include questions concerning the presence of root wads, branches and bark on downed wood available to be placed in streams, the seasonal timing of natural inputs of wood versus added wood and the inability of added wood to affect stream temperature as does riparian vegetation. A determination of whether the benefits of simply installing large structural elements (e.g. wood, boulders) outweigh the costs of increased impacts of turbidity and sedimentation on water quality is also important (Beschta et al., 1992).

Finally, if large wood is to be added, the size of the wood is an important factor to be considered. The diameter of the wood is positively correlated with residual pool volume and the stability of the pieces. Although in this study, large wood is defined as having a midpoint diameter of 60 cm, historically large wood was much bigger than this. Although various aspects of the positioning and orientation are weakly correlated with the parameters of residual pools, the tendency of the wood to shift with flow and adjust itself to the channel may not warrant the extra expense necessary for careful placement. It is suggested that any extra resources be used for obtaining the largest wood possible with root wads, branches and bark.

Land managers using the aquatic habitat inventory method, established by Bisson et al. (1982) should establish objectives for the data before collecting these types of data. If the goal is to assess aquatic habitat in a watershed or channel morphology changes over time at the reach level or higher, aquatic habitat inventories may be an effective tool. However, if managers wish to assess change at the aquatic habitat unit level, they should expect low levels of accuracy. A commitment to monitoring and adaptive management (experimentation as a part of the design and implementation of natural resource and environmental policies) is essential to the long term success of the project (Everest, 1991, Beschta et al., 1994).

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APPENDICES

APPENDIX A: Table of diameter of tagged wood

Table 6: Actual diameter and diameter class assigned to each piece of tagged wood.

PIECE #	ACTUAL DIAMETER	DIAMETER CLASS	ORIGINAL ORIENTATION
PREACHER			
1	**59.5 cm**	**60 cm**	**Spanner**
2	**38.0 cm**	**40 cm**	**Spanner**
3	**17.3 cm**	**20 cm**	**Ramp**
4	**19.8 cm**	**20 cm**	**Ramp**
5	**18.4 cm**	**20 cm**	**Spanner**
6	**53.8 cm**	**60 cm**	**Ramp**
7	**34.1 cm**	**40 cm**	**Spanner**
8	**36.4 cm**	**40 cm**	**Ramp**
9	**15.4 cm**	**20 cm**	**Ramp**
10	**51.5 cm**	**60 cm**	**Spanner**
11	**43.3 cm**	**40 cm**	**Spanner**
12	**53.9 cm**	**60 cm**	**Ramp**
13	**63.4 cm**	**60 cm**	**Ramp**
14	**45.6 cm**	**40 cm**	**Ramp**
15	**63.2 cm**	**60 cm**	**Spanner**
16	**18.3 cm**	**20 cm**	**Spanner**
17	**17.9 cm**	**20 cm**	**Spanner**
18	**42.5 cm**	**40 cm**	**Ramp**
J-LINE			
1	**44.7 cm**	**40 cm**	**Spanner**
2	**29.2 cm**	**20 cm**	**Spanner**
3	**57.7 cm**	**60 cm**	**Ramp**
4	**64.2 cm**	**60 cm**	**Spanner**
5	**65.9 cm**	**60 cm**	**Ramp**
6	**37.4 cm**	**40 cm**	**Ramp**
7	**61.6 cm**	**60 cm**	**Spanner**
8	**23.8 cm**	**20 cm**	**Spanner**
9	**39.0 cm**	**40 cm**	**Ramp**
10	**21.3 cm**	**20 cm**	**Spanner**
11	**19.8 cm**	**20 cm**	**Ramp**
12	**42.6 cm**	**40 cm**	**Spanner**
13	**21.7 cm**	**20 cm**	**Ramp**
14	**36.6 cm**	**40 cm**	**Ramp**
15	**57.2 cm**	**60 cm**	**Ramp**
16	**49.0 cm**	**40 cm**	**Spanner**
17	**23.1 cm**	**20 cm**	**Ramp**
18	**50.9 cm**	**60 cm**	**Spanner**

Appendix B: Table of all variables used in analyses

Table 7: Data including: diameter class (DIAM), vertical orientation (VOR), horizontal orientation (HOR) and opening ratio (RATIO) of wood, year, recurrence interval of peak flow(Q), local substrate (SUB), local gradient (GRAD), residual pool volume (VOL), surface area (AREA) and depth (DEP) and distance moved since last measurement (MOVE). Substrate classifications include; gravel (G), large gravel (L), cobble (C), sand (S), silt (I), organic (O), bedrock (B).

PREACHER CREEK

#	YEAR	DIAM (cm)	Q (year)	RATI	VOR (DEG)	HOR (DEG)	SUB	GRAD (%)	VOL (m^3)	DEP (m)	AREA (m^2)	MOVE (m)
1	89	60	1.61	0	2.55	90	—	1.5	0.00	0.00	0	—
2	89	40	1.61	0	0.99	90	—	1.5	0.00	0.00	0	—
3	89	20	1.61	0.45	13.11	38.18	—	1.5	0.00	0.00	0	—
4	89	20	1.61	0.52	15.67	47.5	—	1.5	0.00	0.00	0	—
5	89	20	1.61	0	1.72	90	—	1.5	0.00	0.00	0	—
6	89	60	1.61	0.25	11.74	26.4	—	1.5	0.00	0.00	0	—
7	89	40	1.61	0	0.21	90	—	1.5	0.00	0.00	0	—
8	89	40	1.61	0.32	10.46	33.47	—	1.5	0.00	0.00	0	—
9	89	20	1.61	0.43	10.98	43.4	—	2.5	1.27	0.30	6.3	—
10	89	60	1.61	0	1.91	90	—	2.5	0.00	0.00	0	—
11	89	40	1.61	0	0.41	90	—	2.5	0.00	0.00	0	—
12	89	60	1.61	0.47	9.34	104.2	—	2.5	0.00	0.00	0	—
13	89	60	1.61	0.24	14.54	16.2	—	2.5	0.00	0.00	0	—
14	89	40	1.61	0.33	13.69	17.13	—	2.5	2.70	0.52	7.6	—
15	89	60	1.61	0	2.03	90	—	2.5	1.52	0.17	12.4	—
16	89	20	1.61	0	0.58	90	—	2.5	0.93	0.14	8.54	—
17	89	20	1.61	0	1.79	90	—	2.5	0.00	0.00	0	—
18	89	40	1.61	—	10.62	—	—	2.5	0.00	0.00	0	—
1	90	60	2.18	0.54	2.38	62.38	L	1.80	1.20	0.27	6.41	0.98
2	90	40	2.18	0.20	3.57	90.05	G	1.80	1.78	0.21	9.96	2.00
3	90	20	2.18	0.64	12.19	27.15	L	1.80	1.00	0.21	7.02	7.44
4	90	20	2.18	0.00	1.58	90.00	G	1.80	0.00	0.00	0.00	22.84
5	90	20	2.18	0.24	1.50	54.50	L	1.80	0.07	0.08	1.35	2.36
6	90	60	2.18	0.18	12.13	49.05	L	1.80	1.27	0.16	11.64	0.07
7	90	40	2.18	0.62	2.94	36.05	L	2.40	0.00	0.00	0.00	5.00
8	90	40	2.18	0.48	8.44	14.56	L	2.40	0.00	0.00	0.00	0.63
9	90	20	2.18	0.51	10.46	46.50	L	2.40	0.00	0.00	0.00	0.91
10	90	60	2.18	0.00	3.69	90.00	G	2.40	1.08	0.33	5.07	0.68
11	90	40	2.18	0.00	1.76	90.00	G	2.40	2.51	0.23	15.19	0.70
12	90	60	2.18	0.51	6.89	63.26	G	2.40	6.79	0.34	30.75	1.11
13	90	60	2.18	0.32	14.42	28.57	G	2.40	0.10	0.13	1.19	0.68
14	90	40	2.18	0.50	13.48	34.56	L	2.40	0.00	0.00	0.00	1.10
15	90	60	2.18	0.00	0.60	90.00	G	2.40	2.05	******	16.05	0.95
16	90	20	2.18	0.42	3.53	30.30	L	2.40	1.15	0.21	7.87	7.63
17	90	20	2.18	0.10	0.43	62.01	G	2.40	0.00	0.00	0.00	4.09
18	90	40	2.18	0.94	11.04	69.00	G	2.40	0.00	0.00	0.00	1.13
1	91	60	1.15	0.48	2.81	110.01	C	2.90	0.13	0.10	1.79	0.84
2	91	40	1.15	0.30	3.88	64.28	C	1.70	0.15	0.11	2.07	0.44
3	91	20	1.15	0.70	12.46	18.17	C	1.70	0.00	0.00	0.00	0.16
4	91	20	1.15	0.00	2.20	90.00	C	1.70	0.00	0.00	0.00	0.26
5	91	20	1.15	0.16	1.65	53.50	C	1.70	0.41	0.13	4.66	0.19
6	91	60	1.15	0.24	12.13	36.06	C	1.70	0.00	0.00	0.00	0.11
7	91	40	1.15	0.64	2.96	46.44	L	1.70	0.00	0.00	0.00	0.14
8	91	40	1.15	0.49	8.39	12.01	C	1.70	0.43	0.13	4.04	0.15
9	91	20	1.15	0.40	10.27	42.14	C	1.70	0.77	0.20	8.75	0.58
10	91	60	1.15	0.00	3.24	90.00	L	1.70	2.46	0.35	10.08	0.48
11	91	40	1.15	0.00	1.69	90.00	L	1.70	0.12	0.11	1.32	0.43
12	91	60	1.15	0.96	6.93	39.54	C	2.30	0.00	0.00	0.00	0.49
13	91	60	1.15	0.29	13.55	30.35	C	2.30	0.00	0.00	0.00	0.79

Table 7. (Continued)

PREACHER CREEK (cont.)

#	YEAR	DIAM (cm)	Q (year)	RATI	VOR (DEG)	HOR (DEG)	SUB	GRAD (%)	VOL (m^3)	DEP (m)	AREA (m^2)	MOVE (m)
15	91	60	1.15	0.00	0.80	90.00	L	2.30	0.34	0.13	3.48	0.95
16	91	20	1.15	0.40	3.67	55.30	C	2.30	0.00	0.00	0.00	1.31
17	91	20	1.15	0.10	0.26	70.60	C	2.30	0.00	0.00	0.00	1.15
18	91	40	1.15	0.89	11.02	74.11	C	2.30	0.00	0.00	0.00	1.27
1	93	60	1.27	0.29	2.27	97.17	L	2.20	2.68	0.27	13.41	0.54
2	93	40	1.27	0.26	3.96	60.56	C	2.20	0.04	0.12	0.65	0.45
3	93	20	1.27	0.69	12.69	46.35	L	2.20	0.00	0.00	0.00	0.06
4	93	20	1.27	0.77	4.60	114.20	L	2.20	0.00	0.00	0.00	9.35
5	93	20	1.27	0.20	1.22	62.34	L	2.20	0.00	0.00	0.00	0.37
6	93	60	1.27	0.15	11.82	36.12	C	2.20	0.27	0.15	2.57	7.47
7	93	40	1.27	0.63	3.23	33.31	C	2.20	0.00	0.00	0.00	0.19
8	93	40	1.27	0.62	1.17	10.11	L	2.20	0.52	0.09	8.08	7.37
9	93	20	1.27	0.88	8.93	27.09	L	2.20	0.00	0.00	0.00	0.56
10	93	60	1.27	0.00	2.51	90.00	L	2.20	0.91	0.18	6.91	2.21
11	93	40	1.27	0.00	1.66	90.00	L	2.60	0.43	0.20	2.85	1.09
12	93	60	1.27	1.00	7.15	43.40	C	2.60	0.00	0.00	0.00	1.23
13	93	60	1.27	0.32	13.12	34.32	C	2.60	0.04	0.12	0.50	1.47
14	93	40	1.27	0.51	12.22	20.38	L	2.60	0.00	0.00	0.00	1.72
15	93	60	1.27	0.00	1.16	90.00	L	2.70	0.40	0.10	4.75	3.63
16	93	20	1.27	0.11	1.81	60.02	C	2.70	0.14	0.09	2.01	3.41
17	93	20	1.27	0.16	0.26	54.46	L	2.70	0.00	0.00	0.00	1.94
18	93	40	1.27	0.49	11.31	84.40	L	2.70	0.00	0.00	0.00	2.26
1	95	60	2.65	0.42	3.61	83.54	C	1.70	0.30	0.14	2.84	0.50
2	95	40	2.65	0.25	4.72	66.20	C	1.70	0.00	0.00	0.00	0.21
3	95	20	2.65	0.71	12.74	79.40	C	1.80	0.00	0.00	0.00	0.15
4	95	20	2.65	0.68	5.78	99.50	C	1.70	0.00	0.00	0.00	0.91
5	95	20	2.65	0.29	0.38	45.40	L	1.80	0.00	0.00	0.00	0.37
6	95	60	2.65	0.23	12.01	34.50	L	1.80	0.00	0.00	0.00	0.15
7	95	40	2.65	0.75	2.71	24.20	C	1.80	0.00	0.00	0.00	0.07
8	95	40	2.65	1.00	0.82	0.00	O	1.60	0.00	0.00	0.00	31.24
9	95	20	2.65	0.65	9.28	40.14	C	2.50	0.00	0.00	0.00	1.16
10	95	60	2.65	0.00	2.53	90.00	L	2.50	2.04	0.30	10.75	1.30
11	95	40	2.65	0.00	0.55	90.00	I	2.50	1.04	0.26	5.33	1.48
12	95	60	2.65	0.87	7.27	52.50	C	2.50	0.00	0.00	0.00	1.17
13	95	60	2.65	0.34	11.75	37.40	S	2.50	0.00	0.00	0.00	1.06
14	95	40	2.65	0.69	12.35	23.40	L	2.50	0.00	0.00	0.00	1.32
15	95	60	2.65	0.00	1.36	90.00	L	2.50	2.92	0.30	12.13	2.63
16	95	20	2.65	0.00	0.46	90.00	C	2.50	0.42	0.12	6.39	1.64
17	95	20	2.65	0.22	0.17	66.23	C	2.50	0.00	0.00	0.00	1.99
18	95	40	2.65	0.48	10.27	62.60	L	2.50	0.00	0.00	0.00	1.81
1	96	60	68	1.00	2.68	29.45	L	1.80	0.38	0.19	2.67	0.57
2	96	40	68	0.37	4.86	25.36	C	1.80	0.00	0.00	0.00	0.52
3	96	20	68	0.85	12.12	34.41	L	1.80	0.07	0.08	1.71	0.29
5	96	20	68	0.27	1.80	47.40	L	1.80	0.00	0.00	0.00	0.55
6	96	60	68	0.45	12.85	21.37	L	2.70	0.00	0.00	0.00	7.28
7	96	40	68	0.64	4.89	32.12	L	1.70	0.66	0.13	6.70	0.72
8	96	40	68	0.58	6.33	65.41	L	1.80	0.57	0.19	4.52	60.18
9	96	20	68	0.89	8.72	20.20	L	1.70	0.00	0.00	0.00	0.76
10	96	60	68	0.68	2.86	32.40	L	2.40	0.00	0.00	0.00	5.49
11	96	40	68	0.00	0.11	90.00	L	2.40	2.17	0.25	10.94	2.17
12	96	60	68	1.00	5.83	39.22	L	2.00	0.00	0.00	0.00	0.25
13	96	60	68	0.76	10.82	36.33	G	2.00	2.26	0.41	9.48	0.61
14	96	40	68	0.92	13.00	49.58	L	2.70	0.79	0.18	6.55	0.44
15	96	60	68	0.24	2.05	69.17	L	2.70	1.23	0.30	5.33	2.85
17	96	20	68	0.25	0.46	61.16	C	2.40	0.25	0.14	3.38	0.34

Table 7. (Continued)

J-LINE CREEK

#	YEAR	DIAM (cm)	Q (YEAR)	RATI	VOR (DEG)	HOR (DEG)	SUB	GRAD (%)	VOL (m^3)	DEP (m)	AREA (m^2)	MOVE (m)
1	89	40	1.61	0	1.11	90.00	—	1.7	0	0	0	—
2	89	20	1.61	0	0.14	90.00	—	1.7	0	0	0	—
3	89	60	1.61	0.27	7.79	34.30	—	2.2	0	0	0	—
4	89	60	1.61	0	0.20	90.00	—	2.2	0	0	0	—
5	89	60	1.61	0.28	8.25	33.60	—	2.2	0	0	0	—
6	89	40	1.61	0.24	5.46	39.30	—	2.2	0	0	0	—
7	89	60	1.61	0	0.69	90.00	—	2.2	0.76	0.24	4.24	—
8	89	20	1.61	0	6.67	90.00	—	2.2	0	0	0	—
9	89	40	1.61	0.3	9.32	65.40	—	2.2	0	0	0	—
10	89	20	1.61	0	6.54	90.00	—	2.2	0	0	0	—
11	89	20	1.61	0.28	10.67	4.40	—	1.5	0	0	0	—
12	89	40	1.61	0	6.08	90.00	—	1.5	0	0	0	—
13	89	20	1.61	0.24	9.92	36.50	—	1.5	0	0	0	—
14	89	60	1.61	0.36	17.59	40.10	—	1.5	0	0	0	—
15	89	60	1.61	0.5	16.24	53.30	—	1.5	—	—	—	—
16	89	40	1.61	0	0.39	90.00	—	9.2	0	0	0	—
17	89	20	1.61	0.34	5.65	50.50	—	1.5	0	0	0	—
18	89	60	1.61	0	0.76	90.00	—	1.5	0	0	0	—
1	90	40	2.18	0.00	6.11	17.10	G	1.3	11.51	0.60	29.46	19.76
2	90	20	2.18	0.00	4.52	90.00	L	2.7	0.06	0.14	0.52	3.64
3	90	60	2.18	0.51	8.39	23.00	L	2.7	0.39	0.14	3.93	1.62
4	90	60	2.18	0.00	0.37	90.00	G	1.7	1.10	0.27	7.09	0.84
5	90	60	2.18	0.38	8.03	16.30	L	1.7	0.00	0.00	0.00	0.83
6	90	40	2.18	0.86	4.94	5.10	L	2.2	0.00	0.00	0.00	2.66
7	90	60	2.18	0.00	2.36	90.00	L	2.2	1.10	0.23	5.96	1.22
8	90	20	2.18	0.73	4.90	20.10	I	6	4.65	0.48	15.22	4.79
9	90	40	2.18	0.67	8.77	21.50	G	6	0.00	0.00	0.00	7.54
10	90	20	2.18	0.20	6.65	49.50	L	2.1	0.89	0.15	7.39	4.65
11	90	20	2.18	0.97	3.41	131.53	G	2.1	0.00	0.00	0.00	2.44
12	90	40	2.18	0.37	1.10	45.30	G	2.1	0.85	0.22	4.66	7.49
13	90	20	2.18	0.91	6.66	35.14	G	2.1	0.00	0.00	0.00	2.92
14	90	60	2.18	0.56	16.19	45.30	L	2.6	0.00	0.00	0.00	1.34
16	90	40	2.18	0.00	2.53	90.00	G	2.6	1.38	0.20	9.26	1.89
17	90	20	2.18	0.54	9.62	42.20	G	2.6	0.79	0.11	10.48	0.94
18	90	60	2.18	0.35	7.62	18.50	G	2.6	0.00	0.00	0.00	2.87
1	91	60	1.15	1.00	6.02	0.00	C	2	1.26	0.34	6.32	0.70
2	91	60	1.15	0.00	4.16	90.00	C	2	0.15	0.10	2.12	1.00
3	91	40	1.15	0.46	8.58	20.00	C	1.7	1.45	0.29	7.86	1.16
4	91	60	1.15	0.00	0.37	90.00	C	1.7	1.79	0.34	7.86	0.41
5	91	20	1.15	0.34	8.03	41.10	C	1.7	0.00	0.00	0.00	0.87
6	91	40	1.15	0.64	5.25	18.30	C	1.6	0.00	0.00	0.00	0.76
7	91	20	1.15	0.00	1.40	90.00	C	1.6	1.02	0.19	6.59	0.67
8	91	20	1.15	0.59	5.08	57.01	C	2.8	0.00	0.00	0.00	0.54
9	91	40	1.15	0.91	11.69	12.30	C	2.8	0.00	0.00	0.00	0.56
10	91	20	1.15	0.00	6.11	90.00	C	2.8	0.00	0.00	0.00	3.69
11	91	60	1.15	0.78	15.87	167.30	C	2.8	0.00	0.00	0.00	0.45
12	91	40	1.15	0.15	1.25	55.00	C	2.8	0.74	0.19	6.01	0.34
13	91	20	1.15	1.00	6.59	40.54	C	2.8	0.00	0.00	0.00	0.40
14	91	40	1.15	0.91	17.62	26.30	C	2.2	0.00	0.00	0.00	0.53
15	91	60	1.15	0.51	15.60	65.00	C	2.2	0.00	0.00	0.00	0.46
16	91	40	1.15	0.00	2.91	90.00	L	2.2	7.28	0.52	19.36	0.49
17	91	20	1.15	0.46	9.66	44.30	C	2.2	0.00	0.00	0.00	0.58
18	91	60	1.15	0.20	6.38	30.01	G	2.2	0.00	0.00	0.00	1.04
1	93	40	1.27	1.00	5.95	0.00	L	1.3	4.86	0.45	15.97	0.67
2	93	20	1.27	0.00	4.02	90.00	L	1.3	0.49	0.18	3.70	0.67
3	93	60	1.27	0.40	8.39	19.36	L	2.6	0.00	0.00	0.00	0.65
4	93	60	1.27	0.00	0.38	90.00	L	2.6	8.02	0.52	24.49	0.41

Table 7. (Continued)

J-LINE CREEK (cont.)

#	YEAR	DIAM	Q	RATI	VOR	HOR	SUB	GRAD	VOL	DEP	AREA	MOVE
		(cm)	(YEAR)		(DEG)	(DEG)		(%)	(m^3)	(m)	(m^2)	(m)
6	93	40	1.27	0.67	4.92	17.10	B	1	0.00	0.00	0.00	0.34
7	93	60	1.27	0.00	1.22	90.00	L	1	0.96	0.25	7.38	0.50
8	93	20	1.27	0.74	4.97	74.00	B	2.7	0.00	0.00	0.00	0.18
9	93	40	1.27	0.88	9.78	21.30	L	2.7	0.00	0.00	0.00	0.30
10	93	20	1.27	0.00	7.12	90.00	L	2.7	0.00	0.00	0.00	0.52
11	93	20	1.27	0.73	1.95	142.00	—	2.7	0.00	0.00	0.00	0.62
12	93	40	1.27	0.11	6.28	64.10	—	2.7	0.71	0.15	6.96	0.82
13	93	20	1.27	1.00	6.61	41.44	—	2.7	0.00	0.00	0.00	0.83
14	93	40	1.27	0.76	19.35	27.20	—	2.7	0.18	0.11	2.36	2.32
15	93	60	1.27	0.55	16.23	37.40	—	2.7	1.04	0.19	7.18	1.76
16	93	40	1.27	0.00	3.04	90.00	—	2.7	1.13	0.21	7.49	2.46
17	93	20	1.27	0.38	9.72	28.20	—	2.7	0.00	0.00	0.00	3.88
18	93	60	1.27	0.27	6.25	38.40	—	2.7	0.00	0.00	0.00	5.00
2	95	20	2.65	0.00	4.65	90.00	C	1.3	0.51	0.16	4.51	0.35
3	95	60	2.65	0.41	7.86	27.40	L	1.3	1.58	0.31	8.28	0.28
4	95	60	2.65	0.00	0.98	90.00	L	1.3	19.52	0.92	31.45	1.44
5	95	60	2.65	0.53	2.34	73.40	L	2.9	0.00	0.00	0.00	9.79
6	95	40	2.65	0.72	4.50	12.10	L	2.9	1.57	0.19	9.60	0.20
7	95	60	2.65	0.00	1.27	90.00	L	2	3.61	0.25	24.01	0.38
8	95	20	2.65	0.73	5.34	40.20	I	1.6	0.00	0.00	0.00	0.43
9	95	40	2.65	0.33	14.70	69.40	I	1.6	0.00	0.00	0.00	0.47
14	95	40	2.65	0.87	18.05	16.30	L	1.9	0.00	0.00	0.00	2.40
15	95	60	2.65	0.46	15.58	33.50	L	1.9	0.18	0.10	2.76	2.45
16	95	40	2.65	0.00	3.70	90.00	C	1.9	0.00	0.00	0.00	3.00
17	95	20	2.65	1.00	1.92	18.54	L	1.9	0.00	0.00	0.00	3.89
18	95	60	2.65	0.80	3.14	13.01	L	1.9	0.19	0.08	3.50	11.71
2	96	20	68	0.00	0.83	90	L	2.1	0.00	0.00	0.00	1.52
3	96	60	68	0.50	7.00	25.2	L	2.1	0.49	0.22	3.66	0.41
4	96	60	68	0.35	4.72	57.09	L	2.1	0.00	0.00	0.00	9.68
5	96	60	68	0.44	7.11	16.54	G	2.1	9.32	0.64	22.72	9.52
6	96	40	68	0.75	2.87	31.58	L	2.1	0.00	0.00	0.00	0.80
7	96	60	68	0.00	4.20	90	L	1.8	3.05	0.34	14.26	0.26
8	96	20	68	0.57	6.15	128.55	L	2.7	0.00	0.00	0.00	26.54
9	96	40	68	0.45	12.31	61.09	S	2.7	0.00	0.00	0.00	0.31
11	96	20	68	0.00	2.69	90	L	2.7	0.82	0.23	5.62	13.05
12	96	40	68	0.57	4.71	76.08	S	2.7	4.79	0.28	26.24	1.79
13	96	20	68	1.00	5.73	45.25	L	1.5	0.00	0.00	0.00	1.23
14	96	40	68	1.00	15.30	31.36	L	1.5	0.00	0.00	0.00	1.67
15	96	60	68	0.46	15.50	37.6	L	1.5	0.55	0.10	6.91	0.90
16	96	40	68	0.54	8.18	54.32	C	1.5	0.00	0.00	0.00	5.54
18	96	60	68	0.28	4.89	54.01	S	9.8	0.52	0.21	5.17	20.27

Appendix C: Frequency Analysis for the annual Peak flows of the East Fork of Lobster Creek near Alsea, Oregon from 1983-1996

A Gumbel distribution was used for a frequency analysis of twelve years of annual peak flow data obtained at a U.S.G.S. gauging station on the East Fork of Lobster Creek near Alsea Oregon (from 1983 when the station was constructed to 1996) (Figure 24). The formula proposed by Gringorton (1963) was used to calculate the probability of exceedence of peak flows; p = (m-.44)/(n+1-(2*.44)), where m equals the rank of the peak flow event, n equals the number of years of record, and .44 is a skew coefficient for Gumbel distributions. With this analysis, a 21.64 year recurrence interval (1/p) was calculated for the peak flow of 1040 cfs in 1996 (Table 8).

Table 8: The rank, recurrence interval and probability of exceedance of peak annual flows on the East Fork of Lobster Creek from 1983-1996, calculated with the Gringorton formula (1963).

	Q(cfs)	RANK	Probability (%)	Recurrence Interval(yrs)
1996	1040	1	0.05	21.6
1985	546	2	0.13	7.77
1984	380	3	0.21	4.73
1986	322	4	0.29	3.40
1995	316	5	0.38	2.66
1990	302	6	0.46	2.18
1988	300	7	0.54	1.85
1989	233	8	0.62	1.60
1992	232	9	0.71	1.42
1993	204	10	0.79	1.27
1991	202	11	0.87	1.15
1994	198	12	0.95	1.05
std =	227			
avg =	357			

Lines of best fit through the flow data were calculated both with and without the extreme value of 1996 (Table 9). If these lines of best fit are used to extrapolate a return interval for the 1996 peak flow, values much higher than 21.64 years are obtained (40 years with the 1996 peak flow and 3,000 years without the 1996 peak flow) (Figure 25).

Table 9: Calculated lines of best fit for the annual peak flow data on the East Fork of Lobster Creek. "Q peak" for the associated recurrence intervals is calculated as the sum of the mean of the peak annual discharge and the product between the standard deviation of the peak flow series and K, the frequency factor for probability (p), from the Gumbel distribution.

Recurrence Interval(yrs)	K	Q peak(cfs) 1983-1996	Qpeak (cfs) 1983-1995
	0.9	578.2	390.1
1	1.	76	470.
2	2.3	881.7	521.4
5	3.2	1099.2	615.5

A downstream gauging station, Alsea at Tidewater, had 38 years of record and thus a frequency analysis of annual peak flows seemed to give a more reasonable estimate for the return interval of an extreme peak flow. A return interval of 68 years was calculated with the Gringorton formula for the 1996 peak flow. This value lies between the two extreme values extrapolated on the East Fork of Lobster Creek data, and thus seems to be a reasonable estimate for the peak flow of 1996. The value of 68 years will be used for the recurrence interval of the 1996 annual peak flow in the analyses. From 1989 to 1995, recurrence intervals calculated with data from the East Fork of Lobster Creek will be used (Table 8).

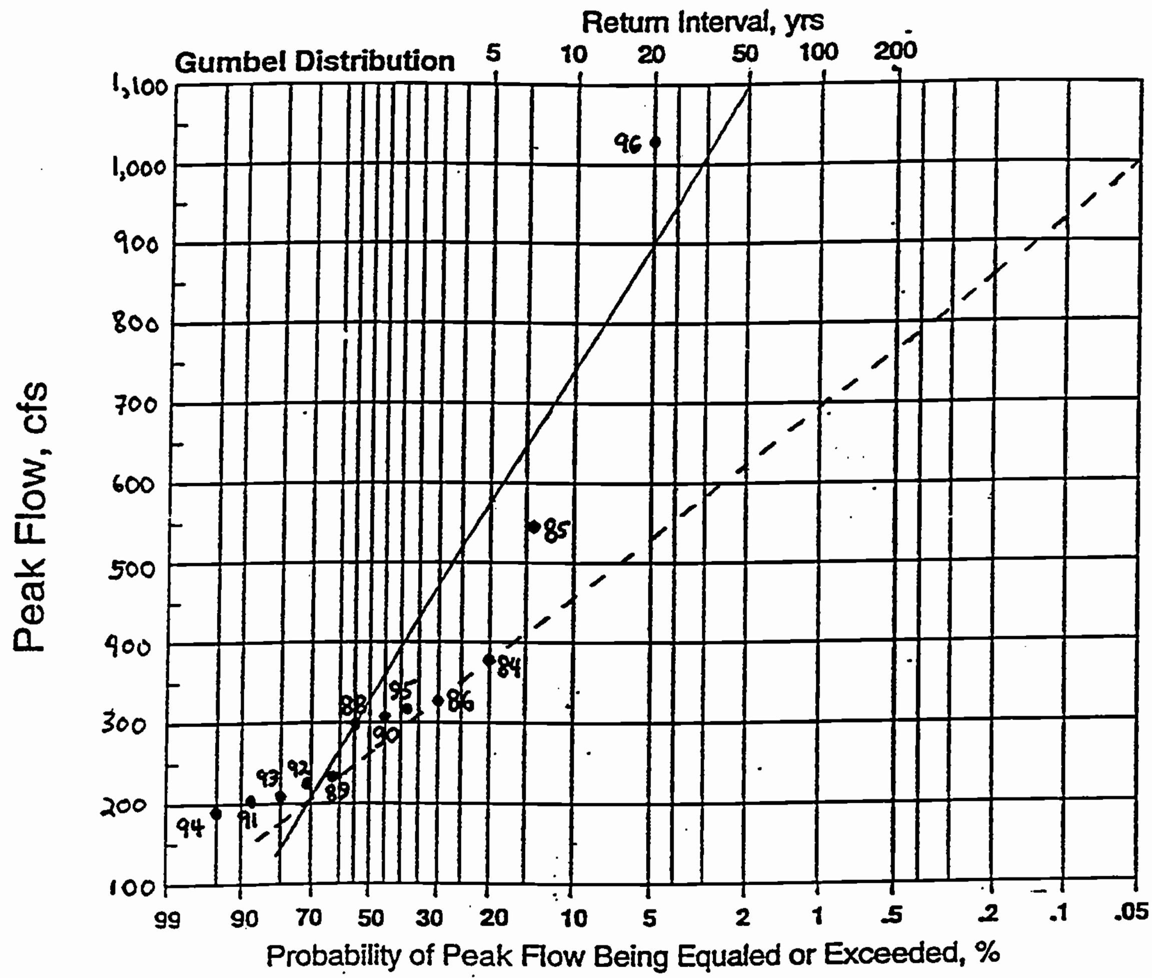

Figure 25: Peak flow frequency analysis using the Gumbel Distribution for 12 annual peak flows on the East Fork of Lobster Creek. Lines of best fit calculated and plotted both with (----) and without (—) the extreme peak flow value in WY 1996.