AN ABSTRACT OF THE THESIS OF

David Marshall Dreher for the degree of Master of Science in Forest Science presented on February 19, 2004.
Title: Effects of input and redistribution processes on in-stream wood abundance and arrangement in Lookout Creek, western Cascade Range, Oregon.

ABSTRACT APPROVED: ______________________________________________.
Frederick J. Swanson

This study explored how selected input and redistribution processes affect the amount and arrangement of in-stream wood within the 64 km$^2$ Lookout Creek watershed in the Andrews Forest, western Cascade Range, Oregon. A longitudinal inventory of in-stream wood was conducted over approximately 20 km of stream length in 2$^{nd}$ to 5$^{th}$-order channels along with reconnaissance activities in stream sections that had originally been mapped in 1970's.

The study had two major parts. The first focused on patterns of in-stream wood amount and arrangement within the study watershed. Flood transport capability of inventoried stream segments was assigned based on channel width. Historical observations of debris flows and earthflow activity over the 50-year period prior to our study were used to delineate influence of those processes on inventoried channel segments. Wood amounts decreased with increases in channel transport capability. As channel transport capability increased the number of wood accumulations also decreased and there was a higher proportion of accumulations created by floods. These observations signal an increase in influence of fluvial transport of wood in the downstream direction. There were lower than expected amounts of wood at locations where debris flows entered mainstem channels and where earthflows were in contact with mainstem channels. This is attributed to the relatively high mobilization capability of channels in these locations. Congested wood

movement associated with the entry of debris flows into mainstem channels and dam-break flood pulses is thought to be responsible for observed differences in wood conditions among segments affected by these processes and segments affected by floods only during the last fifty years. Some evidence exists to support the idea that debris flow entry to mainstem channels and dam-break flood pulses may promote a several decade period of increased wood input as a result of damage and disruption to trees in and adjacent to the channel in disturbed area. However, analysis of the effects of debris flows and earthflow activity on wood amount and arrangement was limited by small sample sizes.

The second part of the study examined relative changes in wood amount and arrangement as well as changes to individual wood accumulations over a 25-year period within 5 stream reaches that had been mapped in detail in the early 1970s. The effect of channel size, input and redistribution processes, piece size, as well as arrangement and location of pieces with respect to the active channel on changes in wood conditions were analyzed. Overall, changes in in-stream wood amount and arrangement were greater in larger channels than in smaller channels. In-stream wood changes resulting from fluvial redistribution also increased with channel size while decomposition and toppling were the processes responsible for most changes in smaller basins. In-stream wood changes were greater among small pieces than large pieces, although substantial changes in large pieces did occur in larger channels as a result of fluvial transport and in smaller channels as a result of toppling. In-stream wood changes were greater among single pieces than pieces in accumulations. Flood transport probably reduced the number of single pieces by collecting them in accumulations. Significant changes in in-stream wood occurred among pieces located both in and out of the channel suggesting that recent flooding, particularly in larger basins, was able to affect wood located along the margins of the channel. Changes in accumulations were generally minor in all sites except the 5th-order channel site.

# EFFECTS OF INPUT AND REDISTRIBUTION PROCESSES ON IN-STREAM WOOD ABUNDANCE AND ARRANGEMENT IN LOOKOUT CREEK, WESTERN CASCADES RANGE, OREGON

by
David Marshall Dreher

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Master of Science thesis of David Marshall Dreher presented on February 19, 2004.

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Dean of Graduate School

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

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David Marshall Dreher, Author

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**PREFACE**

The central theme of this thesis is patterns of wood amount and arrangement (i.e. wood conditions) in mountain watersheds and the processes responsible for observed differences in stream networks. While this thesis focuses on natural input and redistribution processes, land use activities, such as forest harvest and road building, can also influence wood conditions. Czarnomski (2003) has investigated this aspect in the same watershed that was examined in this thesis and should be referenced for comparative purposes.

The first part of my thesis examines patterns of wood amount and arrangement observed in the Lookout Creek watershed (64 $km^2$) in the western Cascade region of Oregon, USA. The spatial scale over which this study was conducted is large enough to investigate landscape level effects of the processes that influence wood conditions in a stream network. Because the basin has been studied extensively for close to half a century we had a more refined idea about the extent and timing of these processes than most other studies that have investigated process influences have had.

The second part of my thesis examines changes in wood amount and arrangement that occurred over a roughly 25-year time period in five, $2^{nd}$ to $5^{th}$-order stream reaches. The time scale over which this study was conducted is long enough to investigate the effects of the processes responsible that influence wood conditions. Detailed map records from the 1970's provided the opportunity to look at both changes in wood amount as well as arrangement of individual accumulations in a manner that has not been available in other studies.

Together the two chapters provide complementary, but distinctive looks, at wood amount and arrangement through a stream network over nearly a 30-year period.

**Part 1: Influence of Input and Redistribution Processes on Wood Amount and Arrangement in a Fifth-Order Mountain Watershed**

## 1. INTRODUCTION

The importance of large wood (> 1 m long and ≥ 0.1 m in diameter) in stream ecosystems of the Pacific Northwest region of North America is well established. Changes in channel morphology (Faustini and Jones, 2003), sediment storage (Harmon et al. 1986, Nakamura and Swanson 1993, Montgomery et al. 1995, Massong and Montgomery 2000), stream habitat (Keller and Swanson 1979, Abbe and Montgomery 1996), and riparian forest development and disturbance (Johnson et al. 2000, Acker et al. 2003) are ecological and geophysical features influenced by wood in stream networks within the Pacific Northwest region and in forested systems globally.

It has been recognized for over two decades that the processes responsible for the input and redistribution of wood vary with position in stream networks (Swanson and Lienkaemper 1978, Keller and Swanson 1979). Montgomery (1999) proposed that landscapes could be mapped into zones (or "process domains") in which different wood input and transport processes operate. Only recently have investigations been conducted over spatial extents large enough to test predictions regarding the effects of these processes and their linkages through stream networks on in-stream wood amounts and arrangement (i.e. wood conditions) at the landscape scale (Nakamura et al. 2000, Martin and Benda 2001, Abbe and Montgomery 2003).

The question guiding this study was: Given our understanding of the relative influence of redistribution process activity across a watershed over approximately the last 50 years, are we able to observe expected patterns in the amount and arrangement of in-stream wood? Hypothesized landscape-scale patterns of in-stream wood amount and arrangement resulting from flood, debris flow, and earthflow activity are investigated within a single watershed in the western Cascade Range of Oregon, USA. Wood conditions in approximately 20 km of stream length collected during a longitudinal inventory during the summer of 2002 are analyzed using statistical and descriptive techniques to test hypothesized landscape-scale patterns.

## 2. FRAMEWORK

In-stream wood conditions in any stream reach are influenced by a number of processes that add wood (i.e. input processes), move wood (i.e. redistribution processes), and remove wood from the channel (i.e. loss processes) (Figure 2-1).

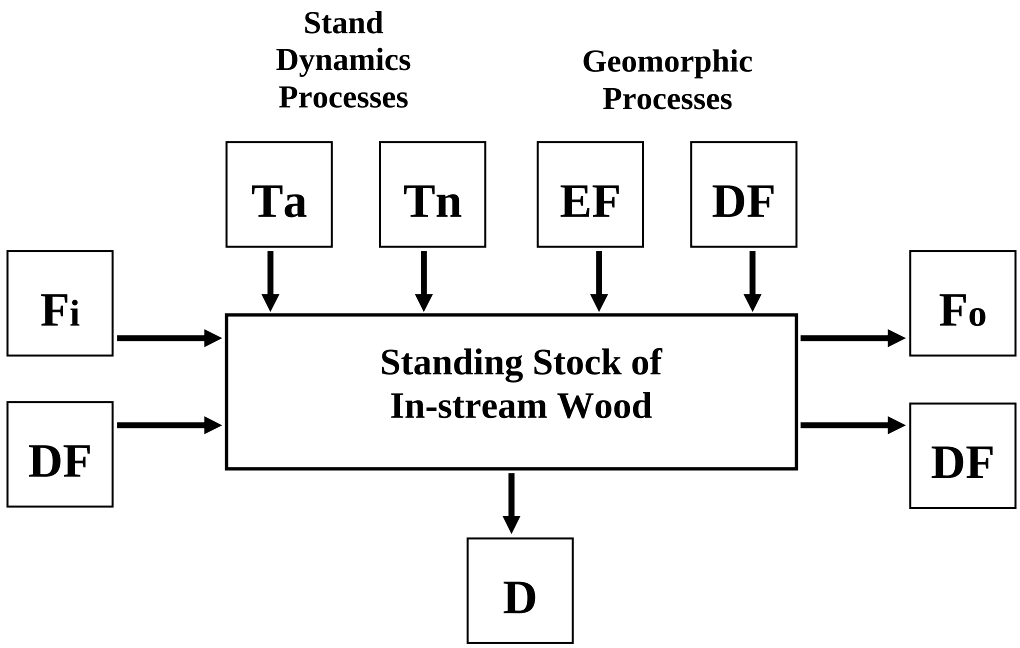



**Figure 2-1: Natural processes influencing wood input and output within western Cascade mountain stream reaches (bold rectangle). Toppling in the near-stream area (Tn), toppling in the away-from-stream area (Ta), earthflow movement (EF), and debris flow (DF) activity make up the suite of input processes. Redistribution processes include debris flow (DF) in small channels as well as flotation transport into (Fi) and out of (Fo) stream reaches. Loss via decomposition (D) results in release of gases to the atmosphere and dissolved nutrient material to stream water and fragmentation to particles smaller than the large wood category.**

## 2.1 Flood transport

During floods in mid- and high-order of the western Cascade Range, wood may travel as individual pieces or in batches of interacting pieces (Johnson et al. 2000), the latter is called "congested" wood movement (Braudrick and Grant 2000). Redistribution of wood during floods is constrained by the relationship of piece size to channel width and water depth (Lienkaemper and Swanson 1987, Bilby and Ward 1989, Braudrick and Grant 2000). Field studies have found that wood moves further and more often in large (> 5$^{th}$-order) than in small (< 5$^{th}$-order) streams (Lienkaemper and Swanson

1987, Bilby and Ward 1989). Smaller pieces have also been found to move further than larger pieces (Lienkaemper and Swanson 1987, Young 1994) with the most mobile pieces being shorter than channel width (Nakamura and Swanson 1994). Piece diameter has also been shown to influence the depth of flow necessary to transport wood (Bilby and Ward 1989, Abbe et al. 1993, Braudrick et al. 1997, Braudrick and Grant 2000). Pieces tend to stop when the channel depth is approximately half the piece diameter (Abbe et al. 1993).

General increases in channel width in the downstream direction within mountain stream networks have two important implications for flood transport of wood. First, as channel width increases more pieces will be shorter than the width of the channel. As a result, a greater proportion of all wood pieces will be mobile. Second, the proportion of the wood source area occupied by the active channel where large wood is not produced increases and results in less wood being added to the channel. Consequently, wood amounts in higher order streams are hypothesized to be lower than amounts of wood in lower order streams. Additionally, we expected wood accumulations to be larger, less frequent, and predominantly formed by fluvial transport in higher order streams.

### 2.2 Debris flow entry points and earthflow impingement zones

Debris flows are rapid movements of water, sediment and wood through narrow, steep stream channels. Debris flows commonly occur when small landslides (i.e.

debris slides) enter and continue down the channel or temporarily block the channel before moving down it (Hack and Goodlett 1960, Sidle et al. 1985). In the western Cascade Range, debris flows generally move through $1^{st}$- to $3^{rd}$-order channels. Debris flows may enter larger ($4^{th}$-order and higher), mainstem channels and leave a deposit of wood and sediment. Debris flow deposits may persist for many years, but high discharges in larger channels may mobilize debris flow deposits immediately or shortly after deposition (i.e. within the same flood). Benda and Cundy (1990) found that confluences of tributaries carrying debris flows and mainstem channels were likely to be deposition sites because of abrupt changes in the direction of flow or rapid energy dissipation that occurs when a debris flow moves from the narrow, confined source tributary channel into a wider, lower-gradient, mainstem channel. In some cases alluvial fans are also effective deposition sites for debris flows because they thin, encounter increasing resistance to flow, and stop as they spread over fans (Grant and Swanson 1995).

Earthflows are discrete areas of slow (mm – m/yr) movements of unstable soil and rock material. In areas where earthflows come in contact with stream channels (i.e. impingement zones) elevated levels of bank erosion occur, which can increase rates of wood input to the stream, function as trapping sites, and lead to channel aggradation in the stream reach the impingement zone (Swanston and Swanson 1977, Sidle et al. 1985, Swanson et al. 1985, Pyles et al. 1987)

Because of the elevated levels of wood input, debris flow entry points and the areas within and above earthflow impingement zones were expected to have higher wood amounts than stream reaches with similar drainage area and stream order that were not affected by these processes.

## 2.3 Downstream effects of debris flow and earthflow processes in mainstem channels

Debris flows and earthflows can also have downstream effects in mainstem channels (Nakamura et al. 2000). Debris flows that enter higher order ($4^{th}$ and $5^{th}$-order) channels can be immediately mobilized in part as rafts of large wood floated by the substantially greater water discharge in large channels. Alternatively, accumulations that form at debris flow entry points may break up during floods, triggering dam-break, flood-pulse events that push a mass of wood in a congested mode of transport (Coho 1993, Braudrick and Grant 2000, Johnson et al. 2000). Similar flood pulses also can occur when accumulations of wood and sediment deposited in channels by streamside sliding at earthflow toes break up during floods (Swanson and Swanston 1977, Coho 1993). Dam-break flood events can cause significant damage to riparian vegetation and may also trigger secondary erosion processes, such as streamside sliding, along the stream reach through which they travel (Benda and Zhang 1989, Coho 1993, Johnson et al. 2000).

Because dam-break floods are high-energy events, wood conditions in disturbed areas were expected to be distinct from areas not affected by these processes. In mainstem channels where movement of larger pieces of wood is not restricted by channel width, the effect of flood transport is great enough to mobilize pieces of any length and obscure evidence of debris flow or dam-break wood additions. Consequently, it was expected channel segments affected by both debris flow entry of dam-break floods and channel segments with similar width and drainage area that were influenced only by floods during the study period would show similar amounts of wood as well as comparable accumulation frequency, size, and type.

In mainstem channels where mobility of larger pieces is limited because channel width is approximately equal to the length of larger pieces, the rate of wood turnover in reaches would differ depending on whether they were influenced only by flood or had additional debris flow entry or dam-break flood disturbances. Higher rates of turnover in segments affected by debris flow entry or dam-break floods were expected to have lower amounts of wood and smaller, less frequent accumulations than segments with similar width and drainage area that were influenced only by floods during the study period because of more frequent mobilization of larger pieces. Additionally, higher wood congestion associated with these disturbances would have greater potential to push wood out of the channel and form accumulations predominantly along the periphery of the channel.

Additionally, the timing of debris flow and dam-break flood disturbance events was expected to result in differences in wood conditions, particularly in channels where transport of larger pieces was limited by channel width. Changes in wood conditions were expected to be more evident as a result of recent events than of earlier events. Also, in segments with greater time since disturbance, we expected to find higher wood amounts and more frequent accumulations as a result of inputs that had occurred following disturbance.

## 3. METHODS

### 3.1 Study design and site description

This study consisted of a field inventory of wood conditions in approximately 20 km of stream length followed by statistical analyses of the relationships between wood conditions and natural redistribution processes active within the study area. The study area was located in the Lookout Creek watershed (64 $km^2$) near Blue River, Oregon (Figure 3-1). The Lookout Creek watershed is located in the western Cascade Range of the Pacific Northwest, USA, and is also the location of the H.J. Andrews Experimental Forest and Long-Term Ecological Research site (hereafter HJA).

Forests composed primarily of Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) cover most of the Lookout Creek watershed. The largest trees in old-growth (~ 400 – 500 years) stands that border much of the inventoried channel length are commonly 70 m tall and have basal diameters of up to 2 m. Clearcut harvesting occurred over approximately 25% of the watershed. Harvesting was concentrated in the 1950s and 1960s with old-growth stands along the route of initial road access in the lower portion of the basin receiving the heaviest impact. Cutting diminished in the 1970s and had largely ceased by the mid-1980s.

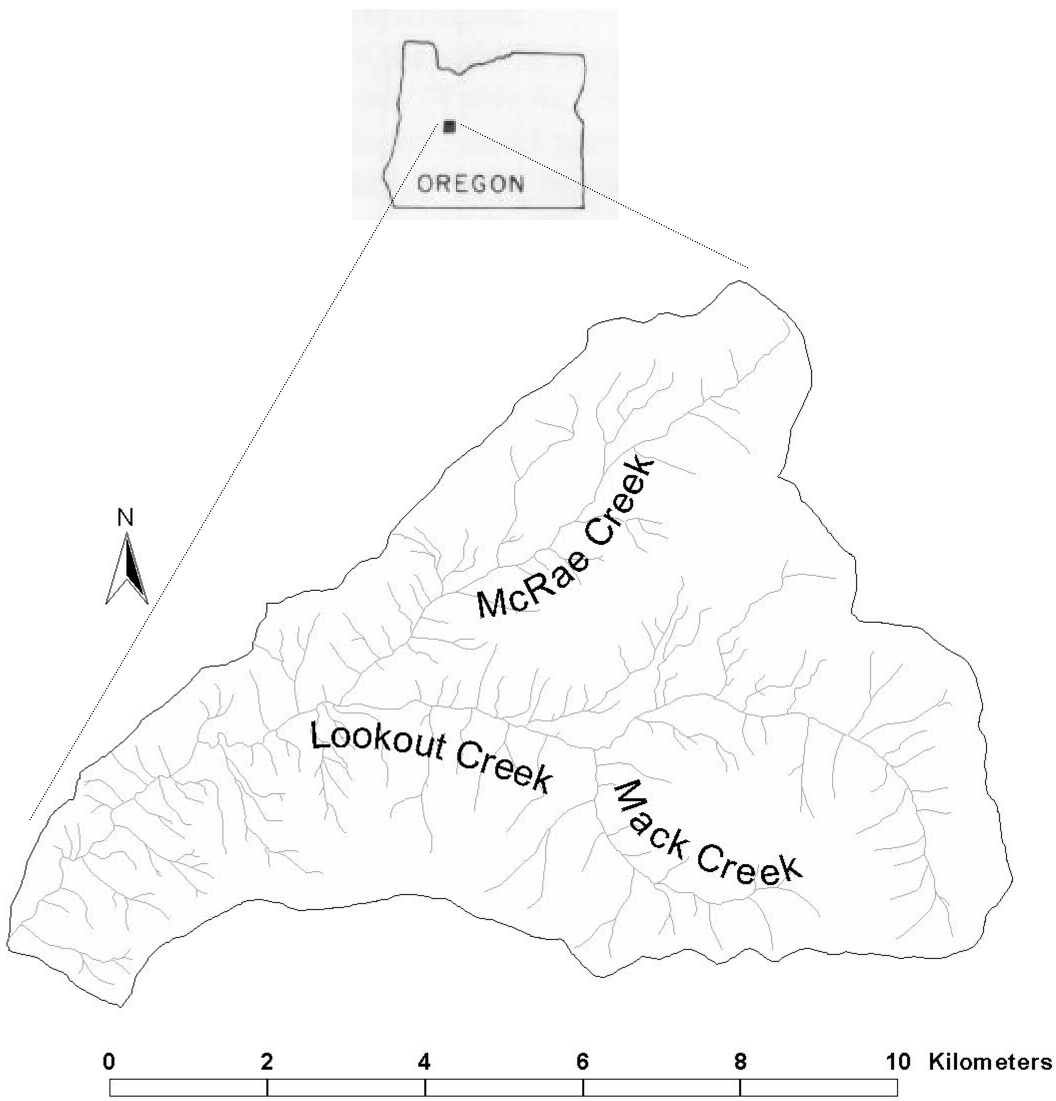



**Figure 3-1: Map depicting location of Lookout Creek watershed.**

### 3.2 Landscape process designation

Observations made over the last 50 years within the Lookout Creek watershed allowed us to determine where localized effects of debris flow and earthflow processes were likely to have influenced the in-stream wood conditions within the segments of mainstem channel length that we inventoried. Physical differences in the channels we inventoried had implications for movement of larger pieces of wood and prompted the development of a system for this study to characterize the relative flood transport capability for wood pieces.

#### 3.2.1 Debris flow

Several researchers have studied debris flows in the Lookout Creek watershed (Dyrness 1967, Swanson and Dyrness 1975, Snyder 2000). Snyder (2000) synthesized records of 91 debris flows from the early 1950's through the 1996 flood. In general, debris flow activity was greatest in the lower portion of the watershed. Steep topography, unstable soil types, rain-on-snow hydrology, and land use (i.e. older road systems) make this part of the watershed susceptible to debris slides which may become debris flows if they reach the stream.

Between 1950 and 1996 debris flows entered the mainstem channel at eight locations within the stream length where the wood inventory was conducted. The point of entry for each of these debris flows was determined by overlaying a GIS layer of debris flow locations created by Snyder (2000) on a layer of the 50 m inventoried segments of stream length. In 1996, there were two locations where debris flows entered the mainstem channel within the stream length where the wood inventory was conducted. The six other entry locations were from debris flows that occurred in the 45 years prior to the 1996 flood.

Segments of stream length located below a debris flow entered the mainstem channel (i.e. places wood conditions were likely to have been influenced by debris flow) were identified using one of two systems depending on when the debris flow event occurred (Figure 3-2). We determined the length of stream below the debris flow entry point that was likely to have been influenced by the two 1996 events using information from the field inventory along with findings from other investigations of these locations (Wondzell and Swanson 1999, Johnson et al. 2000). Because field evidence was less definitive and no information regarding downstream influence for debris flows that occurred prior to 1996 was available, a separate system for delineating which stream segments were likely to have been influenced by debris flow entry was developed. I chose the first 300 meters of mainstem channel length below the point of entry for testing the influence of pre-1996 debris flow events, because I believed it would include the area most likely to still have evidence, if it ever existed, of the earlier events.

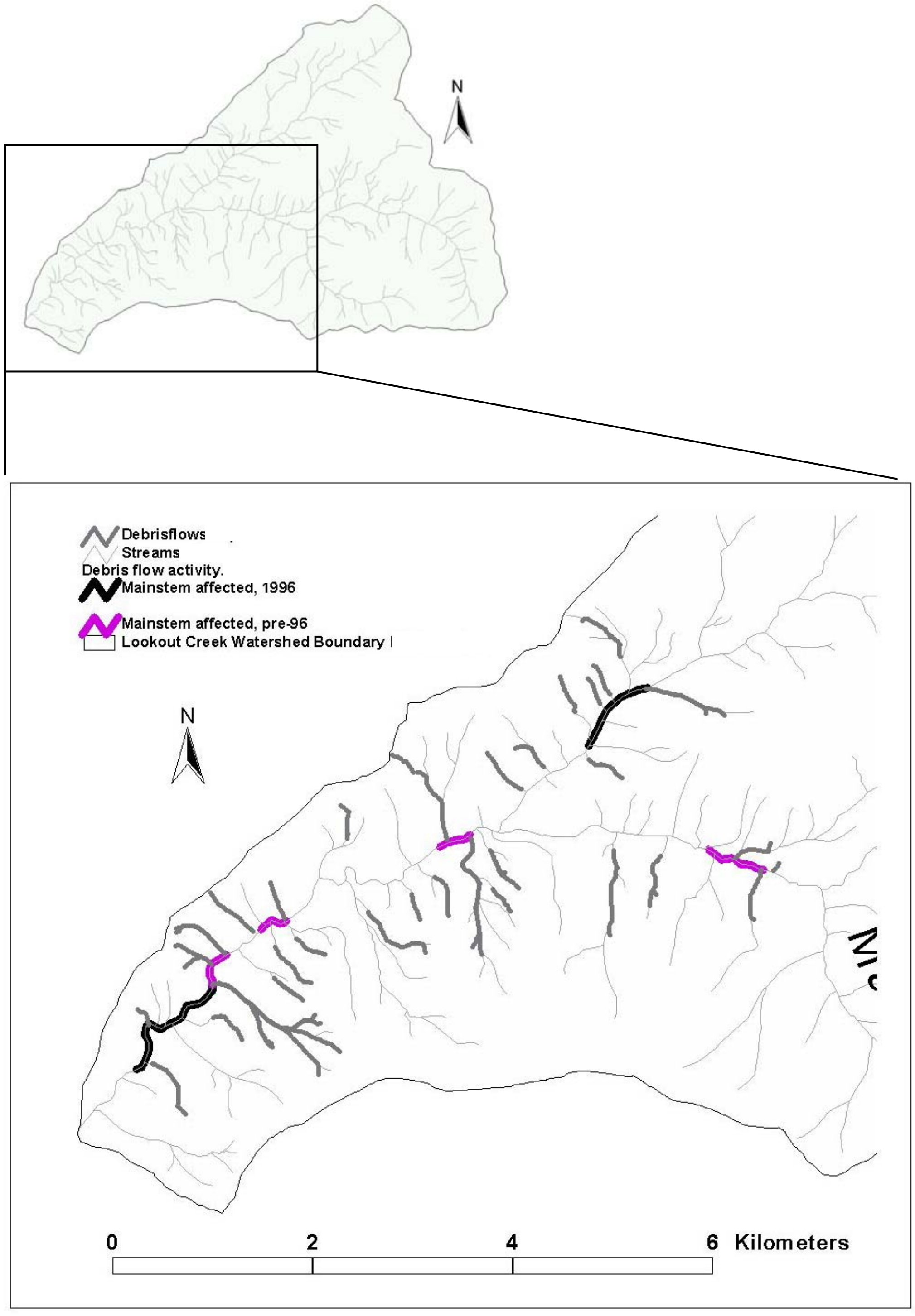



**Figure 3-2: Map depicting debris flow activity within the Lookout Creek watershed between 1950 and 2002 with mainstem stream segments inventoried in this study that were affected by debris flow activity.**

### 3.2.2 Earthflow

A GIS layer showing locations of earthflows in Lookout Creek watershed obtained from the HJA Spatial Database (2004) indicated that few areas within the inventoried stream length had active earthflows present. The layer was compiled from prior investigations of earthflow activity in the watershed that included interpretations of earthflow movement history by direct observation, tree-ring analysis, landform studies, and examination of tree deformation in relation to land movement rate (Swanson and James 1975, Swanson and Swanston 1977, Pyles et al. 1987, Swanson et al. 1987, Vest 1988).

Inventoried segments of stream length were given designations based on the type of earthflow influence (Figure 3-3):

1) Influenced by direct impingement of earthflow movement on the channel,
2) Influenced by dam-break flood pulse,
3) No direct impingement or dam-break flood pulse influence.

The 50 m segments of inventoried stream length directly adjacent to active earthflow sites, according to the GIS layer, were classified as within the direct impingement zone. Only one dam-break flood pulse had occurred within the stream length we inventoried (Swanson and Swanston 1977). This event occurred in the Upper Lookout section in either 1964 or 1965. The 1.6 km of stream length influenced by this dam-break flood event was identified using field observations and prior investigations of the event. Most segments of inventoried stream length had no direct impingement or dam-break flood influence.

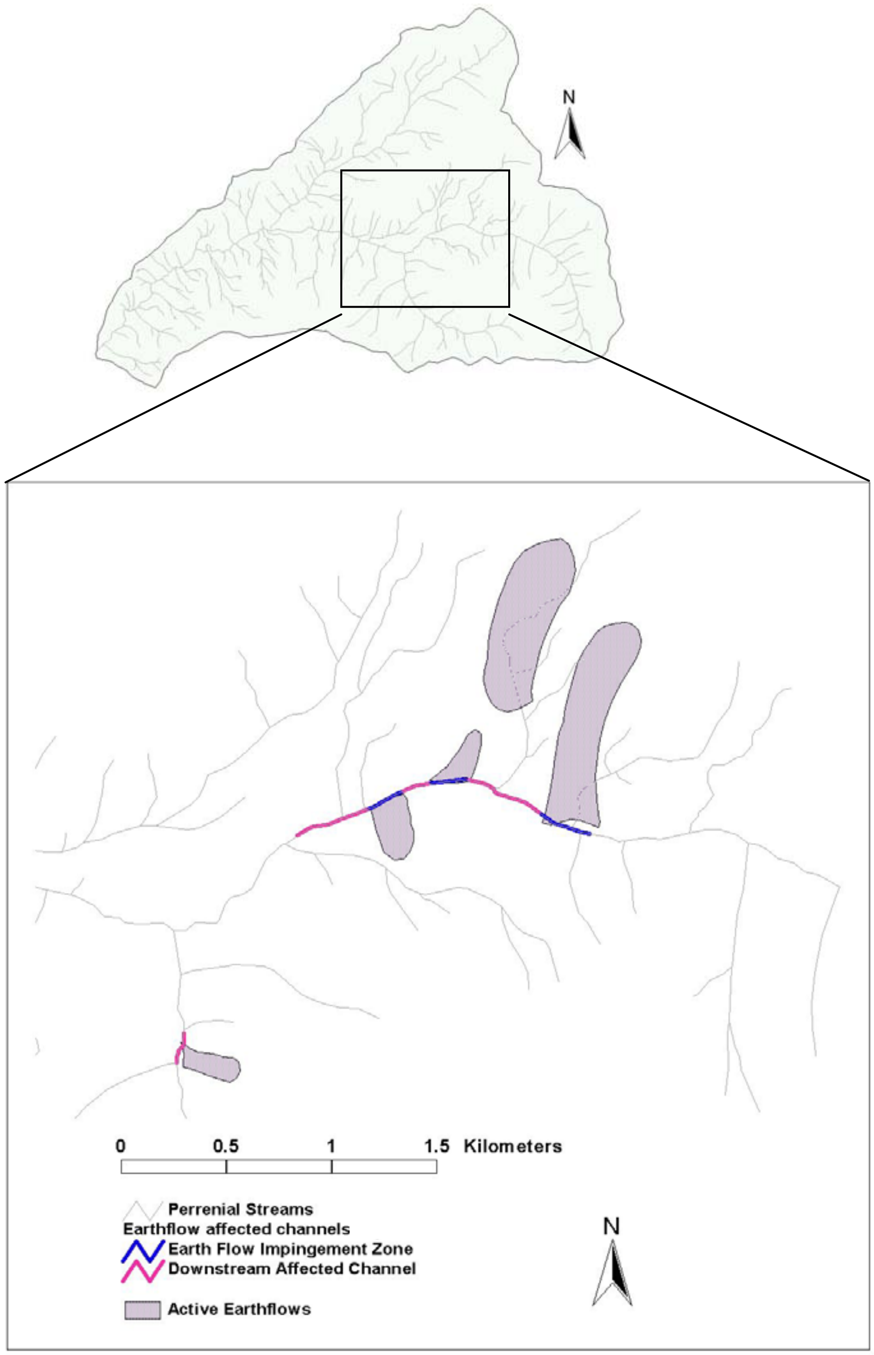



**Figure 3-3: Map depicting active earthflow zones and stream segments inventoried in this study affected by earthflow activity.**

### 3.2.3 Flood transport capability

Classifying the influence of floods on wood conditions within the inventoried stream length was approached differently from the way the influence of debris flow and earthflow processes was delineated. Unlike debris flows and earthflows, floods influence wood conditions over the entire watershed. Large floods (i.e. > 25 year recurrence interval) occurred in Lookout Creek in 1964/65 and 1996 and are known to have substantially rearranged wood over a significant length of the stream network. In addition to being more geographically extensive, research into flood effects in the Lookout Creek watershed indicates that flood disturbance effects are very patchy (Swanson et al. 1998, Johnson et al. 2000).

Small-scale (< 100 m) differences in channel characteristics that can affect wood mobility play a major role in creating the patchy effects of flooding on wood conditions. These differences arise because of the influence of valley floor and valley wall landforms and processes that interact with and constrain the fluvial processes operating within the channel (Grant and Swanson 1995). For example, reaches that are straight, single channels without large (> 1m) boulders have high wood transport capacity. Other areas with wide valley floors permit the formation of secondary channels and a meandering channel pattern, which can impede wood transport. Consequently, there is substantial variation in the general, systematic downstream decrease in channel gradient (Figure 3-4) and increases in channel width (Figure 3-5) and depth in the Lookout Creek watershed as well as other mountain watersheds of the western Cascade Range. These variations in channel geometry cause significant fluctuations in stream power which implies that a sharp threshold of channel width or drainage area delineating the presence or absence of fluvial transport of large wood pieces is unlikely. Instead, fluvial transport of wood is more likely to become influential over a broad transition zone within the watershed.

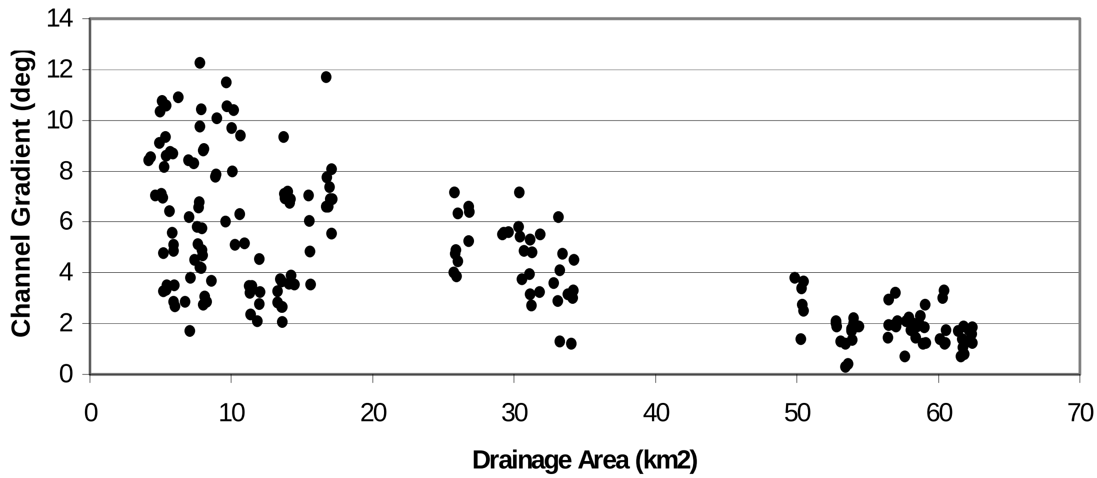



**Figure 3-4: Channel gradient versus drainage area in the Lookout Creek watershed.**

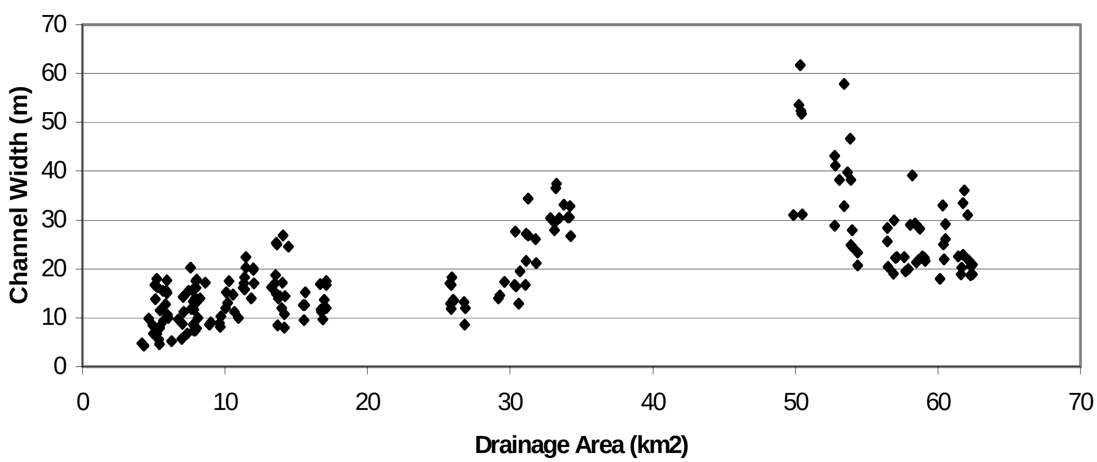



**Figure 3-5: Active channel width versus drainage area in the Lookout Creek watershed.**

Stream order was used for grouping inventoried stream segments with respect to wood transport capability (Table 3-1, Figure 3-6). Low transport capability was ascribed to 2$^{nd}$-order stream segments because average channel width was much less than 15 m, a common length for large pieces. In 3$^{rd}$- and 4$^{th}$-order stream segments channel width was approximately equal to large piece length. Average channel width was greater than large piece length in 5$^{th}$-order channel segments. Stream order designations for segments of stream length inventoried were obtained from a GIS layer of streams for the Lookout Creek watershed developed by George Lienkaemper (HJA Spatial Information Database 2004).

**Table 3-1: Flood transport capability classes.**

| Flood Transport Capability Class | Stream Order | Range of Drainage Area (ha) | Range of Channel Width (m) |
|---|---|---|---|
| Low | 2$^{nd}$ | 400-780 | 4.3-9.8 |
| Intermediate | 3$^{rd}$ – 4$^{th}$ | 490-5000 | 8.8-37.5 |
| High | 5$^{th}$ | 5000-6200 | 18.0-61.7 |

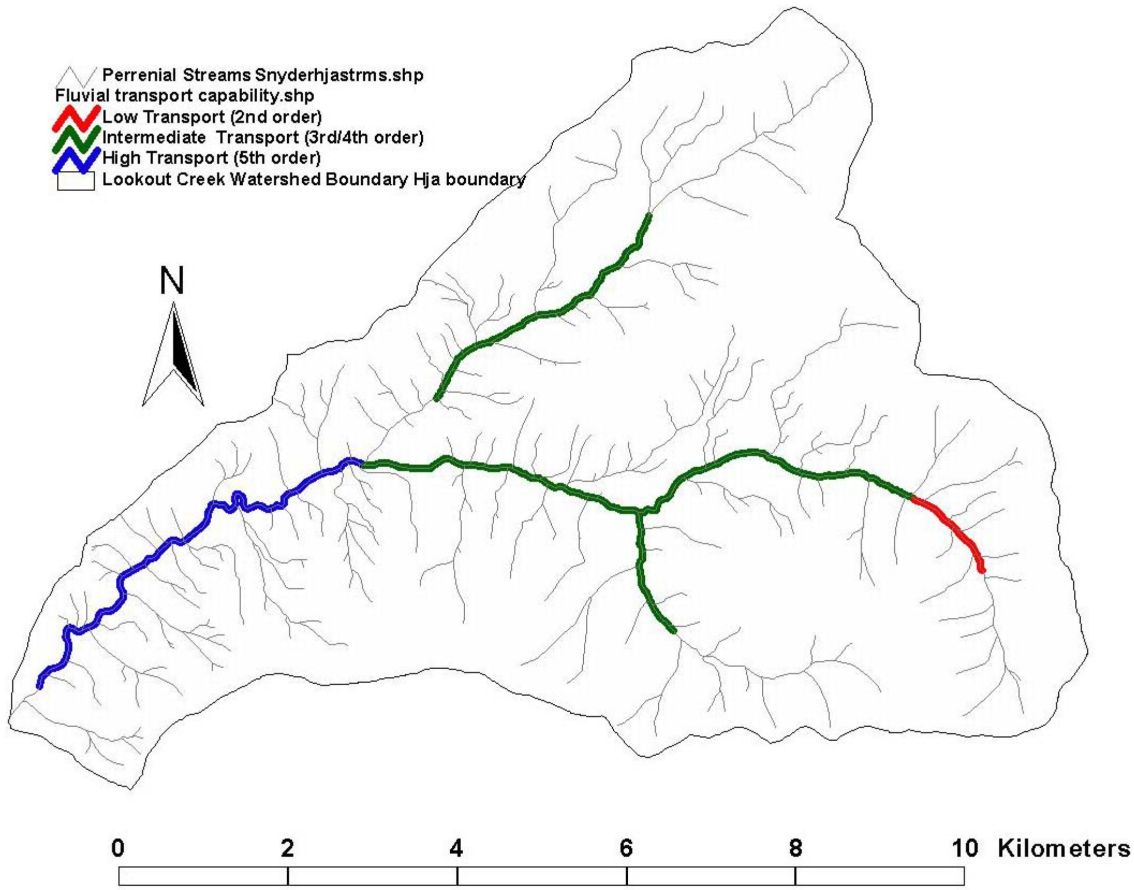



**Figure 3-6: Map depicting relative fluvial transport capability of stream segments inventoried in this study.**

## 3.3 Field survey techniques

Information on in-stream wood as well as characteristics of channel geometry and the adjacent forest conditions was collected at 100 m intervals moving in the downstream direction (Table 3-2). Within each 100 m segment, we characterized the position and arrangement of every piece of wood greater than 10 cm in diameter and 1 m in length located in or immediately adjacent to the active channel. Pieces in accumulations were defined as in contact with at least two other pieces while single pieces were defined as in contact with less than two other pieces. The longitudinal position of a single piece was defined as the central point of the portion of the piece in the channel. For accumulations a start and an end longitudinal position were recorded. The average of the start and end positions was used for the longitudinal position of the accumulation.

**Table 3-2: Variables measured for each single piece of wood, accumulation, or both in stream surveys. The classes used for each categorical variable are shown.**

| Variable | Classes |
|---|---|
| Singles & Accumulations | |
| Midpoint diameter of large wood | Class: 10-30 cm, 30-60 cm, 60+ cm |
| Length of large wood | Class: 1-5 m, 5-10 m, 10-20 m, 20+ m |
| Trapping sediment | Singles: Yes or No<br>Accumulations: None, Minimum, Moderate, High |
| Stopping feature | Streambank, Boulder, Wood, Vegetation, Island, Streambed, Rootwad |
| Emplacement process | Fluvial, Windthrow, Bank Erosion, Debris Flow, Earthflow |
| When emplaced | Pre-1996, 1996, Post 1996 |
| Orientation | With respect to high flow direction: 0-30°, 30-60°, 60-90° |
| Singles Only | |
| Cross-sectional position in channel (zone) | % in Zone: 1-4 (Robison & Beschta 1990) |
| Decay of large wood | Class: 1-5 (Triska & Cromack 1984) |
| Conifer or hardwood | Conifer or Hardwood |
| Accumulations Only | |
| Number of pieces in accumulation | Class: 3-9, 10-20, 21-50, 51-100, 100+ |
| Accumulation span | Class: 0, 1/3, 2/3, 1 |
| Type of accumulation | Fall In, Log Levee, All in Channel, Head of Island, Mass Movement, Tributary Junction, Terrace, Island |

The size and the length of all pieces of wood were estimated visually. Diameters were grouped into 3 classes (10-30, 30-60, and 60+ cm), and lengths were grouped into 4 classes (1-5, 5-10, 10-20, 20+ m). These classes were combined to produce 12 "diameter.length" piece size classes denoted as follows: 1.1, 1.2, 1.3, 1.4, 2.1, … 3.4 (Table 3-3).

**Table 3-3: "Diameter.Length" size classes for pieces of wood. Classes highlighted in bold typeface are considered "large" pieces of wood. Average volumes are derived from measurements of diameter and length of 412 pieces of wood (Appendix 2)**

| Size Class | Diameter (cm) | Length (m) | Average Volume ($m^3$) |
|---|---|---|---|
| 1.1 | 10 to 30 | 1 to 5 | 0.07 |
| 1.2 | 10 to 30 | 5 to 10 | 0.17 |
| 1.3 | 10 to 30 | 10 to 20 | 0.32 |
| 1.4 | 10 to 30 | 20 + | 0.70 |
| 2.1 | 30 to 60 | 1 to 5 | 0.40 |
| 2.2 | 30 to 60 | 5 to 10 | 1.01 |
| **2.3** | **30 to 60** | **10 to 20** | **1.87** |
| **2.4** | **30 to 60** | **20 +** | **4.02** |
| 3.1 | 60 + | 1 to 5 | 1.33 |
| **3.2** | **60 +** | **5 to 10** | **3.33** |
| **3.3** | **60 +** | **10 to 20** | **6.19** |
| **3.4** | **60 +** | **20 +** | **13.28** |

Additional data collected for each single piece included: decay class, whether it was a conifer or hardwood, if it was trapping sediment, the process which appeared to have placed it in the current location, the inferred date of placement, and orientation relative to flow direction (Table 3-2).

Additional information collected about each accumulation included an estimate of the number of pieces in the accumulation, diameter and length classification of pieces counted in the accumulation, extent of channel width occupied by the accumulation, the process(es) which appeared to have placed pieces in their current location, the inferred date of placement, accumulation type, and orientation of the accumulation relative to high flow (Appendix 1).

All variables used to describe wood conditions are categorical and were estimated visually and grouped into pre-determined classes. Some classes had been defined by previous studies (e.g. decay class), but most classes were created for purposes of this study. An element of error is associated with each class based upon the individual collecting data and the definition of the class. It was assumed that defining classifications prior to data collection and having the same two observers collecting data during the entire sampling period would minimize measurement error. However, no formal comparisons of classifications made by the two observers were conducted.

Several variables were used to characterize the channel in each 100 m segment. Channel width was measured at five points within each 100 m stream segment using a laser rangefinder. Tributaries entering the inventoried channel were identified and their longitudinal position and width at the point of confluence were measured. Boulders exceeding 1 m in diameter were counted and these counts were grouped into three boulder frequency classes: 0-10, 10-100, or >100 boulders per 100 m stream segment. Substrate types (boulders, cobble, gravel, bedrock, or sand) were estimated as percent of the area within each 100-m stream segment. Notes on channel sinuosity and constraint were made along with the locations (starting and ending points) of adjacent natural (e.g. streamside slides, windthrow patches) and human disturbances (e.g. harvest units and roads), as observed from the stream.

## 3.4 Data analysis

### 3.4.1 Explanation of dependent variables

For analysis purposes, each 100 m segment was divided into two 50 m segments. This choice was made as a scaling compromise as 50 m segments would be comparable to tree height and channel widths, allow for more precise identification of areas with particular process influences, and provide larger sample sizes.

Wood volume within each 50 m segment was calculated by applying estimated volumes to each piece found based on its “diameter.length” class and then summing the volumes for all pieces found within the segment. Volumes for each of the “diameter.length” classes were estimated using measurements of 412 pieces of large wood from several locations in the Lookout Creek watershed as a calibration set (Appendix 2). For each of the 412 pieces, diameter measurements were taken at each end and the midpoint of each piece using calipers. The length of each piece was measured using a laser range finder device.

Piece counts were used to determine the number of large pieces in each 50 m segment. A large piece was defined as a piece of wood greater than 30 cm in diameter and greater than 10 m in length, or greater than 60 cm in diameter and greater than 5 meters in length (Table 3-3). This includes pieces in diameter.length classes 2.3, 2.4, 3.2, .3.3, and 3.4. These diameter.length classes were chosen to represent large pieces because of their potential to serve a key role in the formation and persistence of accumulations. Size class 3.2, which is shorter than the other size classes in the large pieces category, was included because in channels where transport is flotation-limited there is reason to believe that diameter may be as or more important than length in determining stability (Braudrick and Grant 2000).

The number of accumulations within each 50 m stream segment was computed from field inventory data. Because it was not always possible to count all pieces in an accumulation, the number of pieces in some accumulations was estimated. Underestimation of the number of pieces was increasingly likely in larger accumulations, particularly those with more than 50 pieces because smaller pieces became more difficult to locate and large pieces could also be completely obscured from view.

Wood volume ($m^3$), number of large pieces, and number of accumulations were calculated based upon channel area per 50 m stream segment (ha). Channel area was determined by multiplying the average width for the segment by the segment length (50 m) and then converted to hectares. These values were natural log transformed to normalize the data.

### 3.4.2 Choice of metrics for characterizing wood amount

Prior research characterizing the amount of in-stream wood has employed several metrics for reporting results, such as quantity of wood per unit of channel area ($m^3/m^2$ or $m^3/ha$), per unit of stream length ($m^3/m$) and per unit of channel width ($m^3/m$). The choice of metric has largely depended on the context of the research being conducted. Per unit area is commonly used in carbon and nitrogen budgeting studies, including terrestrial/aquatic comparisons (e.g. Harmon et al. 1986). Per unit length of stream is commonly used in stream habitat inventory work focused on structures that are relevant as habitat, such as pools and pool frequency. One researcher has concluded that the choice of metric is not likely to be critical, but should be made to suit the desired objectives (Fox 2000). Analyses in this investigation were conducted using both per unit area and per unit length to facilitate the use of our findings by other researchers.

### 3.4.3 Flood transport capability analysis

Stream segments that had not been affected by debris flow or earthflow activity during the previous 50 years (i.e. those where redistribution of wood was affected only by floods, according our landscape process designation system (Figure 3-2)) were selected from the set of all segments surveyed. An ANOVA model was run using PROC MIXED in SAS v8.2 to determine if wood conditions differed between stream segments in the three classes of flood transport capability.

Model: y = f (flood transport capability class)

The six dependent variables tested included:

$y_1$ = ln [volume of wood ($m^3$)/ channel area (ha)]

$y_2$ = ln [volume of wood ($m^3$)/ channel length (50 m)]

$y_3$ = ln [number of large pieces of wood / channel area (ha)]

$y_4$ = ln [number of large pieces of wood / channel length (50 m)]

$y_5$ = ln [number of accumulations /channel area (ha)]

$y_6$ = ln [number of accumulations /channel length (50 m)]

Residuals were assessed for adherence to assumptions of normality and constant variance before results were examined. The variables volume, number of large pieces, and number of accumulations were examined for normality, independence, and equality of variance. These variables were log-normally distributed, and were therefore natural log transformed prior to statistical analysis to produce equal variances among groups. Values were back-transformed for reporting of results. A conservative Bonferroni adjustment for unplanned comparisons was used and all reported p-values have been adjusted accordingly.

### 3.4.4 Debris flow entry point and earthflow impingement zone analyses

Because of a limited sample size (eight sites), the effect of debris flows on wood conditions was analyzed using descriptive techniques. Of the eight sites where debris flows in the 50-year record had reached the mainstem channel within sections surveyed for this study, four were in surveyed segments that had intermediate flood transport capability, while the other four locations were in segments with high flood transport capability. To see whether wood amount was consistently higher in segments with debris flows entry points, box plots of wood conditions found in streams of similar flood transport capability (i.e. intermediate or high) were created to depict the range of values found in areas that had not been directly affected by debris flow or earthflow events in the previous 50 years. Scatter plots of wood conditions found in the segments where debris flows had entered the mainstem channel were then superimposed on the box plots.

The limited number of locations where earthflows were actively impinging on the channel (Figure 3-3) also made using rigorous statistical techniques to investigate proposed earthflow impingement zone signatures inappropriate. Additionally, all except one of the impingement zones had been affected by a dam-break flood event in the mid-1960s. Consequently, we chose to analyze wood amounts in, above, and below this impingement zone using longitudinal profiles that stretched 300 meters above and below the impingement zone.

### 3.4.5 Analyses of downstream influence of debris flows and dam-breaks

Portions of the mainstem channel in Lower Lookout Creek and McRae Creek were possibly affected by debris flows in 1996. The 50 m segments that make up these two debris flow-affected tracks, according to our landscape process designation system, were used to form two groups; one representative of wood conditions in streams with possible recent debris flow effects and high fluvial transport capability and another group representative of streams with possible recent debris flow and intermediate fluvial transport capability. Segments of Lookout Creek that were affected by a dam-break event in 1964 were selected to represent wood conditions in streams several decades following such an event.

Inventoried stream segments with debris flow and dam-break flood influence were compared to groups of stream segments that had only flood influence. Two groups, one for segments with intermediate transport capability and another for segments with high transport capability, that had only flood influence were assembled by choosing from all the surveyed segments that had drainage areas similar to the segments affected by debris flows and dam-break floods. "Similar" drainage area was defined as the range from 75% of the smallest drainage area in the affected length to 125% of the largest drainage area in the affected length.

Two sided t-tests were conducted in S-plus v6.1.2 in order to determine whether wood conditions differed between the following pairs of groups:

| **Process Influence** | | **Process Influence** |
|---|---|---|
| High transport capability, flood influence only | vs. | High transport capability, debris flow affected in 1996 |
| Intermediate transport capability, flood influence only | vs. | Intermediate transport capability, debris flow affected in 1996 |
| Intermediate transport capability, flood influence only | vs. | Intermediate transport capability, dam-break flood affected in 1964/65 |
| Intermediate transport capability, debris flow affected in 1996 | vs. | Intermediate transport capability, debris flow affected prior to 1996 |

The six dependent variables investigated were:

$y_1$ = ln [volume of wood ($m^3$)/ channel area (ha)]

$y_2$ = ln [volume of wood ($m^3$)/ channel length (50 m)]

$y_3$ = ln [number of large pieces of wood / channel area (ha)]

$y_4$ = ln [number of large pieces of wood / channel length (50 m)]

$y_5$ = ln [number of accumulations /channel area(ha)]

$y_6$ = ln [number of accumulations /channel length (50 m)]

Residuals were assessed for adherence to assumptions of normality and constant variance before results were examined. The variables volume, number of large pieces, and number of accumulations were examined for normality, independence, and equality of variance. These variables were log-normally distributed, and were natural log transformed prior to statistical analysis to produce equal variances among sub-samples. Values were back-transformed for reporting of results.

To investigate how selected geomorphic processes affect the arrangement of wood, histograms were created showing the distribution of volume of wood in accumulations and general accumulation type (i.e. peripheral vs. in-channel). The volume of wood in each accumulation was estimated by summing the estimated volumes (Table 3-3) for each piece in the accumulation. General accumulation type was ascribed to each accumulation using Table 3-4. Peripheral accumulations were those most often formed by wood transport processes, such as flood, while in-channel accumulations were those generally formed by wood input processes, such as windthrow.

**Table 3-4: System for classifying accumulations into either peripheral or in-channel groups.**

| Accumulation Class | Accumulation Type | Accumulation Span |
|---|---|---|
| Peripheral | Side Channel | 0, 1/3 |
| | Terrace | 0, 1/3 |
| | Island | 0, 1/3 |
| | Log Levee | 0, 1/3 |
| | Fall In | 0, 1/3 |
| | Mass Movement | 0, 1/3 |
| In Channel | All In Channel | 0,1/3, 2/3, 1 |
| | Head of Island | 0,1/3, 2/3, 1 |
| | Log Levee | 2/3, 1 |
| | Fall In | 2/3, 1 |
| | Mass Movement | 2/3, 1 |

# 4. RESULTS

## 4.1 Flood transport effects on wood conditions

### 4.1.1 Wood volume

Among stream segments that did not have debris flow or earthflow influence, the highest wood volume per unit area was found in those with low transport capability (719.0 $m^3$/ha) (Table 4-1). The lowest wood volume per unit area was found in segments with high transport capability (103.8 $m^3$/ha). Wood volume per unit area in segments with intermediate transport capability was intermediate to the two (303.5 $m^3$/ha). The wood volumes in each transport capability class were all significantly different from one another ($p < 0.001$)

The same relationship between wood volume and transport capability was not found when the analysis was performed using volume per unit of stream length as the dependent variable. Stream segments with low and intermediate transport capability had approximately the same volume per unit length (Table 4-1). The lowest wood volume per length was found in segments with high transport capability. The only significant difference was found between segments with high and intermediate transport capability (17.4 and 25.4 $m^3/50m$, $p < 0.004$) (Table 4-1).

**Table 4-1: Estimated wood volumes and 95% confidence intervals for mainstem stream segments with low, intermediate and high flood transport capability influenced by flood only over the last 50 years. Volumes denoted with different lowercase letters are significantly different at p < 0.05 after Bonferroni adjustment.**

**Per Unit Area**

| Transport Capability | N | Volume ($m^3$/ha) | LL ($m^3$/ha) | UL ($m^3$/ha) |
|---|---|---|---|---|
| Low | 24 | 719.0 a | 442.2 | 1169.1 |
| Intermediate | 192 | 305.5 b | 257.2 | 362.7 |
| High | 65 | 103.8 c | 77.3 | 139.5 |

**Per Unit Length**

| Transport Capability | N | Volume ($m^3$/50m) | LL ($m^3$/50m) | UL ($m^3$/50m) |
|---|---|---|---|---|
| Low | 24 | 24.9 | 16.3 | 38.1 |
| Intermediate | 192 | 25.4 a | 21.8 | 29.5 |
| High | 65 | 17.4 b | 13.4 | 22.5 |

### 4.1.2 Number of large pieces

Among stream segments influenced by flood only, those with low transport capability had the highest number of large pieces per unit area, whereas stream segments with high transport capability had the lowest number of large pieces per unit area (Table 4-2). Significant differences in the number of large pieces were observed between high and intermediate transport capability ($p < 0.0001$), and high and low transport capability groups ($p < 0.0001$). There is some evidence of a significant difference between intermediate and low transport capability groups ($p < 0.10$).

The same relationship between the number of large pieces and transport capability was not found when the analysis was performed using the number of large pieces per unit of stream channel length as the dependent variable. The number of large pieces per unit length in segments with low and intermediate transport capability was approximately the same number, while the number of large pieces per unit length was lower in segments with high transport capability (Table 4-2). There is some evidence that a significant difference between high and intermediate transport capability groups may exist ($p < 0.09$).

**Table 4-2: Estimated number of large pieces and 95% confidence intervals for mainstem stream segments with low, intermediate and high flood transport capability influenced by flood only over the last 50 years. Values denoted by different lower case letters are significantly different at p < 0.05 after Bonferroni adjustment.**

**Per Unit Area**

| Transport Capability | N | Large Pieces (#/ha) | LL (#/ha) | UL (#/ha) |
|---|---|---|---|---|
| Low | 24 | 72.7 a | 40.9 | 128.9 |
| Intermediate | 192 | 38.2 a | 31.2 | 45.6 |
| High | 65 | 12.9 b | 8.8 | 18.5 |

**Per Unit Length**

| Transport Capability | N | Large Pieces (#/50m) | LL (#/50m) | UL (#/50m) |
|---|---|---|---|---|
| Low | 24 | 3.6 | 2.3 | 5.3 |
| Intermediate | 192 | 3.6 | 3.1 | 5.2 |
| High | 65 | 2.6 | 2.0 | 3.4 |

### 4.1.3 Number of accumulations

As transport capability increased, fewer accumulations per unit area were found in stream segments affected by flood only (Table 4-3). The number of accumulations per unit area was highest in channels with low transport capability (32.5 accumulations/ha) and lowest in channels with high transport capability (8.6 accumulations/ha). Significant differences were observed among all groups ($p < 0.0001$). (Table 4-3)

When the number of accumulations was analyzed on a per unit of channel length basis instead of a per area basis, the relationship between number of accumulations and transport capability was not observed and no significant differences between groups were found (Table 4-3). Segments with intermediate transport capability had the highest number of accumulations (2.5 accumulations/50m) and while segments with high transport capability had the lowest number of accumulations (1.9 accumulations/50m).

**Table 4-3: Estimated number of accumulations and 95% confidence intervals for mainstem stream segments with low, intermediate and high flood transport capability influenced by flood only over the last 50 years. Values denoted by different lower case letters are significantly different at p < 0.05 after Bonferroni adjustment.**

**Per Unit Area**

| Transport Capability | N | Accumulations (#/ha) | LL (#/ha) | UL (#/ha) |
|---|---|---|---|---|
| Low | 24 | 87.3 a | 67.9 | 112.0 |
| Intermediate | 192 | 44.4 b | 40.6 | 48.6 |
| High | 65 | 22.3 c | 19.0 | 26.0 |

**Per Unit Length**

| Transport Capability | N | Accumulations (#/50m) | LL (#/50m)) | UL (#/50m) |
|---|---|---|---|---|
| Low | 24 | 2.3 | 1.9 | 2.8 |
| Intermediate | 192 | 2.5 | 2.3 | 2.8 |
| High | 65 | 1.9 | 1.2 | 2.5 |

### 4.1.4 Accumulation size and type

Differences in the size of accumulations, in terms of both volume and number of pieces, were observed among flood transport capability classes. Stream segments with low transport capability had the highest mean accumulation volume; however, accumulations in these segments also had the most restricted range of volume and number of pieces (Figure 4-1). The lowest mean accumulation volume was found in stream segments with high fluvial transport capability, but the variability of volume and number of pieces were greater than in any other transport capability class. The mean number of pieces in accumulations was roughly equal in all transport capability classes.

The variable effectiveness of floods on the arrangement of wood can be inferred from the changing frequency of peripheral accumulations that are commonly created when wood is floated during floods (Figure 4-2). Peripheral accumulations were infrequent in stream segments with low transport capability. This suggests that floods are not an effective control on wood arrangement in streams with low transport capability. In stream segments with high transport capability, the frequency of peripheral accumulations is equal to or greater than the frequency of in-channel accumulations across the entire range of accumulation volumes. This suggests that floods have a strong effect on wood arrangement in streams with high transport capability. In streams with intermediate transport capability, peripheral accumulations are frequent (>50%) among smaller accumulations (smallest four volume classes), but larger peripheral accumulations are absent (largest four volume classes). This indicates that the effectiveness of floods on wood arrangement in this transport class is generally limited to smaller accumulations.

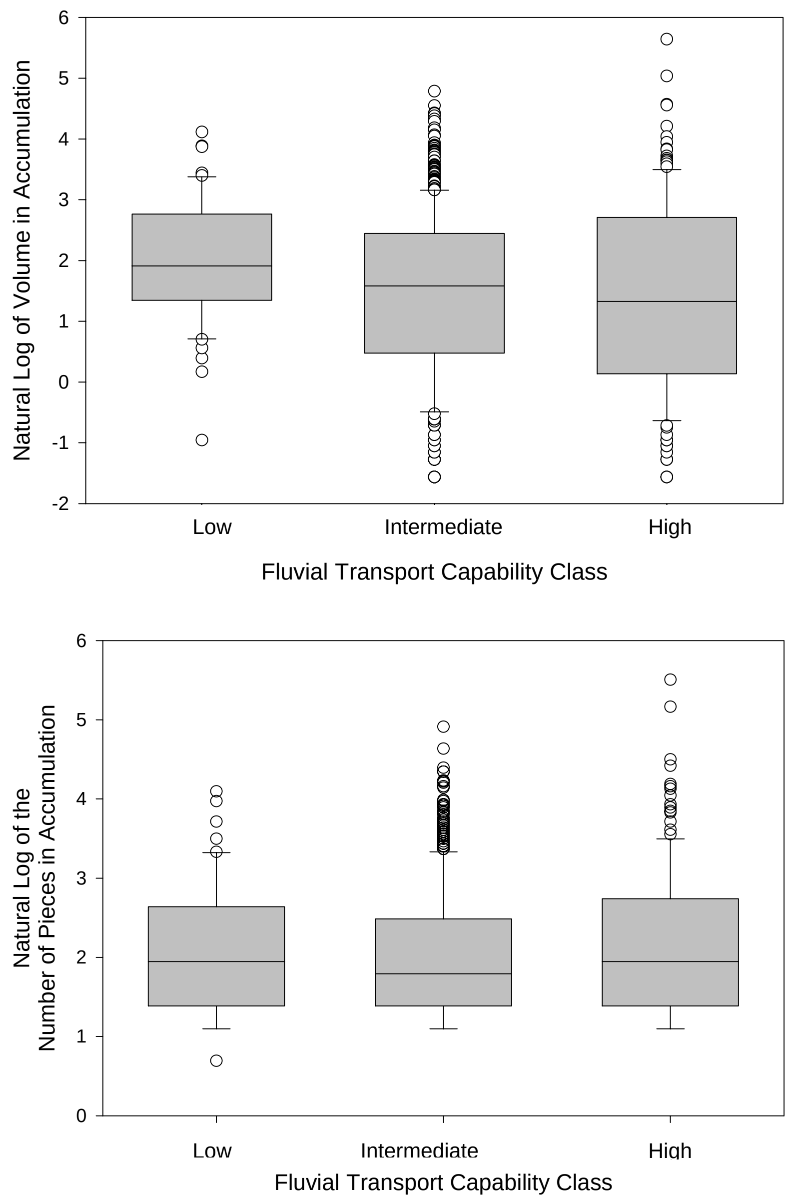



**Figure 4-1: Variation in the volume of and number of pieces in accumulations found in stream segments affected by flood only.**

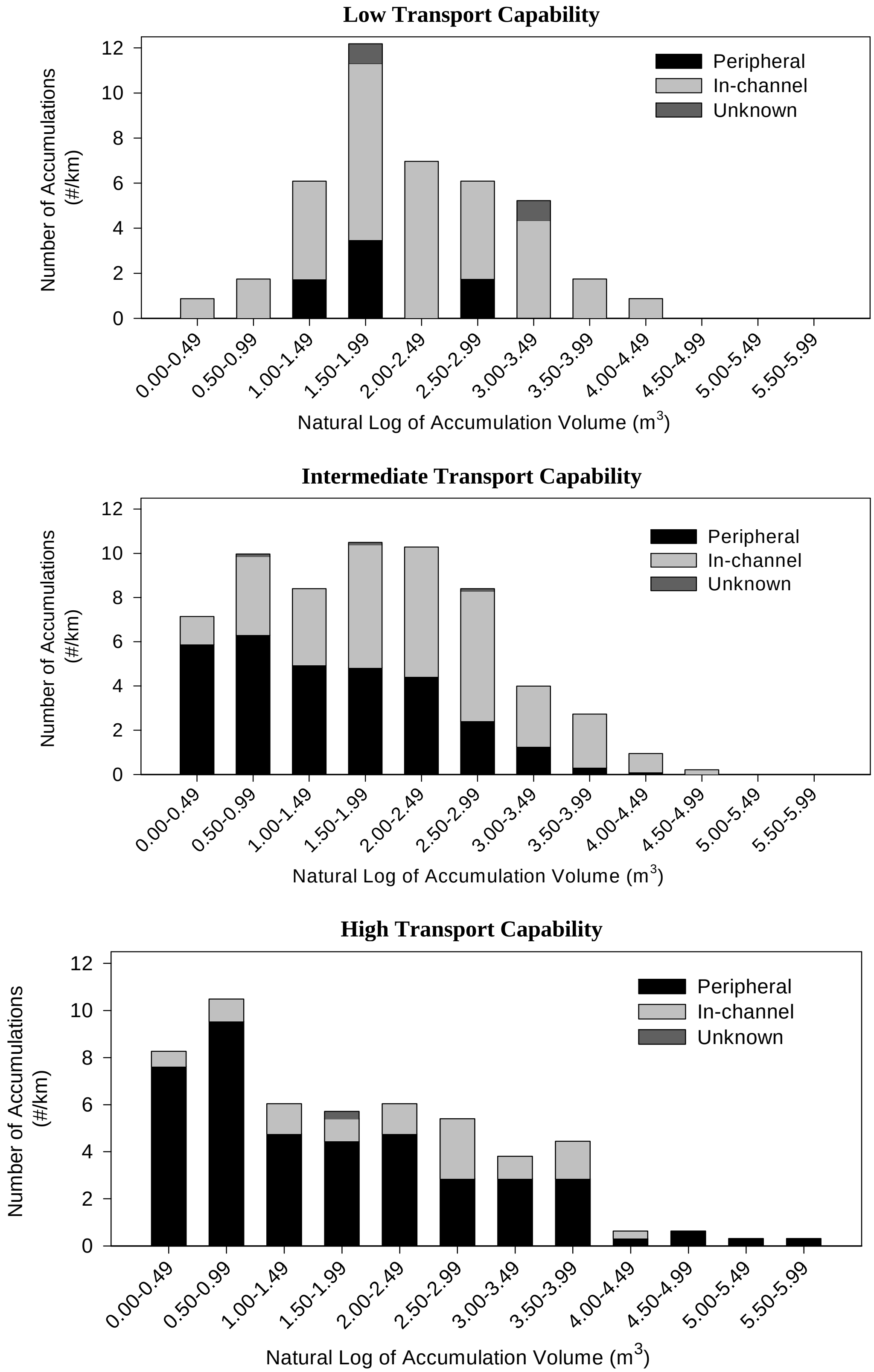



**Figure 4-2. Frequency of accumulation volume in the three fluvial transport capability classes.**

## 4.2 Debris flow effects on wood conditions in mainstem streams

### 4.2.1 Debris flow entry points into mainstem streams

Wood volume in mainstem stream segments with a debris flow entry point was never greater than two standard deviations from the mean for segments with flood influence only (Figure 4-3). In the four segments with high transport capability and a debris flow entry point, three segments had wood volumes less than the average value for all segments with flood influence only, while wood volume at the fourth entry point was approximately equal to the average for segments affected by flood only. In segments with intermediate transport capability and a debris flow entry point, two had amounts above the average observed in streams of similar transport capability and flood influence only, while the other two had amounts that were below the average.

### 4.2.2 Downstream debris flow effects in mainstem streams

#### 4.2.2.1 Mainstem streams with intermediate transport capability

Among stream segments with intermediate transport capability, wood volume was lower in segments that had been affected by a debris flow in 1996 than in segments with similar transport capacity and drainage area that were only affected by floods (Table 4-4). The difference was greater (44% vs. 31% lower in debris flow affected segments) when comparisons were made on a per area basis in a two sided t-test rather than on a per length basis. However, the difference in means was statistically significant only when analyzed on a per unit area basis.

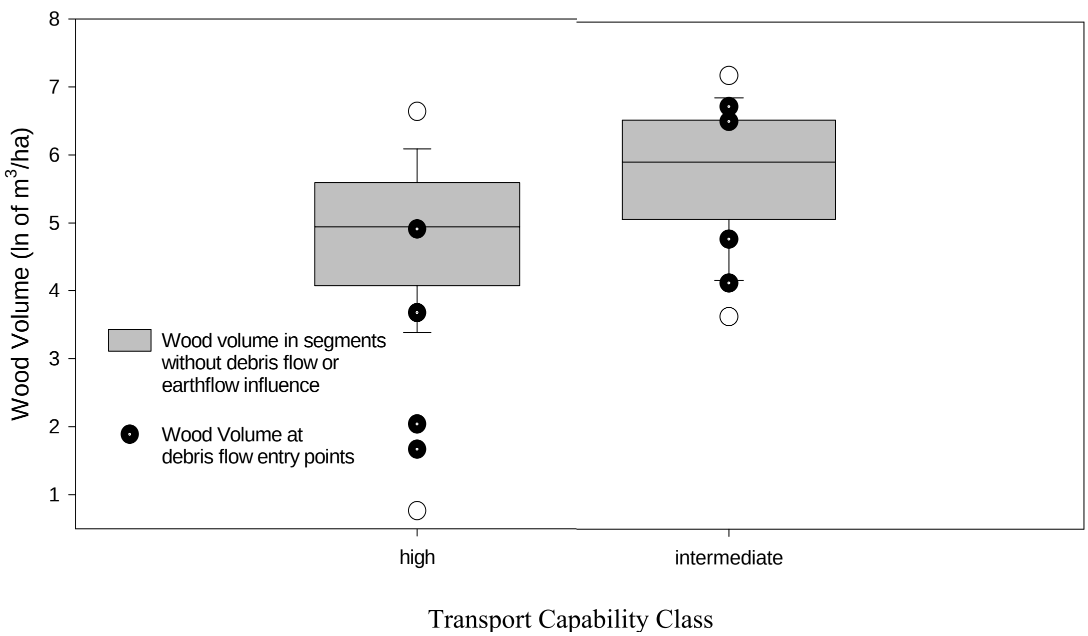



**Figure 4-3: Wood volume in 50-m mainstem stream segments where debris flows have entered the channel within the last 50 years superimposed on the wood volume found in stream segments with similar flood transport capacity that did not experience debris flow or earthflow activity in the last 50 years.**

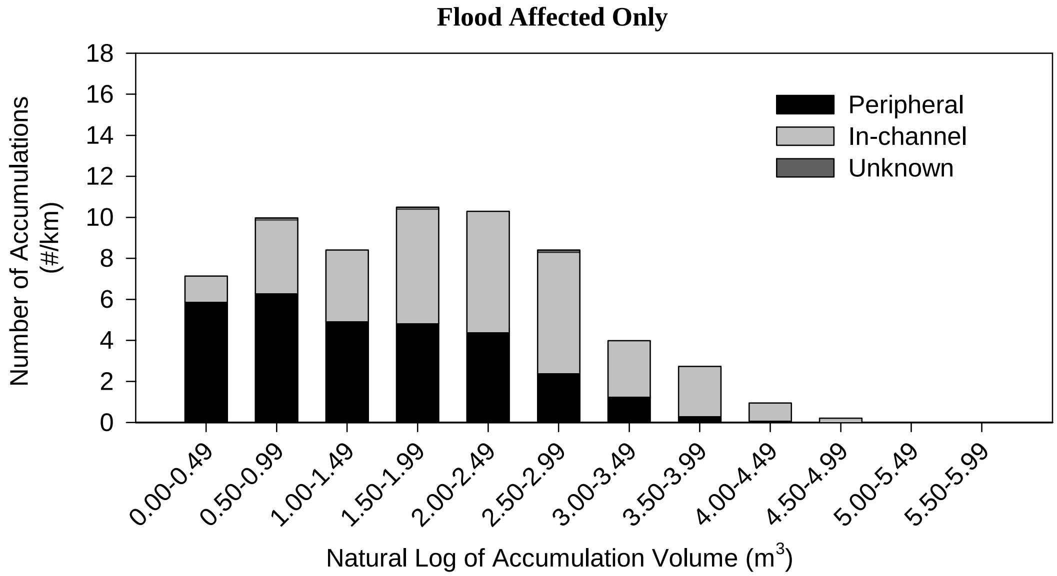
Stream segments with intermediate transport capability that had been affected by debris flows also had fewer large pieces than segments that were not affected by debris flows (Table 4-4). The difference was greater (45% vs. 18% lower in debris flow affected segments) when comparisons were made on a per area basis rather than on a per length basis. However, based on a two sided t-test, statistically significant differences between the means were not found in either comparison.

Stream segments with intermediate transport capability that had been affected by debris flows in 1996 had fewer accumulations than those that had not been affected by debris flows (Table 4-4). On a per area basis, the difference between the mean number of accumulations was significant. However, mean values for the two groups on a per length basis were not significantly different (Table 4-4).

**Table 4-4: Estimated wood volume, number of large pieces, number of accumulations, and p-values from two sided t-tests for differences in mean values between mainstem stream segments with intermediate transport capability and no debris flow or earthflow activity since the 1950's and those with similar drainage area and 1996 debris flow effects in McRae Creek.**

| | Flood Only | Debris Flow 1996 | df |
|---|---|---|---|
| N (50 m segments) | 46 | 18 | 62 |
| **Per Unit Area** | | | p-value |
| Volume ($m^3$/ha) | 404 | 228 | 0.04 |
| Number of Large Pieces (#/ha) | 55 | 30 | 0.10 |
| Number of Accumulations (#/ha) | 54 | 40 | 0.01 |
| **Per Unit Length** | | | |
| Volume ($m^3$/50 m) | 29 | 22 | 0.29 |
| Number of Large Pieces (#/50 m) | 4.5 | 3.7 | 0.40 |
| Number of Accumulations (#/50 m) | 2.9 | 2.8 | 0.83 |

The range of accumulation volume was similar between the groups of intermediate transport segments that had been affected by debris flows in 1996 and those affected only by flooding (Figure 4-4). However, a greater portion of the accumulations in segments affected by debris flow was located along the channel periphery than in segments affected by flood only. This suggests that a mass of wood delivered to the main channel in the 1996 debris flow may have shoved wood to the sides of the channel as it moved downstream, forming the peripheral accumulations.



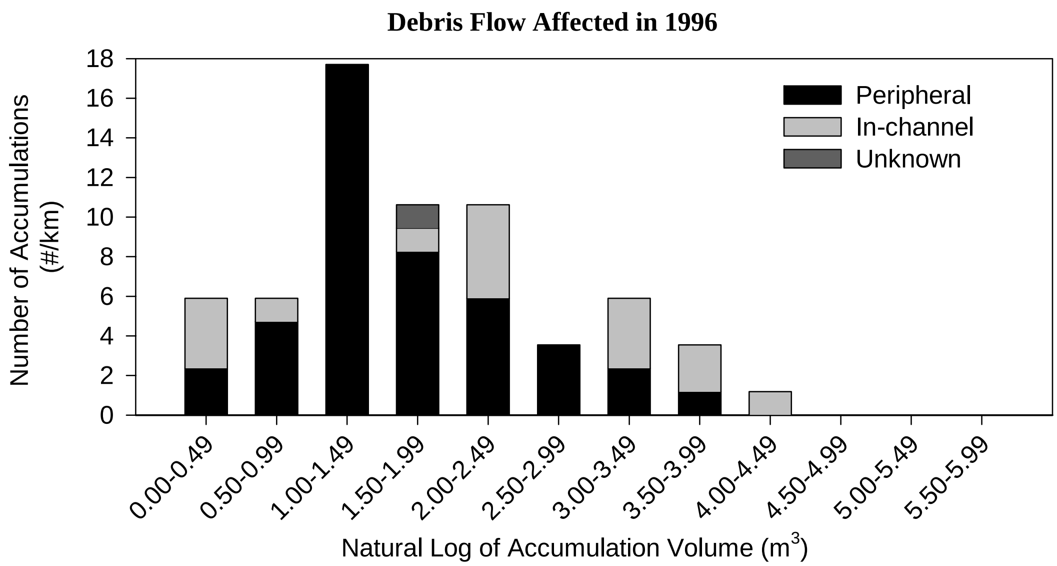




**Figure 4-4: Frequency of accumulation volume in 50-m mainstem stream segments with intermediate transport capability affected only by floods or segments in McRae Creek affected by debris flow in 1996.**

#### 4.2.2.2 Mainstem streams with high transport capability

Differences in wood volume, number of large pieces, and number of accumulations between stream segments with high transport capability that had been affected by debris flows in 1996 and segments with similar transport capability and drainage area that had been influenced only by floods were not statistically significant (Table 4-5).

**Table 4-5: Estimated wood volume, number of large pieces and number of accumulations from two sided t-tests for differences in mean values between mainstem stream segments with high transport capability, similar drainage area, and no debris flow or earthflow activity since the 1950's and those with 1996 debris flow effects in Lower Lookout Creek.**

| | Flood Only | Debris Flow 1996 | |
|---|---|---|---|
| | | | df |
| N (50 m segments) | 65 | 27 | 90 |
| **Per Unit Area** | | | p-value |
| Volume ($m^3$/ha) | 104 | 121 | 0.61 |
| Number of Large Pieces (#/ha) | 12.9 | 14.4 | 0.66 |
| Number of Accumulations (#/ha) | 22.3 | 22.5 | 0.95 |
| **Per Unit Length** | | | |
| Volume ($m^3$/50m) | 17.4 | 15.9 | 0.91 |
| Number of Large Pieces (#/50m) | 2.6 | 2.3 | 0.70 |
| Number of Accumulations (#/50m) | 1.9 | 2.3 | 0.38 |

The distribution of accumulation types indicates that peripheral accumulations are more frequent in segments affected by debris flows in 1996 than segments without debris flow influence. However, the debris flow-affected segments had fewer accumulations and generally lacked accumulations in the largest volume classes.

Accumulations with the greatest volume were found in the high transport stream segments affected only by flood and are dominated by island and terrace accumulations. During the most recent rearrangement event in 1996, these channel features may have been sites of wood deposition in flood-affected reaches and sites of wood removal in debris flow affected reaches (Figure 4-5).

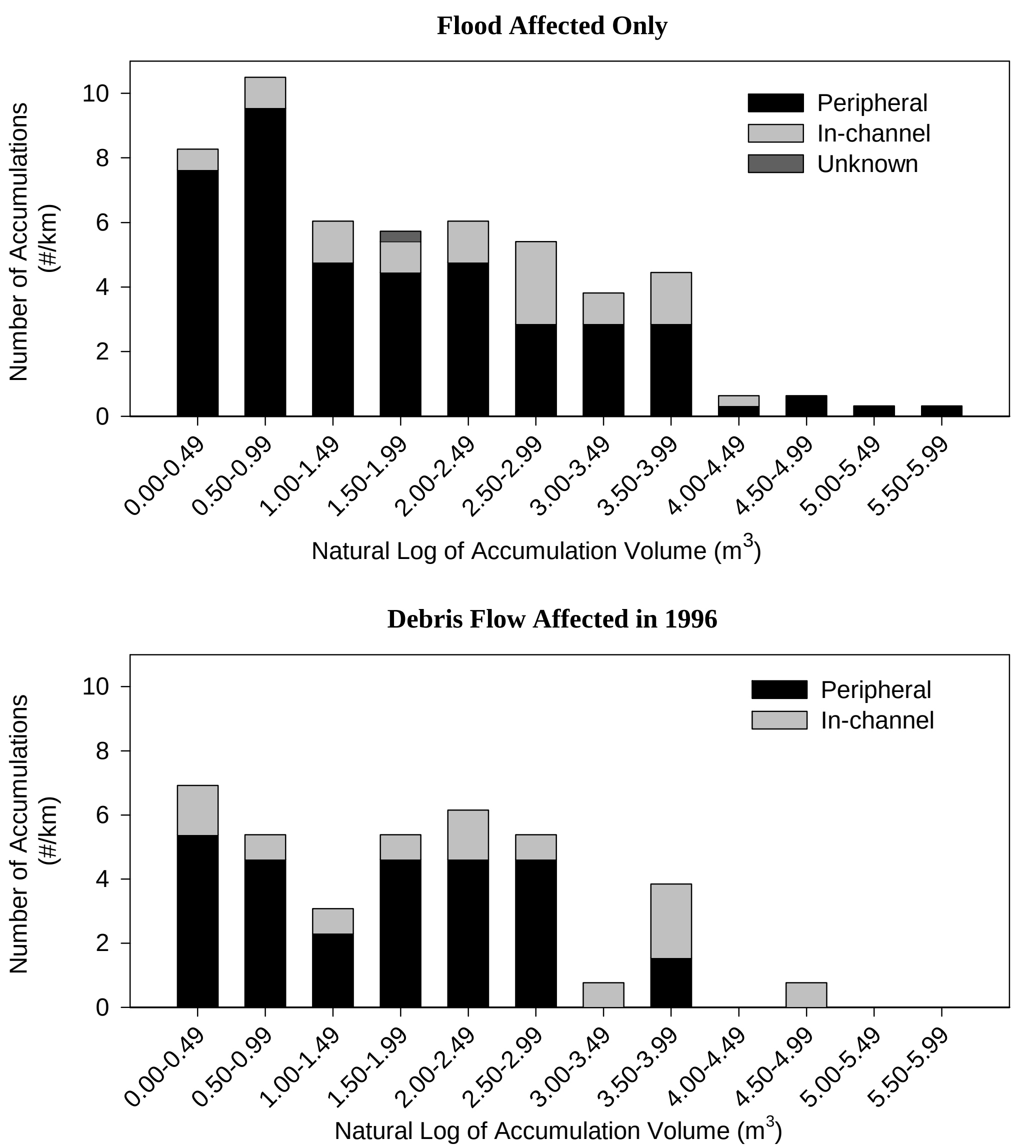



**Figure 4-5: Frequency of accumulation volume in 50-m mainstem stream segments with high transport capability affected only by floods or segments in Lower Lookout affected by debris flow in 1996.**

### 4.2.3 Persistence of debris flow effects in mainstem streams

Wood volumes were higher in mainstem stream segments with more recent debris flows from tributary streams than in those that were affected by debris flows more than 6 years prior to measurement. Wood volume per unit area was approximately 43% higher in segments with high transport capability affected by debris flows in 1996 when compared to segments affected by debris flow prior to 1996 (Table 4-6). However, based on a two sided t-test, mean values for the two groups were not significantly different. The difference was greater in stream segments with intermediate transport capability with volume per unit area being approximately 3.5 times higher in segments affected by debris flows in 1996 as compared to segments with earlier debris flows (Table 4-7). The mean values for the two groups were significantly different based on a two sided t-test.

Wood volumes were also higher in segments more recently affected by debris flows when the analysis was carried out with volume per unit length as the dependent variable. Wood volume per unit length was approximately 22% higher in segments with high transport capability affected by a debris flow in 1996 when compared to segments with high transport capability that were affected by debris flow prior to 1996 (Table 4-6). Mean values for the two groups were not significantly different based on a two sided t-test. In stream segments with intermediate transport capability, volume per unit length was approximately 4.4 times higher affected by debris flows in 1996 compared to segments affected by debris flow prior to 1996

(Table 4-7). The mean values for the two groups were found to be significantly different based on a two sided t-test.

**Table 4-6: Estimated volume, number of large pieces and number of accumulations from two sided t-tests for differences in mean values between channels with high transport capability, similar drainage area, and debris flow activity in 1996 and those with debris flow activity prior to 1996.**

| | Debris Flow 1996 | Debris Flow Pre-1996 | |
|---|---|---|---|
| | | | df |
| N (50 m segments) | 27 | 19 | 44 |
| **Per Unit Area** | | | p-value |
| Volume ($m^3$/ha) | 121 | 88 | 0.36 |
| Number of Large Pieces (#/ha) | 7.2 | 5.5 | 0.86 |
| Number of Accumulations (#/ha) | 22.5 | 21.8 | 0.90 |
| **Per Unit Length** | | | |
| Volume ($m^3$/50m) | 15.9 | 13.5 | 0.63 |
| Number of Large Pieces (#/50m) | 2.3 | 2.4 | 0.86 |
| Number of Accumulations (#/50m) | 2.3 | 2.2 | 0.46 |

When the number of large pieces was used as the dependent variable in comparisons of the two groups, the results were similar in most respects to the results of the volume analyses. In segments with high transport capability, the number of large pieces per unit area was approximately 28% greater for 1996 debris flow-affected segments (Table 4-6). Stream segments with intermediate transport capability had 13.8 times more large pieces per unit area in segments affected by debris flow in 1996 (Table 4-7). The number of large pieces per unit length in segments with high transport capability was slightly smaller for the group affected in 1996, and the difference in means was not significant (Table 4-6). In stream segments with intermediate transport capability, the number of large pieces per unit length was 5.3 times greater in segments affected by debris flows in 1996 (Table 4-7).

**Table 4-7: Estimated volume, number of large pieces and number of accumulations from two sided t-tests for differences in mean values between channels with intermediate transport capability, similar drainage area, and debris flow activity in 1996 and those with debris flow activity prior to 1996.**

| | Debris Flow 1996 | Debris Flow Pre-1996 | |
|---|---|---|---|
| | | | df |
| N (50 m segments) | 18 | 12 | 28 |
| **Per Unit Area** | | | p-value |
| Volume ($m^3$/ha) | 228 | 65 | 0.01 |
| Number of Large Pieces (#/ha) | 30 | 2 | < 0.01 |
| Number of Accumulations (#/ha) | 40 | 33 | 0.17 |
| **Per Unit Length** | | | |
| Volume ($m^3$/50m) | 22 | 5 | < 0.01 |
| Number of Large Pieces (#/50m) | 3.7 | 0.7 | < 0.01 |
| Number of Accumulations (#/50m) | 2.8 | 1.2 | < 0.01 |

Analysis of the number of accumulations in high transport segments showed no significant differences while the number of accumulations was found to be significantly different in segments with intermediate transport capability.

## 4.3 Earthflow effects on wood conditions in mainstem streams

### 4.3.1 Earthflow impingement zone

Wood volumes above, in and below the earthflow impingement zone in Upper Lookout Creek were highly variable (Figures 4-6). The percentage of wood volume in each 50-m segment inferred to have been added to the channel prior to 1996 remained fairly constant in each region.

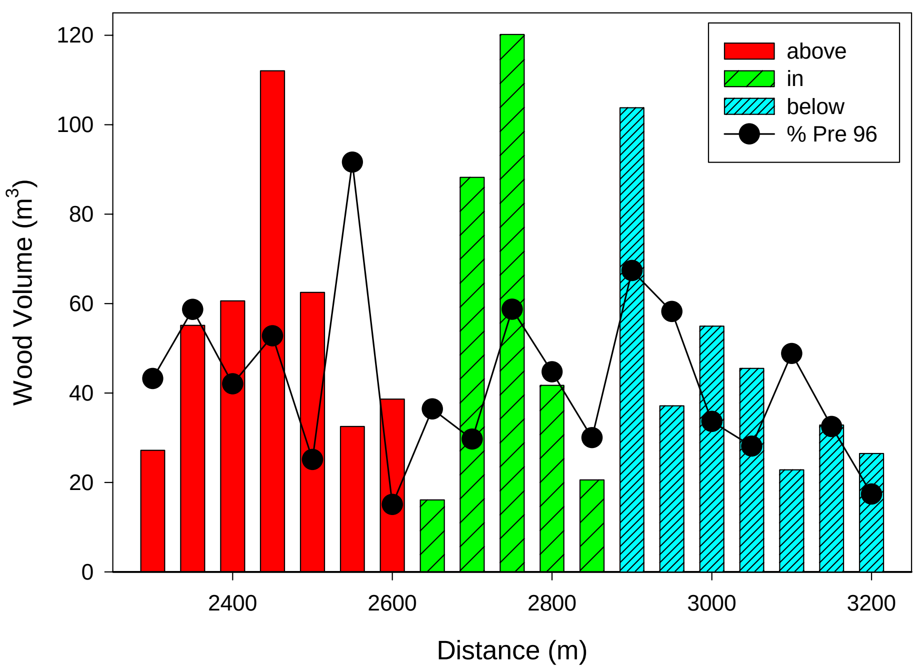



**Figure 4-6: Wood volume above, in, and below the earthflow impingement zone in Upper Lookout Creek. Line plot indicates the percentage of wood volume inferred to have entered the stream prior to 1996.**

### 4.3.2 Downstream effects of dam-break floods

Wood volume per unit area was approximately 1.5 times greater in stream segments downstream of the earthflow in Upper Lookout Creek that were affected by a dam-break flood in 1964/65, when compared to stream segments with similar drainage area and transport capability that were affected only by floods (Table 4-8). Mean wood volume per unit length was higher in segments affected by the dam-break, but the difference between the means of the two groups was not statistically significant based on a two sided t-test.

The number of large pieces was approximately 1.4 times greater in segments affected by the dam break in terms of both number per unit area and per unit length (Table 4-8). However, the difference in means was statistically significant only when analyzed on a per unit length basis based on two sided t-tests.

The numbers of accumulations were not significantly different for both per area and per length measures based on two sided t-tests (Table 4-8).

**Table 4-8: Estimated wood volume, number of large pieces and number of accumulations from two sided t-tests for differences in mean values between channels with intermediate transport capability, similar drainage area, and no debris flow or earthflow activity since the 1950's and those with 1964 dam-break flood effects in Upper Lookout.**

| | Flood Only | Dam-Break 1964/65 | |
|---|---|---|---|
| | | | df |
| N (50 m segments) | 76 | 32 | 106 |
| **Per Unit Area** | | | p-value |
| Volume ($m^3$/ha) | 376 | 574 | 0.05 |
| Number of Large Pieces (#/ha) | 48 | 69 | 0.18 |
| Number of Accumulations (#/ha) | 52 | 50 | 0.70 |
| **Per Unit Length** | | | |
| Volume ($m^3$/50m) | 25 | 34 | 0.16 |
| Number of Large Pieces (#/50m) | 3.9 | 5.6 | 0.06 |
| Number of Accumulations (#/50m) | 2.6 | 2.1 | 0.70 |

# 5. DISCUSSION

The objective of this study was to investigate whether selected hydrologic and geomorphic processes create characteristic patterns in the amount and arrangement of large wood found within 2$^{nd}$- to 5$^{th}$-order mainstem channels. Observations of flood, debris flow, and earthflow activity within the Lookout Creek watershed over the 50 years prior to the study allowed us to delineate process influence zones within inventoried stream reaches. We were particularly interested in changes in wood amount and arrangement patterns resulting from downstream increases in fluvial transport capability. We also wanted to investigate the influence of debris flow and earthflow processes on wood amount and arrangement patterns in 3rd- to 5th-order, mainstem stream channels.

## 5.1 Flood transport influence on in-stream wood amount and arrangement

Findings from our analyses of both wood amount and arrangement support the hypothesis that transport of wood by floods increases in the downstream direction as channels become wider. In our study, less wood was found in streams with higher transport capability. Similar decreases in wood amount have been found as channel width increases have been observed in other studies of streams (Swanson et al. 1982, Harmon et al. 1986, Bilby and Ward 1989).

Because a high magnitude flood event occurred only six years prior to our inventory, the magnitude of the difference observed in wood amount between the transport capability groups may be as large as would be expected for watersheds in the western Cascade Range. The 1996 flood may have mobilized and exported most of the in-channel wood found in portions of the watershed with high transport capability. Some mobilization is likely to have occurred in segments with low transport capability, but generally the distance traveled by pieces would be short and not result in substantial changes in wood amount.

Besides physical changes in the channel that increase wood transport capability, such as increasing channel width, additional factors are probably contributing to the decreasing amount of wood in the downstream direction. The amount of wood added to the stream by trees toppling decreases in the downstream direction as the amount of non-forested valley floor increases (McDade et al. 1990, Van Sickle and Gregory 1990, Meleason et al. 2003). Because trees that yield large wood do not grow in the active channel area, the rate of wood delivery to a channel on a per unit area basis decreases as channel width increases.

Another factor that may be contributing to downstream decreases in wood amount is variation in land-use history within the Lookout Creek basin. More harvesting of streamside forests occurred in the lower portion of the watershed than in the upper portion and may have depressed the amount of large wood in segments with high transport capability. Czarnomski (2003) reported that harvest and road building adjacent to a stream reach could influence wood conditions for more than 50 years. A logical and necessary extension of this work is to examine how the interaction of the human activity and natural processes affects wood amount.

There are substantially fewer studies that have examined aspects of wood arrangement, such as accumulation frequency, type and size, than studies that have examined wood amount over larger spatial scales (Swanson et al. 1976, Martin and Benda 2001, Abbe and Montgomery 2003). Two findings from our analysis of wood arrangement indicate the influence of fluvial transport increases in the downstream direction. First, accumulation frequency decreased as transport capability increased.

Second, as fluvial transport capability increased, the number of accumulations created by lateral input of wood, such as fall-in accumulations, decreased while the number of accumulations created by in-channel transport of wood, such as log levees, increased.

Accumulation frequency was expected to decrease with increasing transport capability because accumulations located in the active channel would be more susceptible to removal if they were in channel segments with higher transport capability. Also, the fraction of the total wood population that is long enough to serve as key pieces in accumulations diminishes in the downstream direction. While segments with high transport capability had the lowest accumulation frequency in terms of per unit area and per unit length, a systematic decrease in accumulation frequency was observed only on a per unit area basis.

Other studies that have investigated accumulation frequency have reported conflicting results. Martin and Benda (2001) found an increase in interjam distance (i.e. decrease in the frequency of accumulations) with increasing drainage area in a 132-$km^2$ watershed in southeast Alaska. However, this relationship was strongly influenced by values at the two largest drainage areas out of a sample size of 28. Abbe and Montgomery (2003) reported a downstream increase in the frequency of accumulations up to drainage areas of 300 $km^2$ in a 742-$km^2$ coastal watershed on the Olympic Peninsula of Washington, USA. Within the range of drainage areas that is common to all three studies, the variability on a per length basis is quite high and does not indicate a strong, consistent relationship between stream size and accumulation frequency. This suggests that use of accumulation frequency in characterizing arrangement pattern is likely to be inappropriate at scales less than 100 $km^2$, such as watersheds like Lookout Creek (64 $km^2$).

The expected increase in accumulation size with increasing transport capability was not observed. While most of the accumulations with the greatest volume were found in streams with high transport capability, the average accumulation volume did not increase with transport capability. The average number of pieces per accumulation is likely to increase in the downstream direction because a greater proportion of the total wood population can be mobilized by high flows and incorporated into accumulations. However, corresponding increases in accumulation volume are not necessarily going to be as large. Accumulations with many, small pieces can have volumes less than or comparable to accumulations initiated by streamside toppling that contain only a few, very large pieces. Abbe and Montgomery (2003) also noted this and additionally point out that locating the largest, key pieces is often difficult because they can easily be obscured by other smaller pieces that have accumulated around the key piece(s).

Increases in transport capability were expected to result in a shift from accumulations formed by local input of wood to those formed by transport of wood. The only other study that has described changes in accumulation types is Abbe and Montgomery (2003), who identified a general downstream progression from *in situ* /autochthonous to combination (peripheral/in-channel) and eventually transport/allochthonous accumulation types. Changes in the types of accumulations observed in this study are most similar to the transition between *in situ* and combination accumulation types. Accumulation types can be useful in the examination of wood effects on sediment retention. For example, accumulations created by debris flows often have tightly networked pieces of wood and can efficiently trap sediment and wood, whereas pieces in accumulations created by toppling and streamside sliding are often more loosely associated and less efficient at trapping sediment.

## 5.2 Debris flow and earthflow influence on in-stream wood amount and arrangement

### 5.2.1 Debris flow entry points and earthflow impingement zones

We found no evidence to support the hypothesis that debris flow entry points have significantly higher amounts of wood than segments affected only by floods. The wood volumes observed at eight debris flow entry points were all within the range of variability observed for stream segments that had similar transport capability and had been influenced only by floods. This finding is in agreement with Snyder (2000) who did not observe substantial wood loads at debris flow track intersections with mainstem channels in this same study area. However, our results are in conflict with findings in the Oregon Coast Range where deposition was found to occur at tributary junctions (Benda and Cundy 1990).

The differences between the findings in the Cascades and the Coast Range are likely to be caused by a higher mobilization capability of channels where debris flows enter mainstem channels in the HJA. Within the Lookout Creek watershed topographic and soil properties as well as the high potential for rain-on-snow runoff create a convergence of debris flow tributary entry points with mainstem channels that are wide enough to allow fluvial redistribution of larger pieces. Channels of similar (i.e. $4^{th}$- and $5^{th}$-) order in the Coast Range are narrower and less capable of transporting larger pieces. Additionally, stream network structure can affect debris flow runout. Some Coast Range stream networks appear to have a trellis-like structure with a high density of high-angle channel junctions at positions along debris flow tracks where they can impede downstream movement of debris flows. In contrast, Cascade Range stream networks appear to have more dendritic structures where the change in channel direction at junctions is not as great.

Similarly, there was no evidence supporting the hypothesis that areas either above or within earthflow impingement zones have higher amounts of wood than the areas below the impingement zone. However, only one earthflow impingement zone was available for analysis in this study. Therefore, additional studies that investigate wood conditions around more earthflows are necessary to more fully characterize the effect of earthflows on wood conditions.

### 5.2.2 Mainstem channels below debris flow entry points and earthflow impingement zones

Some evidence supports the hypothesis that differences in the transport capability of mainstem channels affected by debris flows would contribute to differences in wood conditions. Wood arrangement in debris flow-affected segments with intermediate transport capability was dominated by peripheral accumulations, which implies that wood had been pushed to the sides of the channel by the debris flow. In contrast, in-channel accumulation types created by toppling of streamside trees composed a greater portion of accumulations in segments with intermediate transport capability that were not affected by debris flows. Similar differences in the pattern of wood arrangement were not observed in segments with high transport capability, which implies that the influence of flood transport can overwhelm the effects of debris flows that enter larger channels.

While the presence of debris flows appears to create differences in wood arrangement patterns, such as frequency of accumulation types, their influence on wood amount was more difficult to ascertain. We expected that additional wood delivered by debris flows to mainstem channels would result in higher wood amounts in segments influenced by debris flow than in segments affected only by floods. However, our results did not support this hypothesis. Considering the strong flood effect on wood conditions observed in this study the relatively low amount of wood in stream segments with high transport capability that were affected by debris flows from

Watershed 3 in February 1996 is not surprising. Two other factors may explain why wood amounts below the entry point were lower than average in the high transport capability site below Watershed 3. First, the debris flows occurred prior to the passage of the peak flood flow in Lookout Creek. Consequently, wood introduced by the debris flow was present in the mainstem channel during the period of time when the greatest amount of fluvial redistribution would have occurred. Second, debris flows in Watershed 3 had also occurred in 1964/65, purging much of the wood in the source tributary channels. In the 30 years that followed, dense stands of red alder had developed along the debris flow track. Consequently, the wood introduced to Lookout Creek by debris flows that occurred in Watershed 3 in 1996 was smaller and less voluminous than the wood delivered in 1964/65.

We did observe higher wood amounts in segments with intermediate transport capability in McRae Creek that had been affected by debris flow than segments with intermediate transport capability in other parts of the stream network that had been affected only by flood. However, the observed difference was not great enough to support the hypothesis that wood introduced to mainstem channels by the debris flows would significantly elevate wood amounts in affected sections. Even though only one event is being analyzed, it is somewhat surprising given that Johnson et al. (2000) indicate that the amount of wood carried by the 1996 debris flow that entered McRae Creek was relatively high.

A few factors may be contributing to lower than expected amounts of wood in the debris flow-affected length of McRae Creek. It is possible that the debris flow was not carrying pieces large enough to become lodged in the mainstem channel. Additionally, harvesting in the wood source area along the debris flow-affected reach in McRae may have reduced the general abundance of larger pieces of wood. Czarnomski (2003) found harvesting had occurred within 40 m of the channel over a 300 m stretch within the 800 m of debris flow-affected length and wood volume and number of pieces in this stretch were lower than along other portions of the debris-affected length.

The character of the 1996 debris flow in McRae Creek may have also contributed to the lower than expected amounts of wood in segments with intermediate transport capability that were affect by the debris flow. Johnson et al. (2000) found evidence of congested wood movement in the section of McRae Creek designated as debris flow affected in our study. We observed a downstream increase in wood emplaced in 1996 in the debris flow-affected portion of McRae (Figure 5-1). These findings suggest greater wood mobilization than deposition in the upstream portion of the debris flow-affected area while the opposite (i.e. deposition > mobilization) occurred in the downstream portion. If wood input to upstream segments where wood mobilization dominated was low in the eight years since the debris flow, then wood amounts in those segments would be very low and could have reduced the overall average wood amount for debris flow-affected segments with intermediate transport capability.

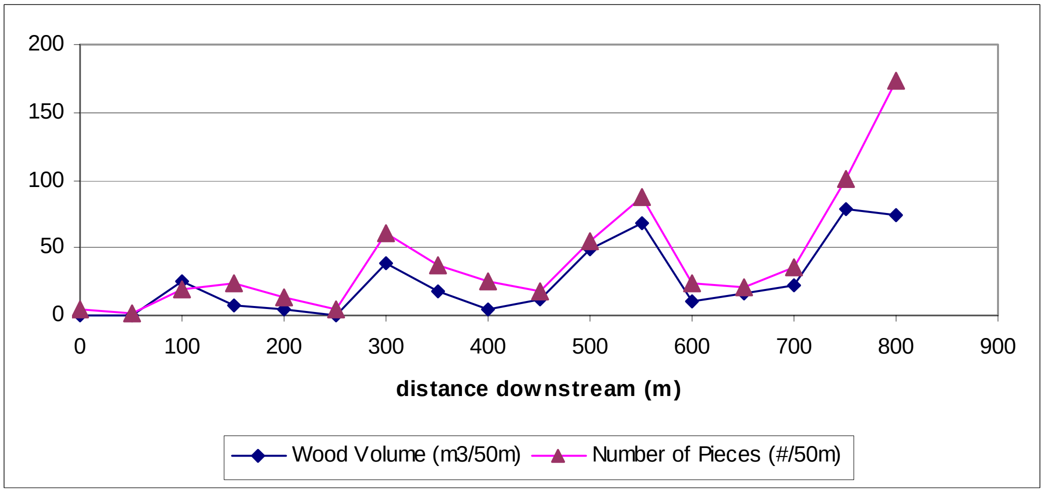



**Figure 5-1: Volume and number of pieces of wood that entered the stream in 1996 in the segments of McRae Creek below the debris flow entry point.**

Because only one dam-break event is known to have occurred in the Lookout Creek watershed within the last 50 years, we were not able to compare the downstream effects in channels with different transport capability as was done with the debris flows. However, a comparison of wood amounts in dam-break affected segments and those with similar transport capability and drainage area that were affected only by flood consistently showed higher volumes and numbers of large pieces in dam-break influenced segments.

### 5.2.3 Temporal considerations of in-channel disturbance processes

There are a number of temporal considerations that need to be considered in analyzing in-stream wood conditions found in any stream network. One factor that was not directly addressed in this study is the age of stands contributing wood to the channel. In the HJA, the wood source area is composed primarily of old-growth conifer forests and riparian alder stands. This leads to a very wide range size in the pieces being added to the stream network. However, species composition and size in other geographic locations may be very different and can have important implications for input, redistribution and loss of wood.

Flood history is also important to consider because it affects the size of pieces and the amount of wood in the channel that can be redistributed during floods. In the HJA, the 1964 flood had a greater number of larger pieces of wood from old-growth conifer stands to mobilize than the 1996 flood, which had a greater number of smaller pieces in the channel as a result of alder stands that had established following the 1964 flood. Flood history becomes a sampling issue when you look at wood conditions relative to the last major redistribution (or input) event.

Lags in tree mortality caused by disturbances can also affect in-stream wood conditions. Several studies have noted that in-channel disturbances, such as debris flows and dam-break flood pulses, can lead to mortality of trees in riparian forest areas and have effects on the forest development (Coho 1993, Johnson et al. 2000, Acker et al. 2003). For example, alder stands that develop shortly after a disturbance may eventually lead to an increase in the number of smaller pieces of wood delivered to the stream. These disturbance processes can also weaken or kill larger trees as a result of disruption of their root systems by bank erosion, deposition leading to raised water tables, or physical damage.

The higher amounts of wood in segments with intermediate transport capability that were affected by a dam-break flood pulse in 1964 than segments affected by a debris flow in 1996 may be an outcome of such a lag in tree mortality following disturbance and indicates how these events may influence wood conditions for many decades. Currently there are patches of standing dead trees in and adjacent to the channel in the section of stream length affected by the dam-break flood and associated deposits in Upper Lookout. These trees were killed when their bases were buried by several meters of flood-deposited, coarse sediment. Fragmentation and toppling of these snags may be responsible for the higher amounts of wood observed in the dam break flood-affected segments in Upper Lookout. Trees adjacent to the channel in the 1996 debris flow-affected section of McRae Creek that suffered fatal damage may not have had adequate time to begin contributing substantial amounts of wood. Given the protracted period of time it takes for standing dead trees to fragment or topple, elevated rates of wood input could continue for decades in these sections.

At the other end of the temporal spectrum is within-flood timing, which can also affect wood conditions. Debris flows in 1996 occurred prior to the peak of the flood flows. Consequently, debris flow deposits could be remobilized within the same flood event.

### 5.2.4 Contexts and limitations

The strength of our inferences is very limited due to the small number of locations where debris flows and earthflows had impacted the mainstem channel in areas we inventoried. Among mountain stream networks, the western Cascades of Oregon is a region of fairly high incidence of debris flows traveling into mainstem channels. Nakamura et al. (2000) found 22 of 39 debris flows delivered wood to 4$^{th}$ and 5$^{th}$-order channels in the Blue River basin that includes the Lookout Creek watershed.

Despite the relatively high frequency of debris flows, the portion of the Lookout Creek stream network affected by debris flows is limited to the lower portion of the basin where channels generally have intermediate to high transport capacity (Figure 5-2). Consequently, it is likely that wood delivered to mainstem channels by debris flows will be redistributed during the same storm event that caused the debris flow. Earthflows affecting mainstem channels also occur over a fairly confined area (Figure 5-2). Debris flows and earthflows may have very different effects on wood conditions in stream networks with other configurations of debris flow-prone channels to fluvial redistribution capability.

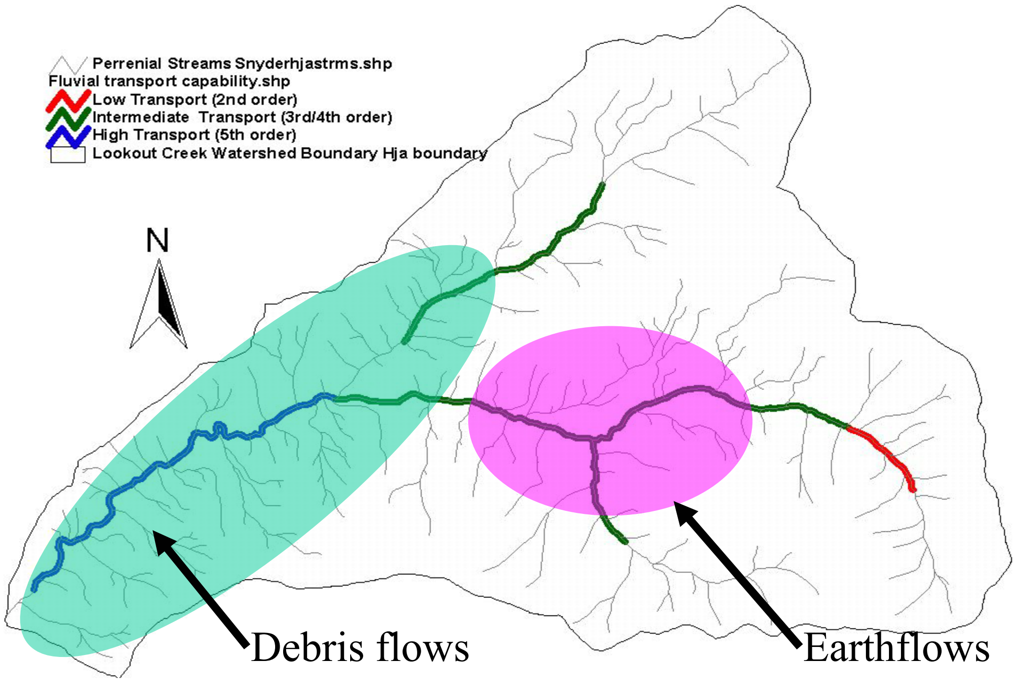



**Figure 5-2: Generalized zones of debris flow and earthflow process influence in the Lookout Creek basin.**

While the timing of floods, debris flows and dam-break flood pulse events could be identified with reasonable accuracy, we were not able to address the magnitude of these events. For example, we could not assess whether the amount of wood introduced by the two 1996 debris flow events or the dam-break flood events were comparable.

It is also important to recognize that this study was carried out in a watershed that has a somewhat unique management history for the western Cascade Range. Cutting in the Lookout Creek watershed began in the early 1950s, was largely curtailed at the end of the 1960s, and only infrequently during the 1970s and 1980s. Extensive cutting on other Forest Service lands began later in the 1950s and continued into the

1990s. Harvesting on private lands in the region also began in the early 1950s, but has continued unabated. Because of the timing of management in the Lookout Creek watershed, particular harvesting and road building techniques were employed that are unlike those of recent decades. Consequently, transferring conclusions drawn from this study to other areas within the region must carefully consider important elements of management history, such as ownership and timing of human activity.

## 6. CONCLUSIONS

This study investigated whether selected hydrologic and geomorphic processes created characteristic patterns of their activity in the amount and arrangement of large wood found within mainstem channels of the Lookout Creek watershed in the western Cascade Range. Observations of flood, debris flow and earthflow activity within the Lookout Creek watershed over a 50-year period prior to the study were used to delineate process influence zones within inventoried stream reaches. In general, while earthflows and debris flows directly affect a relatively small amount of the total stream length, results exhibit how the effects of these processes on wood conditions can extend beyond the immediately affected areas and over several decades in areas where fluvial transport of wood is more limited. Our findings support the following conclusions:

- Decreasing amounts of wood as well as an increase in the proportion of accumulation types formed by fluvial transport signal an increase in influence of fluvial transport in the downstream direction.

- Wood amounts were not higher in locations where debris flows entered mainstem channels or where earthflows were directly impinging on the mainstem channel than in segments without those influences. This is due to the relatively high mobilization capability of mainstem channels in these locations.
- Lower wood amounts and a greater proportion of accumulations located along the channel margin in recently debris-flow affected segments than in segments that had been affected by floods only. Congested wood movement associated with the entry of debris flows into mainstem channels may be responsible for these differences.
- Wood amounts were higher in segments affected by a dam-break flood pulse that occurred in 1964 or 1965 than in recently debris flow affected segments and segments affected only by floods. Trees adjacent to the channel damaged or killed by the dam-break flood event may be responsible for the observed differences and suggest that the effects of in-channel disturbances on wood conditions may continue for several decades.

**Part 2: Changes in wood conditions over 25 years in selected western Cascade stream channels**

## 7. INTRODUCTION

The importance of large wood (> 1 m long and ≥ 0.1 m in diameter) in stream ecosystems of the Pacific Northwest region of North America is well established. Changes in channel morphology (Faustini and Jones 2003), sediment storage (Harmon et al. 1986, Nakamura and Swanson 1992, Montgomery et al. 1996, Massong and Montgomery 2000), stream habitat (Keller and Swanson 1979, Abbe and Montgomery 1996), and riparian forest development and disturbance (Johnson et al. 2000, Acker et al. 2003) are ecological and geophysical features influenced by wood in stream networks within the Pacific Northwest region and in forested systems globally.

Wood dynamics, an expanding theme of wood in rivers research, considers changes in amount, location and arrangement of wood (i.e. wood conditions) throughout watersheds along with the processes that are responsible for movement of wood into and through stream networks. Several approaches have been used to investigate changes in in-stream wood, including periodic relocation of marked (Bilby 1984, Gregory in press) and unmarked (Lienkaemper and Swanson 1987) pieces; historical reconstruction techniques such as dendrochronology (Swanson et al. 1976, Keller and Tally 1979, Hogan et al. 1998) and isotope dating analysis (Hyatt and Naiman 2001); direct manipulation of wood (Gregory and Wildman 1999, Keim et al. 2000); repeat mapping (Swanson et al 1984, Lienkaemper and Swanson 1987, Nakamura and Swanson 1993, Hogan et al. 1998, Faustini 2001) and simulation modeling (Benda and Cundy 1990, Van Sickle and Gregory 1990, Martin and Benda 2001, Meleason et al. 2003).

Studies of wood dynamics in Pacific Northwest streams have demonstrated that wood from conifers can persist for more than 100 years and may last for millennia if pieces are buried and saturated. Additionally, pieces longer than bankfull width can be stable for decades. Consequently, greater stability of wood is found in smaller stream channels. However, studies that analyze changes in in-stream wood over a range of channel sizes are fairly limited (Zimmerman et al. 1967, Lienkaemper and Swanson 1987, Nakamura and Swanson 1993, Young 1994, Miller and Benda 2001).

This study investigated changes in wood conditions in 1st- to 5th-order channels in basins of different sizes over a period of approximately 25 years that included a flood event with 50-year recurrence interval. Large pieces of wood introduced to the stream channel from adjacent forests range from 1 – 50 meters in length and have maximum diameters of 2 meters. The stream channels studied, like many in the western Cascade Range, are relatively steep and straight with rough cobble beds. Lateral migration of the active channel due to bank cutting is generally very limited. Channel widths range from a few meters in 1st- and 2nd-order channels to tens of meters in 5th-order channels.

The factors examined in this study that could affect changes in in-stream wood include:

1) Location within a watershed
2) Size of wood
3) Arrangement of wood
4) Location of wood relative to the active channel
5) Processes influencing the input and loss of wood

We were specifically interested in determining whether:

1) Change would be greater in larger basins than in smaller basins.
2) Change would be greater among small pieces than large pieces, particularly in smaller basins, because small pieces are more mobile than large pieces.
3) Change would be greater among single pieces than pieces in accumulations, because pieces in accumulations are more stable due to their association with other pieces in the accumulation.
4) Change would be greater among pieces in the active channel than pieces out of the active channel, because high flows that could affect wood out of the channel are more infrequent.
5) Fluvial transport caused more change in larger basins than smaller basins.
6) Inputs from toppling were similar among all sites and not related to basin size.

7) Outputs from decomposition were similar among all sites and not related to basin size.

This study is distinctive for two reasons. First, the length of the study period over which changes are analyzed is longer than most wood dynamics field investigations. This time scale is better aligned with the processes involved in wood input, decomposition, and redistribution. Second, the study capitalizes on mapped records of in-channel wood configurations in order to examine changes in wood and to interpret the history of processes that may have caused the observed changes.

## 8. FRAMEWORK

In-stream wood conditions can change as the result of a number of processes that add wood (i.e. input processes), move wood (i.e. redistribution processes), and remove wood from the channel (i.e. loss processes) (Figure 8-1). Keller and Swanson (1979) first described the spatial variability of processes influencing wood conditions and provided a general outline of where processes responsible for input, redistribution and loss were influential in a longitudinal stream profile in the western Cascade Range. Nakamura et al. (2000) described how these processes can be linked in a “disturbance cascade” and recent work by Miller and Benda (2001) has incorporated estimates of various process rates in a quantitative wood budgeting approach. We utilized prior studies and long-term observations of our study sites to formulate a hypothetical system of influence for wood input and redistribution processes for streams in the western Cascade Range (Figure 8-2).

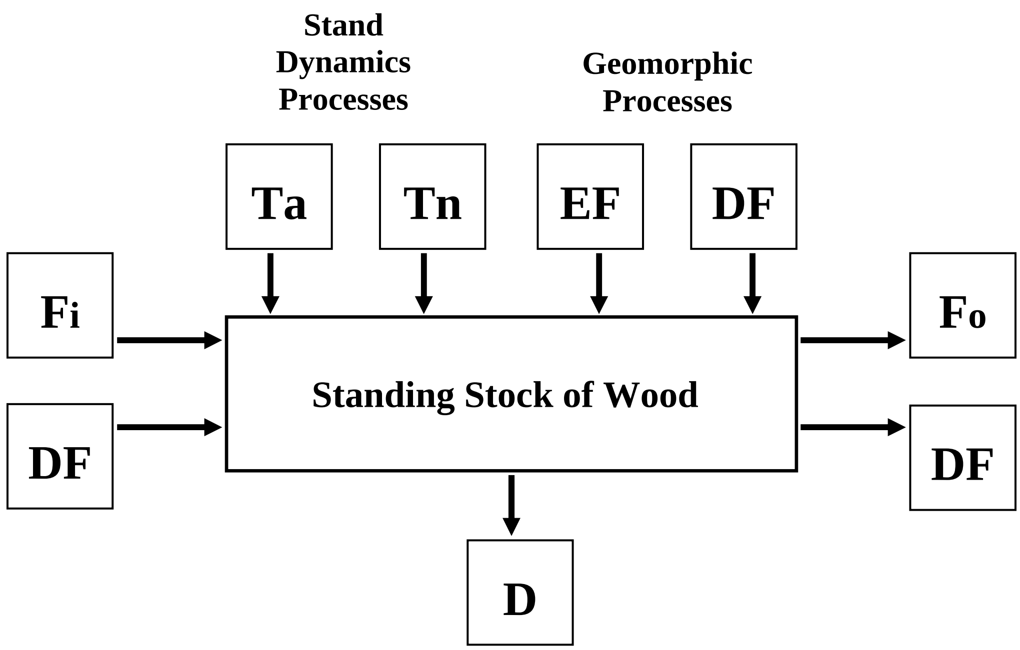



**Figure 8-1: Processes influencing wood input and output processes within western Cascade mountain stream reaches (bold rectangle). Toppling near streambank (Tn), toppling away from streambank (Ta), earthflow movement (EF), and debris flow (DF) activity make up the suite of input processes. Redistribution processes include debris flow (DF) in small channels as well as flotation transport into (Fi) and out of (Fo) a stream reach. Loss via decomposition (D) results in release of gases to the atmosphere and dissolved nutrient material to stream water and fragmentation to particles smaller than the large wood category.**

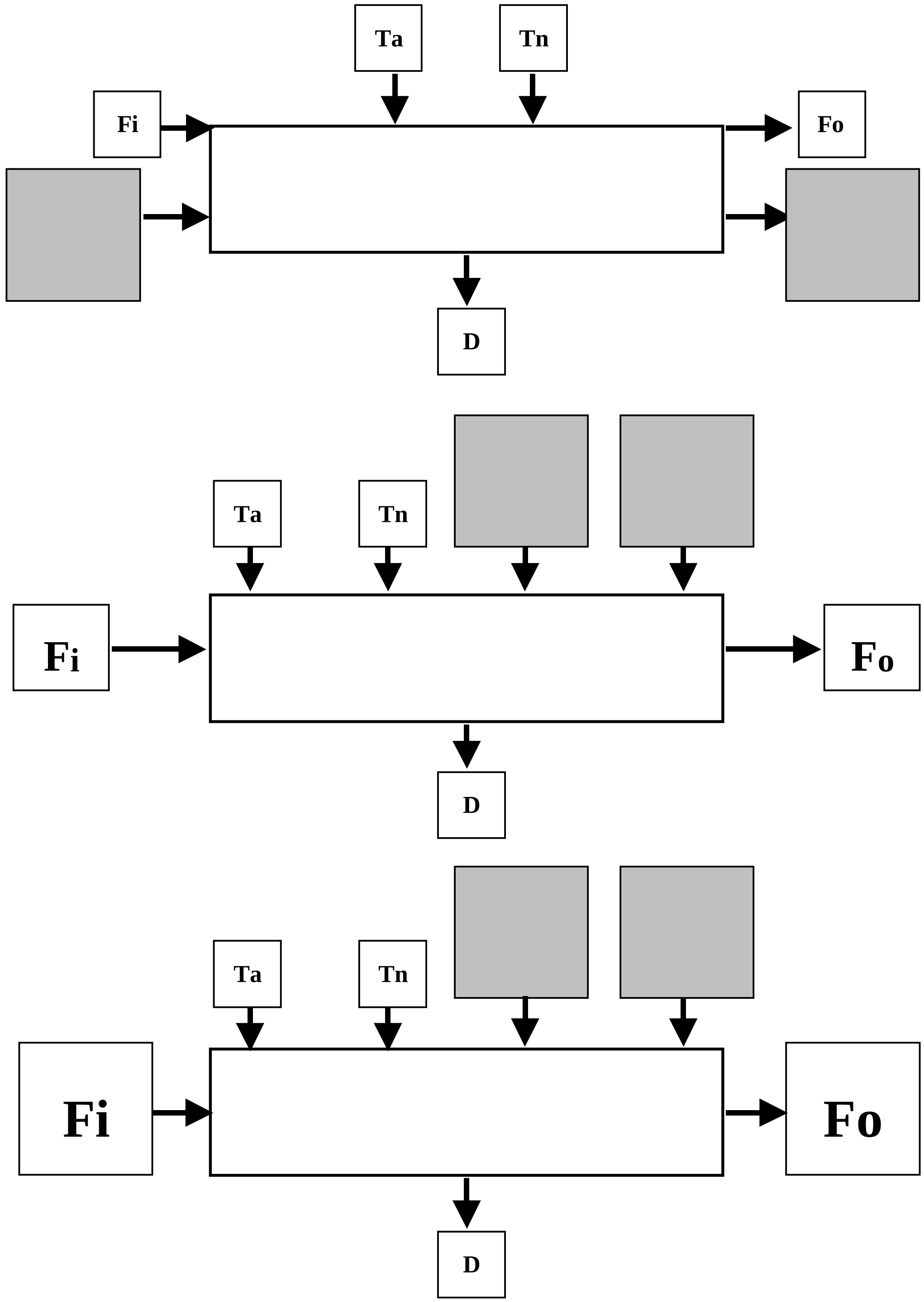



**Figure 8-2: Hypothesized relative influence of wood input, redistribution and loss processes expected over the 25-year study period on the standing stock of wood in small, intermediate-sized, and large channel types. Box size indicates the relative magnitude of process influence. Shading indicates that the process was not active in inventoried sites during the study period.**

## 8.1 Input processes

### 8.1.1 Toppling

Trees in the riparian area that topple into streams are generally rooted within a distance equal to the height of the tallest trees in the adjacent forest. The area defined by this distance away from the stream bank can be divided into two separate zones, near-stream and away-from-stream, based on the processes that cause the toppling of trees. Toppling of trees in the near-stream zone may in part be the result of undercutting by lateral channel erosion. In general, the incidence of toppling in the near-stream zone increases in the downstream direction as bank erosion increases, and as more streamside trees lean into canopy openings over the channel. Trees from the away-from-stream zone enter the channel as a result of forest disturbance processes, such as windthrow and root rot. Localized effects that influence the susceptibility of trees to wind and rooting conditions are important controls on the incidence of toppling in the away-from-stream zone.

Lienkaemper and Swanson (1987) concluded that wind-related toppling was the dominant input process for streams in old-growth Douglas-fir forests of the western Cascade Range and estimated rates of input to be between 5 and 22 $m^3$/ha-yr for 1st- through 5th-order channels in the region. Because steep hillslopes are frequently in close proximity to the channel there is little lateral channel movement. Consequently, the near-stream zone is limited to a few (0-3) meters where trees rooted in the streambank are susceptible to destabilization. Because the near-stream zone is generally less than 10% of the area where toppling contributes wood to the stream, most wood comes from the away-from-stream zone (McDade et al. 1990).

### 8.1.2 Debris flow

Debris flows are rapid (10 m/s) downslope or down-channel movements of 10s – 1000s $m^3$ of soil, vegetation, and alluvium. Hillside slides (i.e. debris slides) may turn into debris flows if they enter narrow, steep stream channels (Swanson et al. 1978). In the western Cascade Range, debris flows occur primarily in steep, geologically unstable areas within elevation bands where rain-on-snow processes augment runoff or where harvest and road construction have elevated susceptibility of debris slides (Snyder 2000).

Within the western Cascade region, wood in small (1st- and 2nd-order) channels can be mobilized by debris flows and deposited in larger (3rd-order and higher) channels. High discharges in larger channels may mobilize debris flow-deposited material immediately or shortly after deposition (i.e. within the same flood) or deposits may persist for years. The author is unaware of any quantification of wood added to streams by debris flows.

### 8.1.3 Earthflow

Earthflows are discrete areas of slow moving (mm – m/yr) mass movements of unstable soil and rock material. Earthflows encroaching on stream channels can cause changes in the direction of stream flow that may lead to increased levels of bank erosion on the side of the channel opposite of the earthflow. Because of their movement, earthflow toes are also more unstable and prone to streamside sliding. Both of these situations can elevate inputs of wood to the stream from forests adjacent to the stream. However, no estimates of wood input resulting from earthflow movement have been reported.

## 8.2 Redistribution processes

### 8.2.1 Flood transport

Wood movement by floods has been documented using a variety of techniques including periodic surveying of mapped channel sections (Swanson et al. 1976; Megahan 1982; Toews and Moore 1982, Lienkaemper and Swanson 1989), relocating marked pieces (Bilby 1984, Gregory pers. comm.), physical modeling (Braudrick and Grant, 1999) and direct observation (Grant pers. comm.). Wood redistribution during floods has been found to be constrained by the relationship of piece size to channel width and water depth (Lienkaemper and Swanson 1987, Bilby and Ward 1989, Braudrick and Grant 2000). In mid- and high-order streams wood transported during a flood can travel as individual pieces or in batches of interacting pieces, called “congested” wood movement (Braudrick and Grant 1999, Johnson et al. 2000).

### 8.2.2 Debris Flow

Redistribution of wood by debris flows is generally limited to small, 1st – 3rd order channels in the western Cascade Range (Snyder 2000). Benda and Cundy (1990) found that confluences of tributaries carrying debris flows and mainstem channels were likely to be deposition sites. This is because of abrupt changes in the direction of flow or rapid energy dissipation that occurs when a debris flow moves from the narrow, confined source tributary channel into a wider, lower-gradient, mainstem channel. Alluvial fans have also been identified as deposition sites for debris flows because as the debris flow thins when it spreads out over a fan resistance to flow increases and may cause the debris flow to stop (Grant and Swanson 1995).

Debris flows and earthflows may also be associated with dam-break flood pulse events in larger (4th-order and higher) channels. Dam-break flood pulses can occur when accumulations formed by debris flows or earthflows break up during floods. During a dam-break flood event a mass of wood moves downstream in a congested mode of transport (Coho 1993, Braudrick and Grant, 2000), often causing significant damage to riparian vegetation and possibly triggering secondary erosion processes, such as streamside sliding, along the area they travel through (Benda and Zhang 1989, Coho 1993).

## 8.3 Loss processes

### 8.3.1 Decomposition

A large portion of the wood entering the stream becomes geomorphically ineffective over time as a result of decomposition (Swanson 2003). As pieces decompose their density decreases and they become increasingly unable to withstand the forces imposed by flowing water or the weight of sediment. Consequently, pieces become increasingly fragmented and are exported as small particles, dissolved material, or gases. While the amount of time that pieces of in-stream wood can be geomorphically effective has not been investigated, large pieces of wood from conifer species have been found to be stable in accumulations for more than 100 years (Swanson et al. 1976, Swanson and Lienkaemper 1978). Pieces derived from hardwoods (particularly red alder in the Pacific Northwest) have been found to decompose much more quickly than conifer pieces (Swanson et al. 1976, Swanson and Lienkaemper 1978) and therefore should lose their geomorphic effectiveness more quickly.

The fact that our knowledge of the role of decomposition is limited is somewhat understandable, given the long period of time observations have to be made to capture the rate of loss from this process. Current field studies are underway that are better suited to provide estimates for aquatic systems. (Harmon, pers. comm.) and a number of simulation models have been developed to represent depletion of in-stream wood through decomposition (Murphy and Koski 1989, Hyatt and Naiman 2001, Meleason 2001).

### 8.3.2 Influence of land use activities on in-stream wood

Research on the influence of forest harvesting and road building on standing stocks and input rates indicates that harvesting in contributing areas can lead to depressed in-stream wood amounts for decades after harvest (Czarnomski 2003). Harvesting in areas that are potential wood sources generally results in lower wood inputs. However, increased input has been attributed to higher incidence of windthrow in areas where buffer strips have been left as part of the cutting prescription (Steinblums et al. 1984) and logging operations prior to the 1960s which left substantial amounts slash in the stream (Froehlich 1973).

Other land use activities have reduced the number of large pieces of in-stream wood. Salvage logging and road building operations in the 1960s and 1970s often involved removing merchantable pieces of wood directly from the stream channel. Investigations of salvage potential often involved bucking large pieces of in-stream wood to check for decay. The author knows of no quantification of losses as a result of these practices in the study area or for the geographic region under consideration.

# 9. METHODS

## 9.1 Study area and site selection

In the fall of 2002 we conducted surveys of large wood (> 1 m in length, ≥ 0.1 m in diameter) in the bankfull channel area at five sites within the Lookout Creek watershed near Blue River, Oregon (Figure 9-1). The Lookout Creek watershed is located in the western Cascade Range of the Pacific Northwest, USA and is also the location of the H.J. Andrews Experimental Forest and Long-Term Ecological Research Program.

Forests composed primarily of Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) cover the majority of the Lookout Creek basin. Patch clearcutting over approximately 25% of the basin area was concentrated in the lower portion of the basin because this was the route of initial road access. Plantations of Douglas-fir that were established after clearcutting and broadcast burning border the stream at many locations. Most harvesting occurred in the 1950s and 1960s, declined in the 1970s and largely ceased by the mid 1980s. Despite the level of human activity in the basin, much of the forest area adjacent to the channels, including the stands adjacent to all study sites in this investigation, is in old-growth (> 200 years) and mature (80-200 years) age classes.

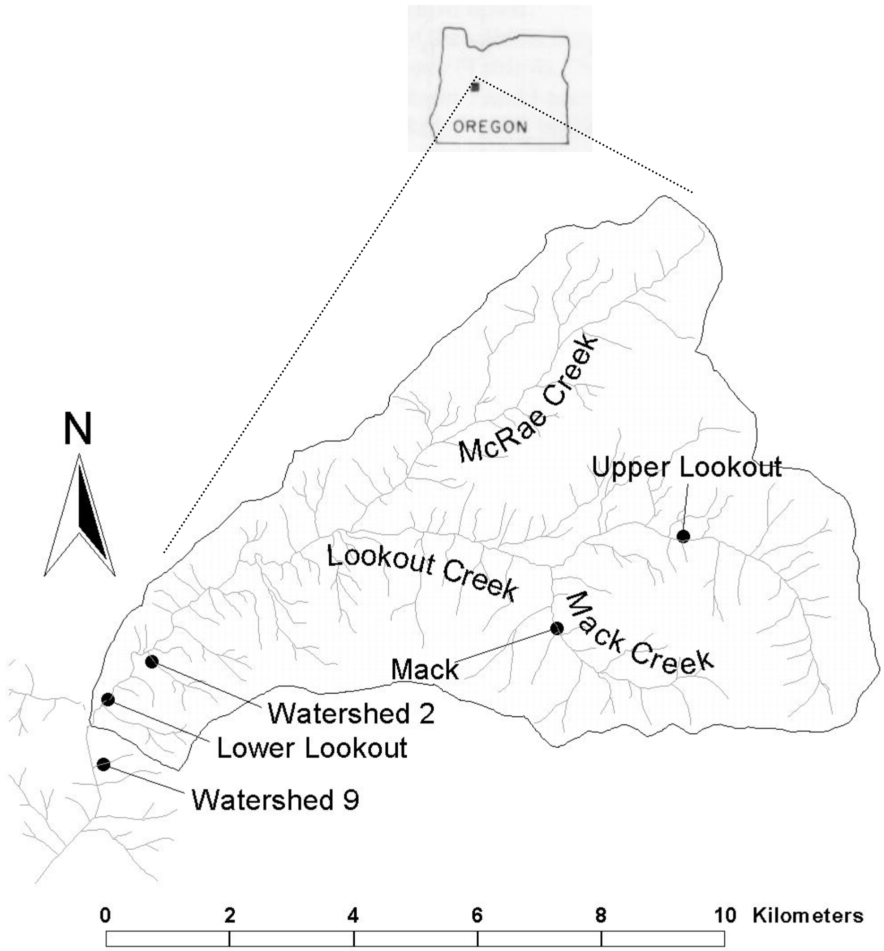



**Figure 9-1: Map of Lookout Creek basin showing location in Oregon (small, black rectangle on Oregon map) and study site locations (black dots on the Lookout Creek basin map).**

Average annual precipitation is 220 cm and falls between October and May as a mix of snow and rain. Storms are generally of long duration and low intensity with the highest peak flows occurring during rain-on-snow events (Harr, 1981). The largest flood on record for the Lookout Creek basin occurred in February 1996 and is the most recent event to have had major widespread effects on in-stream wood.

The five sites analyzed in this study are locations where detailed maps of the stream channel had been made in the mid 1970's (Swanson et al. 1976, Lienkaemper and Swanson 1986). These mapped areas were located throughout the Lookout Creek basin (Figure 9-1) and were originally selected to represent a range of channel sizes in old-growth forest settings (Table 9-1). Channel width increases and decreases in channel gradient occur as drainage area increases (Figure 9-2).

**Table 9-1: Study site characteristics. Stream order, elevation and channel gradient data are from Lienkaemper and Swanson (1987). Single asterisks indicate Lienkaemper (unpublished data). Two asterisks indicate data in Nakamura and Swanson (1993). A plus sign indicates data in Faustini (2001).**

| *Study Site* | Year(s) Maps Were Made | Stream Channel Length (m) | Stream Order | Drainage Area (ha) | Elevation (m) | Mean Bankfull Width (m) | Channel Gradient (%) |
|---|---|---|---|---|---|---|---|
| Watershed 9 (WS9) | 1976 | 150 | 1 | 10 | 500 | 4.1 | 37 |
| Watershed 2 (WS2) | 1976 | 116 | 2 | 80 | 550 | 6.7 | 26 |
| Mack Creek (Mack) | 1975<br>1977*<br>1996+ | 278 | 3 | 860 | 785 | 11.5 | 13 |
| Upper Lookout (ULO) | 1975<br>1977*<br>1979* | 193 | 3 | 1055 | 775 | 18.7 | 8 |
| Lower Lookout (LLO) | 1977<br>1984*<br>1990**<br>1996+ | 160 | 5 | 6400 | 435 | 21.0 | 3 |

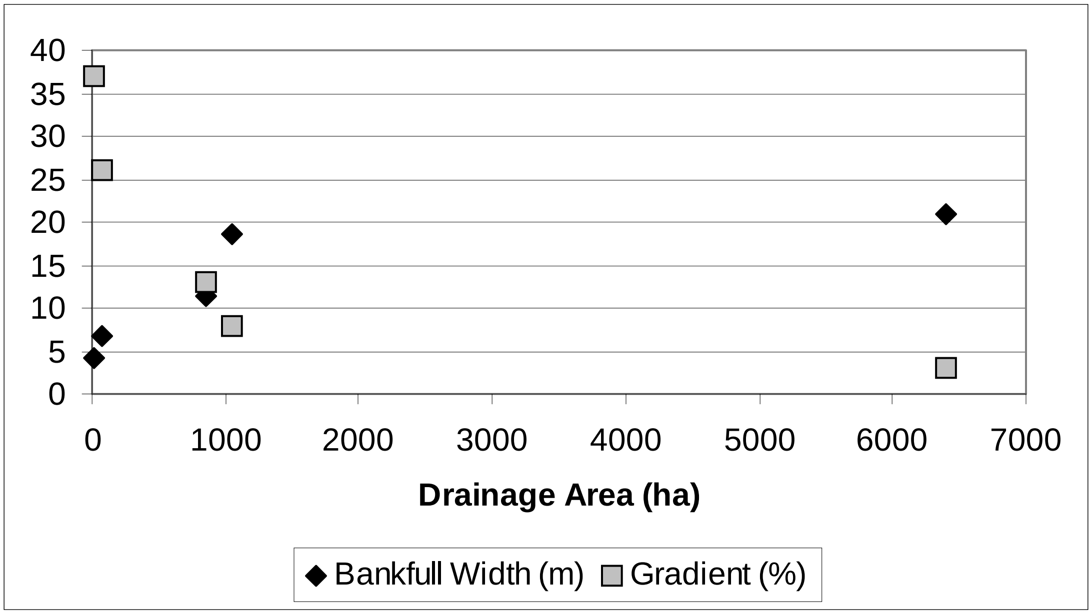



**Figure 9-2: Relationship between drainage area, bankfull channel width, and channel gradient for the study sites.**

The influence of debris flows and earthflows on study sites during the period between the mid 1970s and 2002 was inferred from prior studies of these processes, by field observations and descriptions made by other researchers (Swanson and James 1975, Johnson et al. 2000, Snyder 2000). No debris flows occurred in either of the study sites steep enough to carry debris flows (Watershed 2 or Watershed 9) within the last 50 years and no debris flows directly entered any of the study sites located in mainstem channels through tributaries during the last 25 years (Snyder 2000). Although multiple debris flows entered Lookout Creek approximately 1 km above the Lower Lookout site in 1996, we concluded their influence on wood conditions was minor compared to other flood effects, based on interpretations of the amount and type of wood introduced by the debris flow (Johnson et al. 2000).

Prior research on earthflow features in the Lookout Creek watershed indicated that Upper Lookout was the only site with potential earthflow influence (Swanson and James 1975). The zone of movement of the earthflow in this area is well defined and has been monitored for nearly 30 years (Swanson and Swanston 1977, Pyles et al.1987). Only the mapped channel area upstream of the zone of movement was analyzed for this study because we believed that including areas affected by earthflow would skew estimates of toppling and flood transport.

Unlike debris flows and earthflows, documentation of the removal of wood from the channel during logging and salvage activity is very limited. While it is known that this practice was widespread when the majority of harvesting in the watershed occurred, only one instance of wood removal is thought to have occurred within the study sites after initial mapping in the 1970's. In Upper Lookout three large pieces estimated to be approximately 7% of the total volume of wood in 1976 were removed as part of a roadside salvage harvest shortly after the mapping of the area had been completed. These pieces were positioned on top of others in accumulations and were not trapping any other pieces. Consequently, their removal did not appear to have resulted in the mobilization of other pieces based on the 1979 map of the site. Because of its location with respect to roads and harvest activity, no removal of material from the Lower Lookout site is thought to have occurred during the study period.

Several assumptions were made about the behavior of lateral input and decomposition processes within the five sites. The size distribution and frequency of pieces entering each of the study sites by toppling were assumed to be similar because the stand age, species composition, and elevation of the adjacent forest were comparable. Similarly, the rates decomposition in all of the sites were assumed to be similar.

## 9.2 Quantifying wood amount and arrangement in study sites

### 9.2.1 Characterizing initial wood conditions using maps of study sites

The amount and arrangement of wood in each site in the 1970s were depicted on maps made by George Lienkaemper (Figure 9-3). Tape and compass surveying techniques were used to produce 1:118 scale maps that included the size, shape, orientation and location of all pieces of wood $^3$ 10 cm in diameter and $^3$ 1.5 m in length (Lienkaemper and Swanson, 1987). Details of landforms, such as low flow and bankfull channel boundaries, bars, islands, and the type of material trapped by accumulations, were shown along with other landmarks, such as large boulders and large trees. Additional mapping in Mack Creek, Upper Lookout, and Lower Lookout sites during subsequent years was completed as parts of other studies (Nakamura and Swanson 1993, Lienkaemper unpublished data, Faustini 2001). The techniques used to produce these maps were similar to those used in the production of the original maps, but the level of detail was generally not as high.

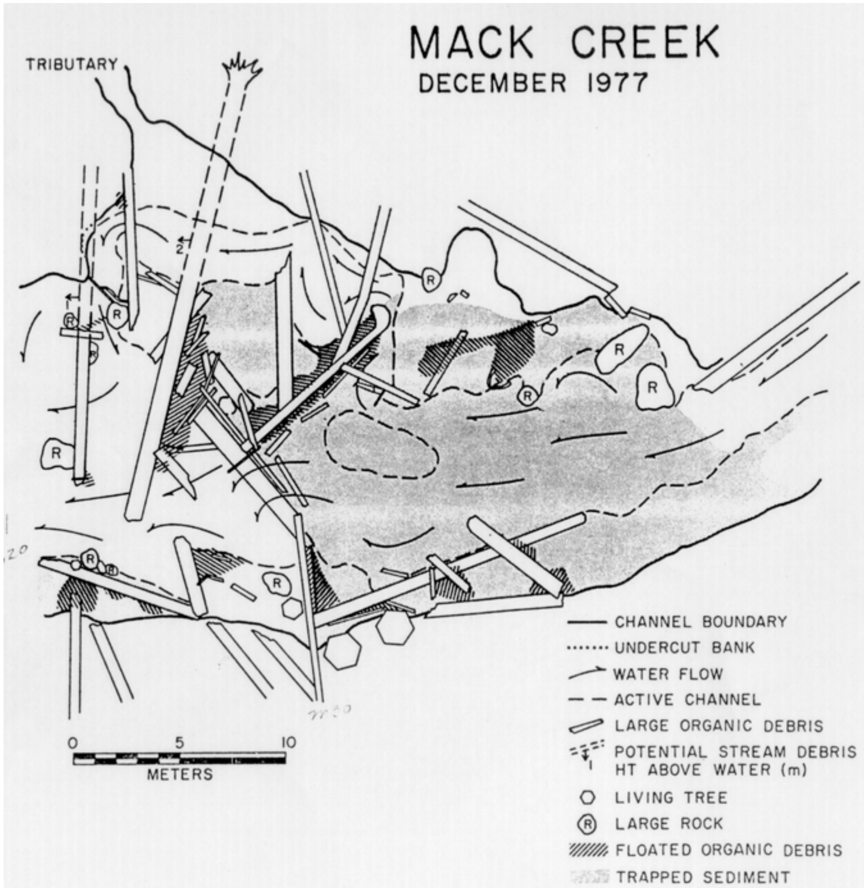



**Figure 9-3: Sample wood map. Lienkaemper (unpublished data).**

From these maps, three attributes of each piece were used to determine the amount of wood present in each site in the 1970's: length, length located within the bankfull channel boundaries, and diameter. These values were collected for each piece from digital images of the maps using Scion Image software (NIH, Bethesda, MD). Using the diameter and length measurements acquired from the scanned images, each piece was assigned to one of three diameter classes and one of four length classes (Table 9-2). Average values within each diameter and length class were derived from length and diameter measurements made on a sample of 400 pieces in a separate portion of our study (Appendix 1). The volume of each piece was calculated using the equation for the volume of a cylinder with average values for each diameter ($d_{av}$) and length ($l_{av}$) class:

$$Volume = (\pi(d_{av}/2)^2) * l_{av}$$

This method of map analysis was adopted to allow direct comparisons of volume estimates for each site from the scanned image analysis to those made using field data collected in 2002.

**Table 9-2: Diameter and length classification scheme with average values within each class based on a sample of 412 pieces of wood (See Appendix 1).**

| Diameter Range (cm) | Diameter Class | Average in Diameter Class (m) |
|---|---|---|
| 10 –30 | 1 | 0.18 |
| 31-60 | 2 | 0.43 |
| >60 | 3 | 0.78 |

| Length Range (m) | Length Class | Average in Length Class (m) |
|---|---|---|
| 1.0-5.0 | 1 | 2.8 |
| 5.1-10.0 | 2 | 6.9 |
| 10.1-20.0 | 3 | 12.9 |
| >20.0 | 4 | 27.6 |

We also characterized the mapped arrangement of wood in each site. The orientation with respect to the direction of flow and designation as part of an accumulation or a single piece were recorded for each piece. A piece was considered part of an accumulation if the map showed that it was in contact with two or more other pieces and had associated stored fine wood and/or sediment. If the piece appeared to be holding other pieces of the accumulation in place, it was designated as “key” to the accumulation. Each piece judged to be part of an accumulation was assigned an accumulation number (ex. LLO5 – Lower Lookout Accumulation 5). Using this information, the number and size of pieces within each accumulation at the time of mapping were determined.

Additional detail about the arrangement of accumulations included the general form of each accumulation, characterized as a log levee, fall-in, head of island, or all-in-channel, using criteria described in Appendix 1. The feature(s) responsible for initiating the formation of the accumulation was noted as wood, island, boulder, or stream bank. The orientation of the accumulation with respect to the direction of flow and the percentage of the active channel width blocked by the accumulation were also noted.

9.2.2 Characterizing wood conditions in 2002 through return surveys

We returned to each mapped study site in 2002 and relocated pieces using major landmarks and distinctive large pieces that, given their size, were unlikely to have moved. For pieces that were successfully relocated, any change in position greater than 1 meter since original mapping was noted as well as whether the piece had fragmented. If a piece had fragmented, we noted how much had broken off so that changes to the volume of the piece could be calculated. Identifying a transported fragment could be done with confidence only if it was still in close proximity to the source piece. Fragments that were not close to the source piece were classified as removed from the site, but they may have been counted as new pieces in downstream sites in a few instances.

For pieces that could not be relocated we attempted to determine whether a piece was still present, but buried, or whether it had been intentionally removed from the site, decomposed, or transported by flood. Pieces were considered buried, but still present, if they had been part of an accumulation in the 1970's that was still intact in 2002, but had obviously accumulated sediment or more wood in the area where the piece had been located. Only the three pieces that were removed in the late 1970s during the salvage sale were designated as such.

If burial and salvage logging were not interpreted, we used a combination of piece size, orientation, location, association with other pieces, and state of decay at the time of mapping to determine whether a piece had been lost from the site via flood transport or decomposed in place. Decomposition was a favored interpretation over flood transport for pieces of larger diameter (> 30 cm) and with length greater than channel width. Similarly, pieces with at least 50% of their length outside of the bankfull channel boundary or orientation predominantly with the flow were indicators that decomposition was more likely than transport to account for pieces that were missing. In some cases, ages of pieces that were based on tree-ring analysis of trees growing on downed trees were given on the maps and provided additional information on the likely state of decay for some pieces in the 1970's (Swanson et al. 1976). Mapped pieces were also considered to have decomposed if they were located outside of the bankfull channel boundaries and now obscured from view by vegetation or visible but too decomposed to have structural integrity in the channel.

We also quantified and characterized wood pieces that were not among those originally mapped; these are referred to as new pieces. Besides their absence on the original maps, new pieces had indicators of recent placement, such as intact bark, presence of small twigs, branches with needles, and/or jagged edges on fragmented surfaces. Diameter, length, and decomposition classes were assigned to each of these pieces and used to determine amount of new material in each site. The process responsible for the placement of each new piece was interpreted as flotation, windthrow, or bank erosion. Whether the piece had been placed in the current position prior to, during, or after the 1996 flood event was also noted using physical characteristics, such as the degree to which the piece was embedded in the streambank or channel bed, the amount of intact bark, the presence of angular or rounded edges, and the presence of moss or saplings growing on the piece.

The arrangement of new pieces was interpreted using the same criteria outlined for pieces that had been mapped in the 1970's. If pieces were incorporated in an accumulation that had been present in the 1970's, the original accumulation numbers were ascribed to the new pieces. If pieces were part of an accumulation that was not present in the 1970's, a new accumulation number was given. Characterizations of new accumulations followed those for accumulations that had been present in the 1970's.

## 9.3 Quantifying changes in wood conditions and process influences

### 9.3.1 Changes in wood volume and number of pieces between the mid 1970s and 2002.

In the analysis of wood size, arrangement, and location with respect to the active channel, absolute change and relative change were determined for each site. Absolute change was found by taking the difference between values in 2002 and the mid 1970s. Relative change was calculated as the absolute change divided by the 1970s value and converted to a percentage.

To investigate the effect of piece size on changes in wood conditions over time, all pieces were classified as either large or small. A large piece was defined as a piece of wood ≥ 30 cm in diameter and ≥ 10 m in length, or ≥ 60 cm in diameter and ≥ 5 meters in length (Table 9-3). This includes pieces in diameter.length classes 2.3, 2.4, 3.2, .3.3, and 3.4. These diameter.length classes were chosen to represent large pieces because of their potential to function as key pieces in accumulations. Size class 3.2, which is shorter than the other size classes that are a part of the large pieces category, was included because in areas where flotation is limited there is reason to believe that diameter may be as or more important than length in determining stability (Braudrick and Grant 2000).

**Table 9-3: "Diameter.Length" size classes for pieces of wood. Classes highlighted in bold typeface are "large" pieces of wood. Average volumes are derived from measurements of diameter and length of 412 pieces of wood (Appendix 2).**

| Size Class | Diameter (cm) | Length (m) | Average Volume ($m^3$) |
|---|---|---|---|
| 1.1 | 10 to 30 | 1 to 5 | 0.07 |
| 1.2 | 10 to 30 | 5 to 10 | 0.17 |
| 1.3 | 10 to 30 | 10 to 20 | 0.32 |
| 1.4 | 10 to 30 | 20 + | 0.70 |
| 2.1 | 30 to 60 | 1 to 5 | 0.40 |
| 2.2 | 30 to 60 | 5 to 10 | 1.01 |
| **2.3** | **30 to 60** | **10 to 20** | **1.87** |
| **2.4** | **30 to 60** | **20 +** | **4.02** |
| 3.1 | 60 + | 1 to 5 | 1.33 |
| **3.2** | **60 +** | **5 to 10** | **3.33** |
| **3.3** | **60 +** | **10 to 20** | **6.19** |
| **3.4** | **60 +** | **20 +** | **13.28** |

The effect of wood arrangement on change in wood conditions over time was investigated by assigning pieces to one of two groups: single pieces or pieces in accumulations. Single pieces were defined as pieces that were in contact with less than two other pieces of wood. Pieces in accumulations were in contact with two or more pieces of wood.

To assess the effect of wood location with respect to the active channel, pieces were divided into two groups: pieces located in the channel and pieces located out of the channel. Pieces located in the channel had at least 50% of their total length in Zones 1-3 as defined by Robinson and Beschta (1990). Pieces located out of the channel had more than 50% of their total length in Zone 4 as defined by Robinson and Beschta (1990).

### 9.3.2 Input, redistribution and loss processes and their influence on wood conditions

To assess the influence of selected processes on wood conditions, 2002 field data describing what had happened to pieces that had appeared on the 1970's maps were used to calculate percentages of pieces and of wood volume removed from each study site by three processes: fluvial transport, decomposition, and removal during salvage logging operations. Similar percentages were also calculated using field data that assessed the process responsible for the placement of new pieces. Percentages were calculated for fluvial transport, toppling from the near-stream zone, and toppling from the away-from-stream zone.

### 9.3.3 Changes in individual accumulation size and blockage of the channel

For each accumulation that appeared on the 1970's maps, changes in the number of pieces and the amount of channel blockage were assessed. Using categories for size and blockage (Table 9-4), significant change occurred if there was a change in either accumulation size class or channel blockage class.

**Table 9-4: Accumulation size and channel blockage classifications.**

| Size Class | Number of Pieces | Channel Blockage (%) |
|---|---|---|
| Removed | < 3 | 0-15 |
| Small | 3-10 | 16-50% |
| Intermediate | 11-20 | 51-75% |
| Large | 20+ | >75% |

# 10. RESULTS

## 10.1 Overall changes in wood conditions, 1977-2002

There was considerable variation in the changes in wood volume and the number of pieces among study sites. In the 1970s wood volume ranged from 75 to 1657 $m^3$/ha, and in 2002 it ranged from 155 to 1915 $m^3$/ha (Table 10-1). Between the mid 1970s and 2002, absolute changes in wood volume ranged from -201 to +587 $m^3$/ha, and relative changes ranged from -15 to +107 %. In the mid 1970s the number of pieces of wood ranged from 182 to 1512 pieces/ha, and in 2002 it ranged from 241 to 1209. Between the mid 1970s and 2002, absolute changes in numbers of pieces of wood ranged from -618 to +113 pieces/ha, and relative changes ranged from -40 to +33%.

**Table 10-1: Changes in wood volume and number of pieces from 1975 to 2002, by site. Basins are arranged from small to large, left to right.**

| | WS 9 | WS 2 | Mack | Upper Lookout | Lower Lookout |
|---|---|---|---|---|---|
| Wood volume ($m^3$/ha) | | | | | |
| 1970's | 1657 | 1328 | 758 | 1302 | 75 |
| 2002 | 1669 | 1915 | 734 | 1101 | 155 |
| Difference | +12 | + 587 | - 24 | - 201 | + 80 |
| Change (%) | +1 | + 44 | - 3 | - 15 | + 107 |
| Number of pieces (#/ha) | | | | | |
| 1970's | 1512 | 1145 | 416 | 394 | 182 |
| 2002 | 894 | 1209 | 465 | 507 | 241 |
| Difference | -618 | +64 | +50 | +113 | +60 |
| Change (%) | -40 | +6 | +12 | +29 | +33 |

Wood volume and the number of pieces declined with increasing basin size in the mid 1970s and in 2002. Wood volume was 1657 $m^3$/ha in the mid 1970s and 1669 $m^3$/ha in 2002 in the smallest basin (WS9) but was only 75 $m^3$/ha in the mid-1970s and 155 $m^3$/ha in 2002 in the largest basin (LLO) (Table 10-1). There were 1512 pieces/ha in the mid-1970s and 894/ha hectare in 2002 in the smallest basin (WS9) but only 182 pieces/ha in the mid-1970s and 241/ha in 2002 in the largest basin (LLO).

Relative change in the number of pieces from the mid 1970s to 2002 was related to basin area. The smallest basin (WS9) had the largest decrease in number of pieces and the largest basin (LLO) had the largest increase in number of pieces. Changes in the three other sites were increasingly positive. In contrast, there was not a trend in the relative change in wood volume with respect to basin size.

### 10.2 Effect of piece size on changes in wood conditions, 1970s - 2002

The volume of large pieces and small pieces varied considerably among study sites. In the mid 1970s the volume of large pieces ranged from 29 to 1179 $m^3$/ha, and in 2002 it ranged from 89 to 1567 $m^3$/ha (Table 10-2). Between the mid 1970s and 2002, absolute changes in the volume of large pieces ranged from -36 to +561 $m^3$/ha, and relative changes ranged from -18 to +207%. In the mid 1970s the volume of small pieces ranged from 46 to 478 $m^3$/ha, and in 2002 it ranged from 66 to 347 $m^3$/ha. Between the mid 1970s and 2002, absolute changes in wood volume of small pieces ranged from –254 to +20 $m^3$/ha, and relative changes ranged from -53 to +43%.

Large pieces composed the majority of wood volume in study sites, but small pieces composed the majority of the number of pieces. The volume of large pieces ranged from 2.5 to almost 9 times that of small pieces in both years at all study sites, except at Lower Lookout (Table 10-2). In Lower Lookout the volume of large pieces was less than that of small pieces in the mid 1970s, and only slightly larger than that of small pieces in 2002. Small pieces were 1.5 to 5 times more common than large pieces in both years at all study sites, except at Lower Lookout. At Lower Lookout small pieces were 20 times more frequent than large pieces in the mid 1970s, but about equally frequent in 2002. A large flood event in 1964 or 1965 is probably responsible for the relatively low number of large pieces in Lower Lookout. It is likely this event transported large pieces out of the site and left levee-type accumulations composed primarily of smaller pieces along the channel margin.

The amount of wood in large pieces was generally higher in smaller basins and lower in larger basins. The highest values for large piece volume and number of large pieces in both the 1970s and 2002 were found in the two smallest basins (WS9, WS2) while the lowest values for both metrics in both years were found in the largest basin (LLO) (Table 10-2). Exceptions to the trend of decreasing large piece volume with increasing basin size were found in the 1970s (ULO) and 2002 (WS2).

**Table 10-2: Effect of wood size on change in volume and number of pieces from the 1970's to 2002, by site. Large pieces were those at least 10 meters in length with a midpoint diameter greater than 30 cm or at least 5 meters in length with a midpoint diameter greater than 60 cm.**

| | WS9 | WS2 | Mack | ULO | LLO |
|---|---|---|---|---|---|
| **Large pieces** | | | | | |
| Wood volume ($m^3$/ha) | | | | | |
| 1970's | 1179 | 1006 | 630 | 1166 | 29 |
| 2002 | 1444 | 1567 | 594 | 956 | 89 |
| Difference | + 265 | + 561 | - 36 | -210 | + 60 |
| Change (%) | + 22 | + 56 | - 6 | - 18 | +207 |
| Number of pieces (#/ha) | | | | | |
| 1970's | 293 | 206 | 114 | 172 | 9 |
| 2002 | 276 | 283 | 100 | 135 | 15 |
| Difference | -16 | +77 | -14 | -38 | +6 |
| Change (%) | -6 | +38 | -12 | -21 | +67 |
| Change in volume/piece ($m^3$) | -16.3 | +7.3 | +2.6 | +5.6 | +10.1 |
| **Small pieces** | | | | | |
| Wood volume ($m^3$/ha) | | | | | |
| 1970's | 478 | 322 | 129 | 136 | 46 |
| 2002 | 224 | 347 | 140 | 145 | 66 |
| Difference | - 254 | +25 | + 11 | + 9 | + 20 |
| Change (%) | - 53 | + 8 | +9 | + 7 | +43 |
| Number of pieces (#/ha) | | | | | |
| 1970's | 1203 | 939 | 302 | 222 | 173 |
| 2002 | 618 | 926 | 366 | 372 | 226 |
| Difference | -585 | -13 | +64 | +150 | +54 |
| Change (%) | -49 | -1 | +21 | +68 | +31 |
| Change in volume/piece ($m^3$) | +0.4 | -2.0 | +0.2 | +0.1 | +0.4 |
| Volume of large:small | | | | | |
| 1970's | 2.5 | 3.1 | 4.9 | 8.6 | 0.6 |
| 2002 | 6.4 | 4.5 | 4.2 | 6.6 | 1.3 |
| Number of large:small | | | | | |
| 1970's | 0.24 | 0.21 | 0.38 | 0.77 | 0.05 |
| 2002 | 0.44 | 0.31 | 0.27 | 0.36 | 1.3 |
| Volume change in large:small | -1.0 | +21.8 | -3.1 | -24.0 | +3.0 |
| Piece changes large:small | +0.03 | -6.00 | -0.22 | -0.25 | +0.11 |

Changes in the number of large and small pieces varied considerably among study sites. In the mid 1970s the number of large pieces ranged from 9/ha to 293/ha, and in 2002 it ranged from 15/ha to 283/ha (Figure 10-1). Between the mid 1970s and 2002, absolute changes in the number of large pieces of wood ranged from –38/ha to +77/ha, and relative changes ranged from -21 to 67% (Table 10-2). In the mid 1970s the number of small pieces of wood ranged from 173/ha to 1203/ha, and in 2002 it ranged from 226/ha to 926 /ha. Between the mid 1970s and 2002, absolute changes in numbers of small pieces of wood ranged from –585/ha to +150/ha, and relative changes ranged from -49 to +68 %.

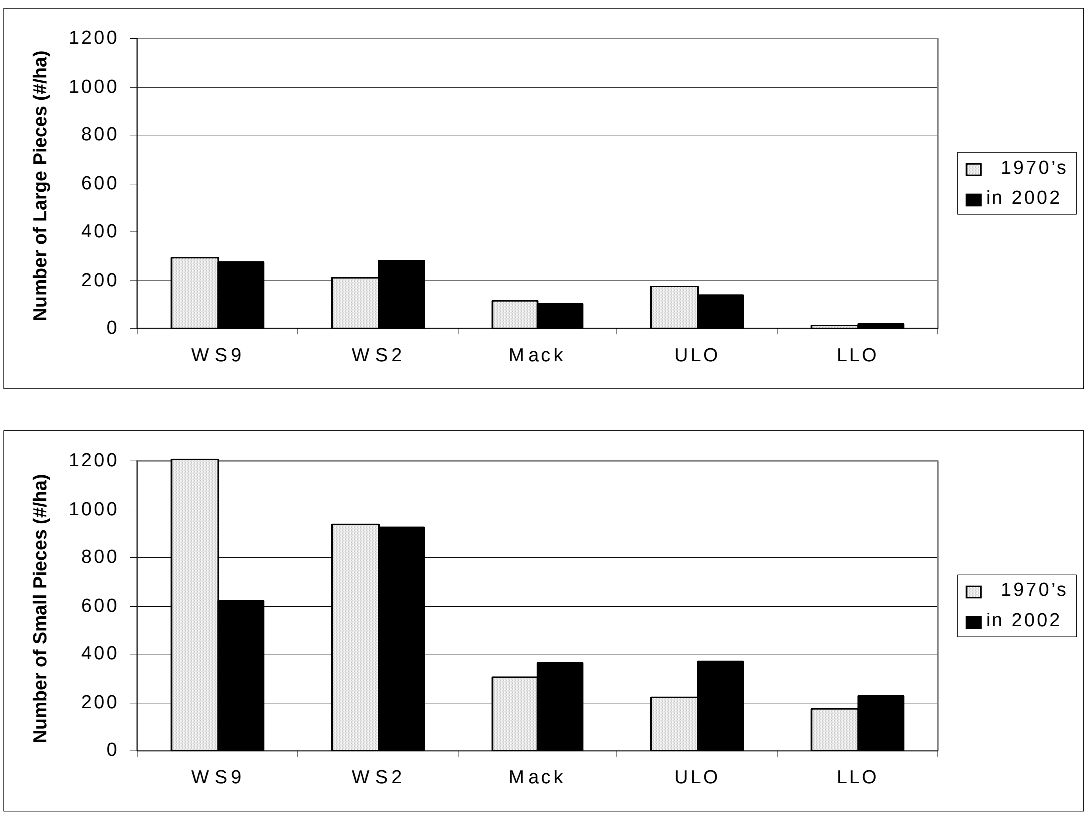



**Figure 10-1: Changes in the number of large pieces and small pieces. Large pieces were those at least 10 meters in length with a midpoint diameter greater than 30 cm or at least 5 meters in length with a midpoint diameter greater than 60 cm.**

Over the study period relative changes in the number of small pieces tended to go from losses in small basins to gains in large basins. The three largest basins all had increases in the number of small pieces over the study period (Mack, ULO, LLO), while the two smallest basins had decreases in the number of small pieces (WS9, WS2) (Table 10-2). However, there were not similar trends with increasing basin size for the relative change in small piece volume, large piece volume, and number of large pieces.

Changes in the volume of large pieces were much greater than changes in the volume of small pieces. The ratio of change in volume of large pieces to change in volume of small pieces from the 1970s to 2002 ranged from –24.0 to +21.8 and the absolute value of all ratios were greater than or equal to 1 (Table 10-2). This ratio means that changes in volume of large pieces from the mid 1970s to 2002 were more than an order of magnitude larger than changes in volume of small pieces. These ratios are expected to be greater than 1 since the ratio of the average volume of pieces in the smallest class of "large" pieces to the volume of the average volume of pieces in the largest class of "small" pieces was slightly greater than 1 (i.e. 1.9/1.3).

The number of small pieces changed more than the number of large pieces in all sites except Watershed 2. In these sites, for every net change of one large piece, there was a net change ranging from 4 (ULO) to 30 (WS9) small pieces (Table 10-2). The absolute value of this ratio is generally expected to be less than 1 because small pieces are more mobile than large pieces. The ratio was greater than 1 in Watershed

2 because the addition of a few large pieces in Watershed 2 to the relatively small number of large pieces caused a substantial relative change in the number of large pieces.

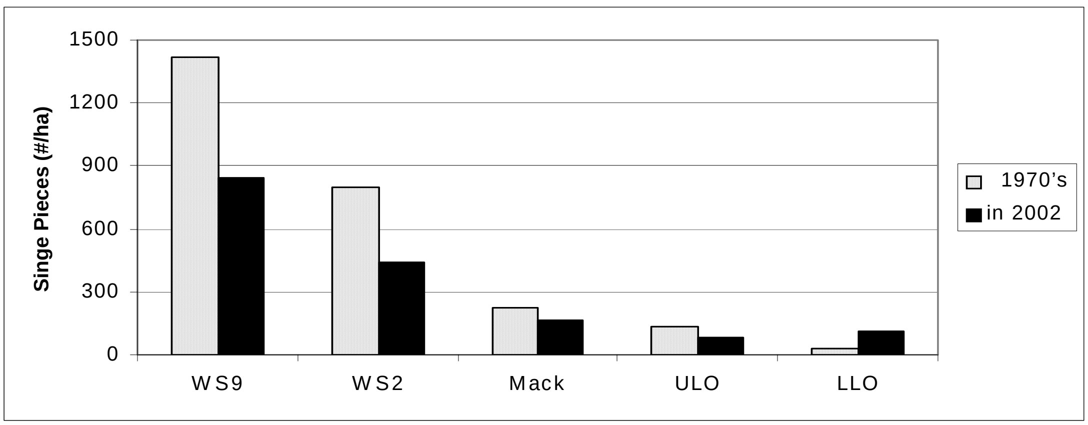
### 10.3 Effect of wood arrangement on changes in wood, 1970s - 2002

There was substantial variation in the changes in both single pieces and pieces in accumulations among sites. In the mid 1970s the volume of single pieces in all sites ranged from 9 to 1530 $m^3$/ha, and in 2002 it ranged from 68 to 1550 $m^3$/ha (Table 10-3). Between the mid 1970s and 2002, absolute changes in the total volume of single pieces ranged from –220 to +59 $m^3$/ha, and relative changes ranged from -48 to +656%. In the mid 1970s, the volume of accumulations ranged from 66 to 840 $m^3$/ha, and in 2002 it ranged from 87 to 1333 $m^3$/ha. Between the mid 1970s and 2002, absolute changes in the volume of accumulations ranged from –8 to +597 $m^3$/ha, and relative changes ranged from -6 to +81%. In the mid 1970s, the number of single pieces ranged from 33 to 1415 per hectare, and in 2002 it ranged from 85 to 846 per hectare. Between the mid 1970s and 2002, absolute changes in the number of single pieces ranged from -569/ha to +77/ha, and relative changes ranged from -40 to +236%. In the mid 1970s the number of pieces in accumulations ranged from 98/ha to 347/ha, and in 2002 it ranged from 49/ha to 772/ha. Between the mid 1970s and 2002, absolute changes in numbers of pieces in accumulations ranged from -49 to +425 per hectare, and relative changes ranged from –50 to +122%.

**Table 10-3: Effect of wood arrangement on change in volume and number of pieces from the 1970's to 2002, by site. Pieces in accumulations had contact with two or more other pieces. Otherwise pieces were considered to be a singles.**

| | WS9 | WS2 | Mack | ULO | LLO |
|---|---|---|---|---|---|
| **Single pieces** | | | | | |
| Wood volume ($m^3$/ha) | | | | | |
| 1970's | 1530 | 592 | 281 | 462 | 9 |
| 2002 | 1550 | 582 | 255 | 242 | 68 |
| Difference | + 20 | - 10 | - 26 | - 220 | + 59 |
| Change (%) | + 1 | - 2 | - 9 | - 48 | + 656 |
| Number of pieces (#/ha) | | | | | |
| 1970's | 1415 | 798 | 222 | 131 | 33 |
| 2002 | 846 | 438 | 164 | 85 | 110 |
| Difference | -569 | -360 | -58 | -47 | +77 |
| Change (%) | -40 | -45 | -26 | -36 | +236 |
| Change in volume/piece ($m^3$) | -0.03 | +0.03 | +0.45 | +4.7 | +0.77 |
| **Accumulations** | | | | | |
| Wood volume ($m^3$/ha) | | | | | |
| 1970's | 127 | 736 | 477 | 840 | 66 |
| 2002 | 119 | 1333 | 480 | 859 | 87 |
| Difference | - 8 | + 597 | + 3 | + 19 | +21 |
| Change (%) | - 6 | + 81 | + 1 | + 2 | + 32 |
| Number of pieces (#/ha) | | | | | |
| 1970's | 98 | 347 | 194 | 263 | 149 |
| 2002 | 49 | 772 | 302 | 422 | 131 |
| Difference | -49 | +425 | +108 | +159 | -18 |
| Change (%) | -50 | +122 | +56 | +61 | -12 |
| Volume singles:accum | | | | | |
| 1970s | 12.0 | 0.8 | 0.6 | 0.55 | 0.14 |
| 2002 | 13.0 | 0.43 | 0.53 | 0.28 | 0.78 |
| # pieces, singles:accum | | | | | |
| 1970s | 14.4 | 2.3 | 1.1 | 0.50 | 0.22 |
| 2002 | 7.1 | 0.56 | 0.54 | 0.20 | 0.83 |
| Change in volume/piece ($m^3$) | +0.17 | +1.4 | +0.02 | +0.12 | -1.2 |
| Volume change in sing:acc | -0.4 | -58 | -0.1 | -0.1 | +0.3 |
| Piece change in sing:acc | +0.1 | -1.2 | -1.9 | -3.4 | -0.2 |

Generally, more wood was arranged as singles pieces in small basins and in accumulations in large basins. For example, in the mid 1970s the volume of single pieces was 12 times that of accumulations in the smallest basin, but it was only 1/7 of that of accumulations in the largest basin (Table 10-3). Similarly, in the mid 1970s single pieces were 14 times more common than pieces in accumulations in Watershed 9 but only 1/5 as common in Lower Lookout (Figure 10-2). In 2002, the trend was similar although Upper Lookout, the second largest basin, had the least volume and number of pieces in accumulations compared to singles.



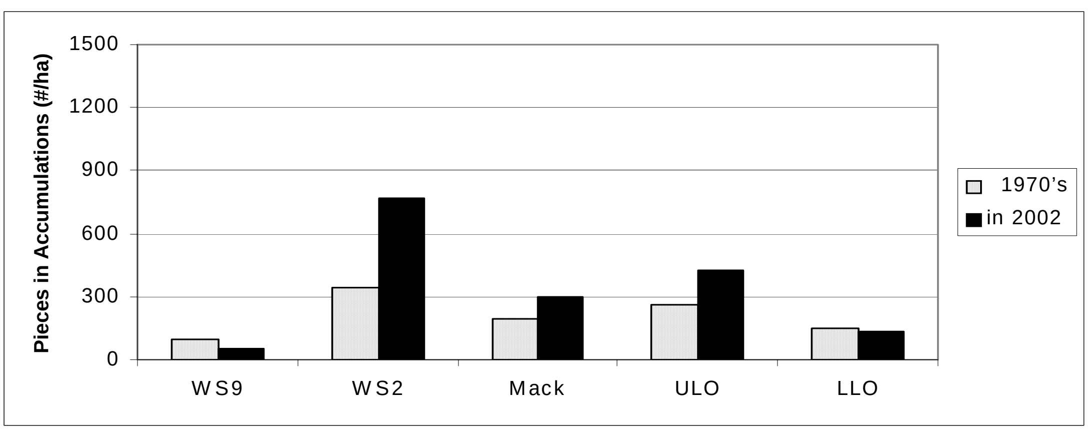




**Figure 10-2: Changes in the number of single pieces and pieces in accumulations. Pieces in accumulations had contact with two or more other pieces. Otherwise pieces were considered to be a singles.**

Greater change in single piece volume occurred in larger basins than in smaller basins. The magnitude of change in single piece volume was much greater in Lower Lookout than in any other site (Table 10-3). Relative changes in single piece volume for Mack and Upper Lookout were generally an order of magnitude less than changes in Lower Lookout. In the two smallest basins (WS9, WS2) basically no change in single piece volume occurred. Similar trends with respect to basin size was not observed for the number of single pieces, number of pieces in accumulations, or volume in accumulations.

Between the 1970s and 2002 changes in the volume of single pieces were less than changes in the volume of pieces in accumulations. Changes in volume per single piece ranged from –0.03 to +0.77 $m^3$, while changes in volume per piece in accumulations ranged from –1.2 to +1.4 $m^3$ (Table 10-3). The observed changes in volume per piece may be higher for pieces in accumulations because changes to accumulations may often include changes to generally larger, key piece(s).

### 10.4 Effect of position relative to the channel on wood change, 1970s-2002

Generally, more wood was located out of the channel in the smallest and largest basins than in the mid-sized basins. In the mid 1970s, the volume in the channel ranged from 1.4 times that of volume out of the channel in Upper Lookout, to as little as 1/10 of that of volume out of the channel in Lower Lookout (Table 10-4). In 2002 the volume in the channel ranged from 2.6 times that of volume out of the channel in

Upper Lookout, to only 1/3 of that of volume located out of the channel in Lower Lookout. In the mid 1970s pieces in the channel ranged from 4.9 times more common than pieces outside the channel in Watershed 2 to only 1/10 as common in Lower Lookout (Figure 10-3). In 2002 pieces in the channel ranged from 6.9 times more common than pieces out of the channel in Watershed 2 to 1.2 times as common at in Upper Lookout.

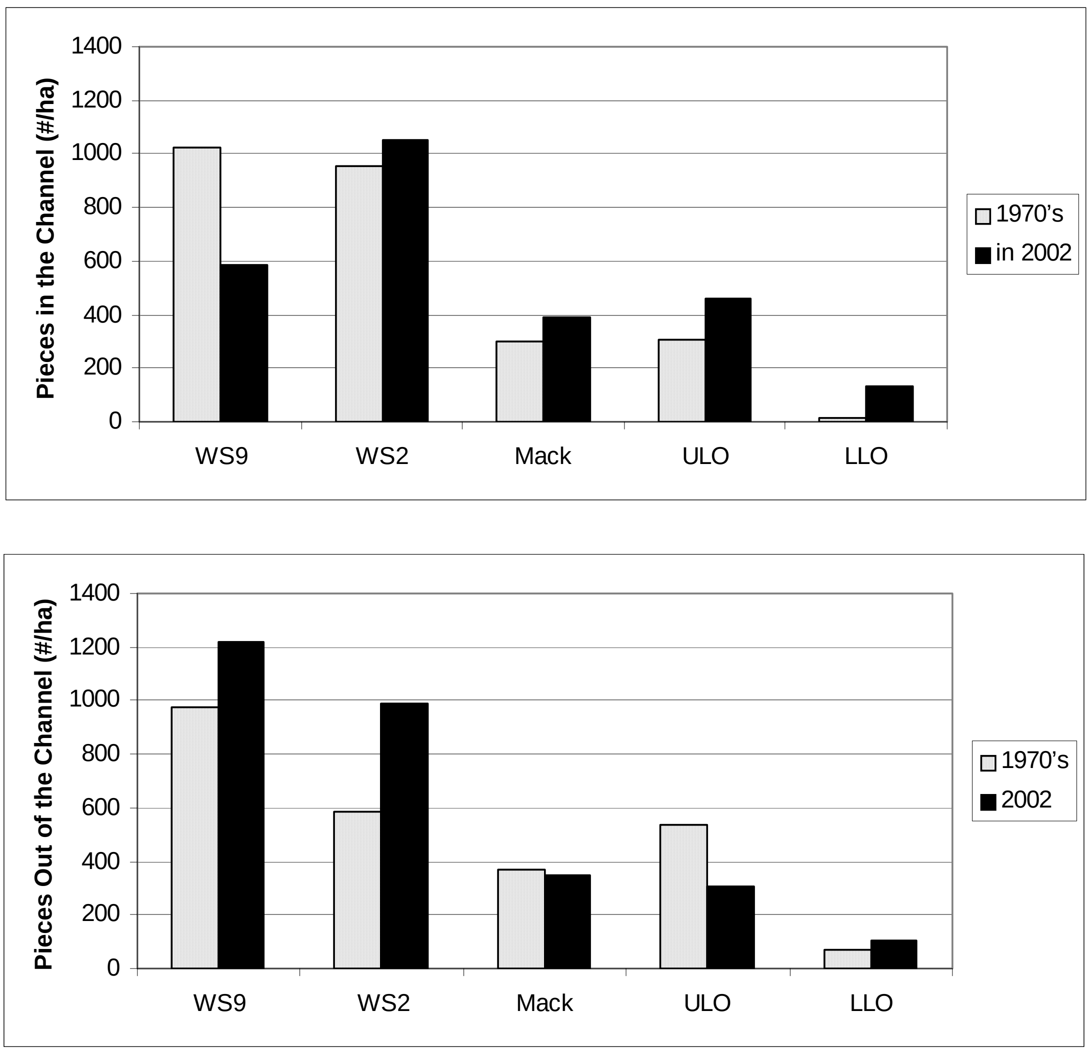



**Figure 10-3 Changes in the number of pieces located in the channel and out of the channel. In channel locations were defined as pieces with less than 50% of their length in Zone 4 as defined by Robinson and Beschta (1990). Out of channel locations were defined as pieces with 50% or more of their length in Zone 4.**

**Table 10-4: Effect of wood location on change in volume and number of pieces from the 1970's to 2002, by site. In channel locations were defined as pieces with less than 50% of their length in Zone 4 as defined by Robinson and Beschta (1990). Out of channel locations were defined as pieces with 50% or more of their length in Zone 4.**

| | WS9 | WS2 | Mack | ULO | LLO |
|---|---|---|---|---|---|
| **In channel** | | | | | |
| Wood volume ($m^3$/ha) | | | | | |
| 1970's | 658 | 746 | 391 | 765 | 6 |
| 2002 | 450 | 924 | 386 | 793 | 50 |
| Difference | -208 | +178 | - 5 | + 28 | + 44 |
| Change (%) | -32 | +24 | - 1 | + 4 | + 733 |
| Number of pieces (#/ha) | | | | | |
| 1970's | 1024 | 952 | 299 | 307 | 15 |
| 2002 | 585 | 1055 | 393 | 457 | 131 |
| Difference | -439 | +103 | +94 | +150 | +116 |
| Change (%) | -43 | +11 | +32 | +49 | +780 |
| Change in volume/piece ($m^3$) | +0.5 | +1.73 | -0.1 | +0.2 | +0.4 |
| **Out of channel** | | | | | |
| Wood volume ($m^3$/ha) | | | | | |
| 1970's | 972 | 583 | 367 | 537 | 70 |
| 2002 | 1220 | 992 | 348 | 308 | 106 |
| Difference | +248 | +409 | -19 | -229 | +36 |
| Change (%) | +26 | +70 | - 5 | - 43 | +51 |
| Number of pieces (#/ha) | | | | | |
| 1970's | 488 | 193 | 116 | 88 | 167 |
| 2002 | 309 | 154 | 72 | 50 | 110 |
| Difference | -179 | -39 | -44 | -38 | -57 |
| Change (%) | -37 | -20 | -38 | -43 | -34 |
| Volume, in:out | | | | | |
| 1970s | 0.67 | 1.3 | 1.1 | 1.4 | 0.09 |
| 2002 | 0.37 | 0.93 | 1.1 | 2.6 | 0.47 |
| # pieces, in:out | | | | | |
| 1970s | 2.1 | 4.9 | 2.6 | 3.5 | 0.09 |
| 2002 | 1.9 | 6.9 | 5.5 | 9.1 | 1.2 |
| Change in volume/piece ($m^3$) | -1.4 | -10.6 | +0.4 | +6.1 | -0.6 |
| Volume change in:out | -0.95 | +0.43 | +0.24 | -0.12 | +1.21 |
| Number of pieces change in:out | +2.45 | -2.67 | -2.13 | -4.00 | -2.05 |

Changes in wood located in the channel varied substantial during the study period. In the mid 1970s volume in the channel ranged from 6 to 765 $m^3$/ha, and in 2002 it ranged from 50 to 924 $m^3$/ha (Table 10-4). Between the mid 1970s and 2002 absolute changes in volume in the channel ranged from –208 to +178 $m^3$/ha, and relative changes ranged from -32 to +733%. In the mid 1970s the number of pieces in the channel ranged from 15/ha to 1024/ha, and in 2002 it ranged from 131/ha to 1055/ha. Between the mid 1970s and 2002 absolute changes in number of pieces in the channel ranged from –439/ha to +150/ha, and relative changes ranged from -43 to +780%.

Changes in wood located out of the channel also varied substantially among sites. In the 1970s volume out of the channel ranged from 70 to 972 $m^3$/ha, and in 2002 it ranged from 106 to 1220 $m^3$/ha (Table 10-4). Between the mid 1970s and 2002, absolute changes in volume out of the channel ranged from -229 to +409 $m^3$/ha, and relative changes ranged from -43 to +70%. In the mid 1970s the number of pieces out of the channel ranged from 88/ha to 488/ha, and in 2002 it ranged from 50/ha to 309/ha. Between the mid 1970s and 2002, absolute changes in the number of pieces out of the channel ranged from –179/ha to -39/ha, and relative changes ranged from -20 to -43%.

Changes in the number of pieces in the channel were greater than changes in the number of pieces located out of the channel. There was also a tendency for the number of pieces out of the channel to decrease over time while the number of pieces in the channel tended to increase. The ratio of change in the number of pieces located in the channel compared to the number of pieces located out of the channel ranged from –4.00 to +2.45 (Table 10-4). Since the absolute value of all ratio values was greater than 2, pieces in the channel were twice as likely to change than pieces located out of the channel. In all basins the number of pieces out of the channel decreased while the number of pieces in the channel increased in all basins except Watershed 9 between the mid 1970s and 2002.

Changes in volume of pieces located in the channel were less than changes in the volume of pieces located outside of the channel (Table 10-4). The maximum change in mean volume per piece for pieces in the channel was 1.73 $m^3$ and the absolute value of all the other volume per piece values were $\leq 0.5$ $m^3$. For pieces located out of the channel, the absolute value of change in mean volume per piece was greater than 0.5 $m^3$ for all sites except Mack.

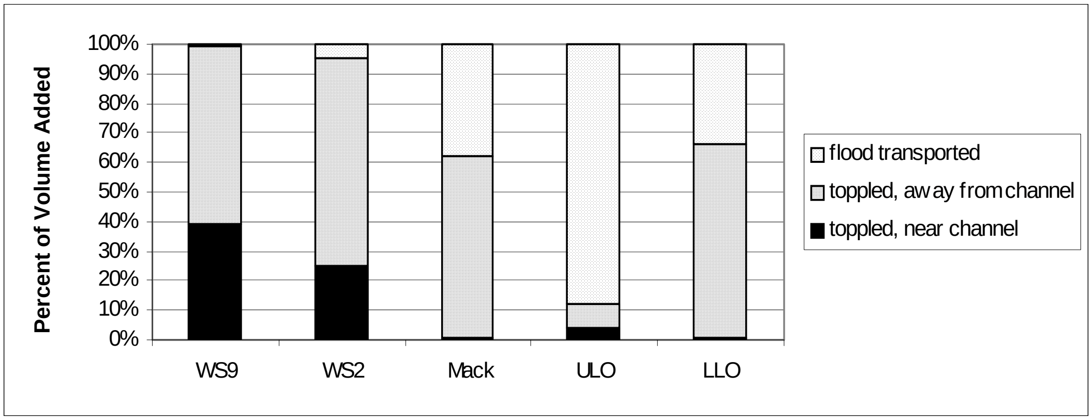
## 10.5 Effect of wood input processes on change in wood, 1970s - 2002

Inputs from toppling were substantial (> 20% of volume and number of pieces) in most sites (Table 10-5). Toppling near the channel represented 1 to 39% of the total inputs of wood volume, and 1 to 39% of the total number of pieces added between the mid 1970s and 2002 (Figure 10-4). Wood toppling near the channel was most important in Watershed 9 and least important in Mack. Wood toppling away from the channel represented 8 to 70% of the total inputs of wood volume, and 7 to 60 % of the total number of pieces added between the mid 1970s and 2002. Wood toppling away from the channel was most important in Watershed 2 and least important in Upper Lookout.

Inputs from fluvial transport increased with basin size (Table 10-5). Fluvial transport represented 1 to 88% of the total inputs of wood volume, and 3 to 91% of the total number of pieces added between the mid 1970s and 2002. Fluvial transport was most important in Upper Lookout and least important in Watershed 9.

**Table 10-5: Effect of wood input processes on change in volume and number of pieces from the 1970's to 2002, by site. See explanation in Methods for description of criteria used to ascribe input process to pieces.**

| | WS9 | WS2 | Mack | ULO | LLO |
|---|---|---|---|---|---|
| **Wood volume** | | | | | |
| Added, 1970s-2002 ($m^3$/ha), of which | 674 | 764 | 188 | 151 | 134 |
| % toppled. near channel | 39 | 25 | 1 | 4 | 1 |
| % toppled, away from channel | 60 | 70 | 61 | 8 | 65 |
| % fluvially transported | 1 | 5 | 38 | 88 | 34 |
| Total | 100 | 100 | 100 | 100 | 100 |
| **Number of pieces** | | | | | |
| Added, 1970s-2002 (#/ha), of which | 504 | 669 | 297 | 288 | 146 |
| % toppled. near channel | 39 | 11 | 1 | 2 | 2 |
| % toppled, away from channel | 58 | 60 | 21 | 7 | 18 |
| % fluvially transported | 3 | 29 | 78 | 91 | 80 |
| Total | 100 | 100 | 100 | 100 | 100 |



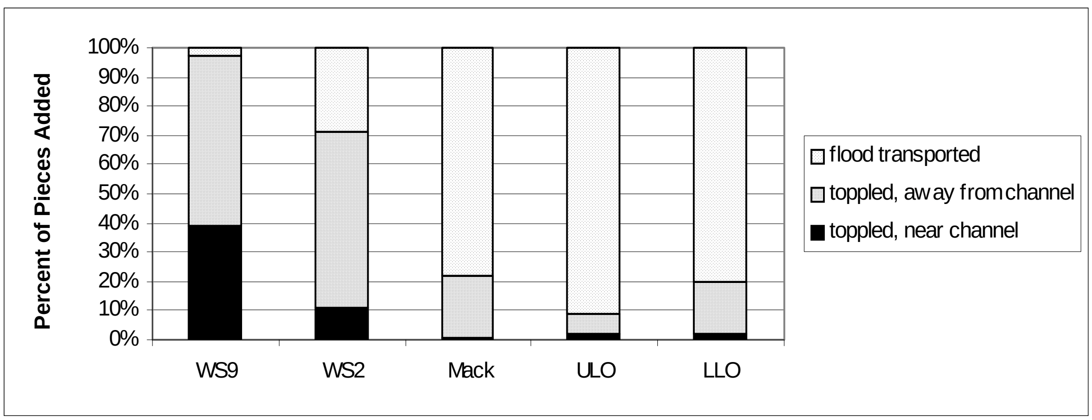




**Figure 10-4: Percentage of the total volume and total number of pieces added to the study sites by flood transport and toppling between the 1970s and 2002. See explanation in Methods for description of criteria used to ascribe input process to pieces.**

## 10.6 Effect of wood output processes on change in wood, 1970s - 2002

Losses from fluvial transport increased while losses from decomposition decreased with increasing basin size. Wood decomposition represented 12 to 89 % of the total outputs of wood volume, and 7 to 67% of the total number of pieces lost between the mid-1970s and 2002 (Table 10-6, Figure 10-5). Decomposition was most important in Watershed 9 and least important in Lower Lookout. Fluvial transport represented 11 to 88% of the total outputs of wood volume, and 29 to 93% of the total number of pieces lost between the mid-1970s and 2002. Fluvial transport was most important in Lower Lookout and least important in Watershed 9.

**Table 10-6: Effect of wood output processes on change in volume and number of pieces from the 1970's to 2002, by site. See explanation in Methods for description of criteria used to ascribe output process to pieces.**

| | WS9 | WS2 | Mack | ULO | LLO |
|---|---|---|---|---|---|
| **Wood volume** | | | | | |
| Lost, 1970s-2002 ($m^3$/ha), of which | 662 | 177 | 212 | 349 | 54 |
| % decomposition | 89 | 69 | 36 | 27 | 12 |
| % fluvially transported | 11 | 31 | 58 | 46 | 88 |
| % salvage removal | 0 | 0 | 0 | 27 | 0 |
| % unknown | 0 | 0 | 6 | 0 | 0 |
| Total | 100 | 100 | 100 | 100 | 100 |
| | | | | | |
| **Number of pieces** | | | | | |
| Lost, 1970s-2002 (#/ha), of which | 1122 | 605 | 175 | 247 | 86 |
| % decomposition | 67 | 60 | 20 | 13 | 7 |
| % fluvially transported | 29 | 40 | 75 | 80 | 93 |
| % salvage removal | 0 | 0 | 0 | 7 | 0 |
| % unknown | 4 | 0 | 5 | 0 | 0 |
| Total | 100 | 100 | 100 | 100 | 100 |

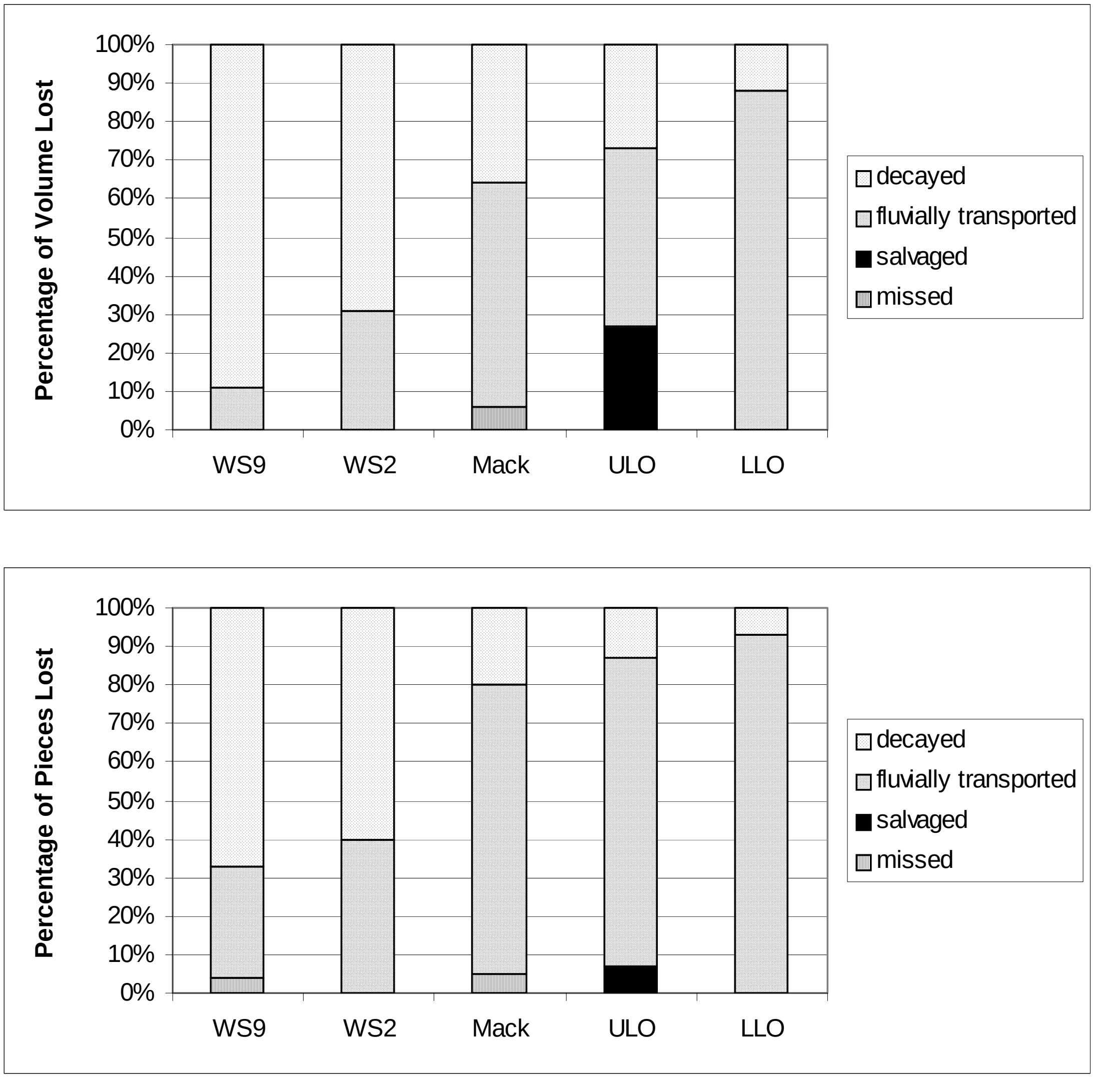



**Figure 10-5 Percentage of the total volume and total number of pieces added to the study sites by flood transport and toppling between the 1970s and 2002.**

## 10.7 Effect of basin size on changes in wood accumulations, 1970s – 2002

There were more changes in the attributes of wood accumulations in larger basins than in smaller basins. In this analysis the attributes of interest are accumulation size, measured in terms of number of pieces, and channel blockage, measured in terms of percent of the active channel width blocked by the accumulation.

10.7.1 Small basins

In Watershed 2 and Watershed 9, addition of pieces to two of the four accumulations resulted in increases in accumulation size class (Figure 10-6). No change in channel blockage was observed among accumulations in these two sites as all accumulations blocked at least 50% of the channel width in both 1976 and in 2002. Three new accumulations had formed in Watershed 2, but none had formed in Watershed 9.

10.7.2 Intermediate-sized basins

In Mack and Upper Lookout, piece additions and losses resulted in size class changes among eight of the twenty-one accumulations that were present in 1975 with five increasing and three decreasing size classes (Figure 10-7). A similar percentage of the accumulations (7 of 21) exhibited changes in channel blockage. Transport, fragmentation, and/or rotation of key pieces were responsible for decreases in the six accumulations that had lower levels of channel blockage in 2002.

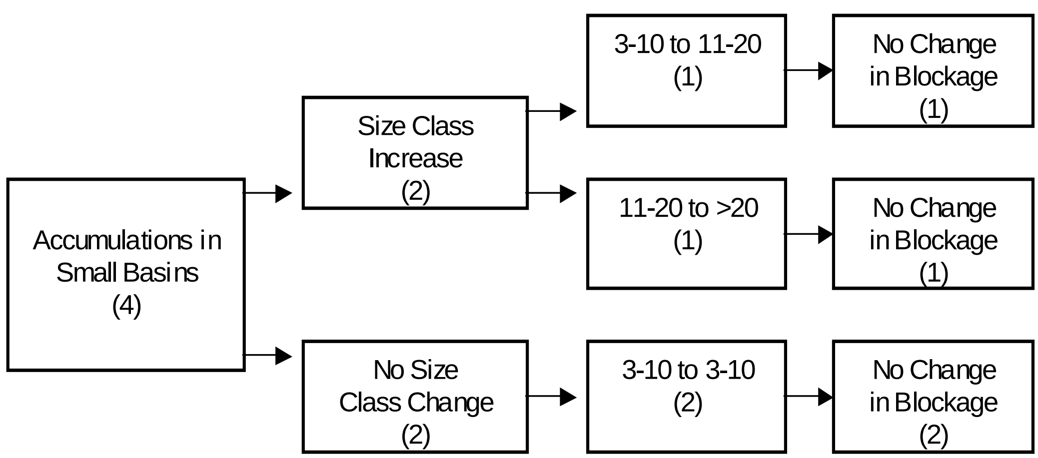



**Figure 10-6: Changes in size and channel blockage by wood accumulations in Watershed 2 and Watershed 9 sites between 1976 and 2002. Addition or loss of pieces was used to determine size class changes. The number in parentheses indicates the number of accumulations.**

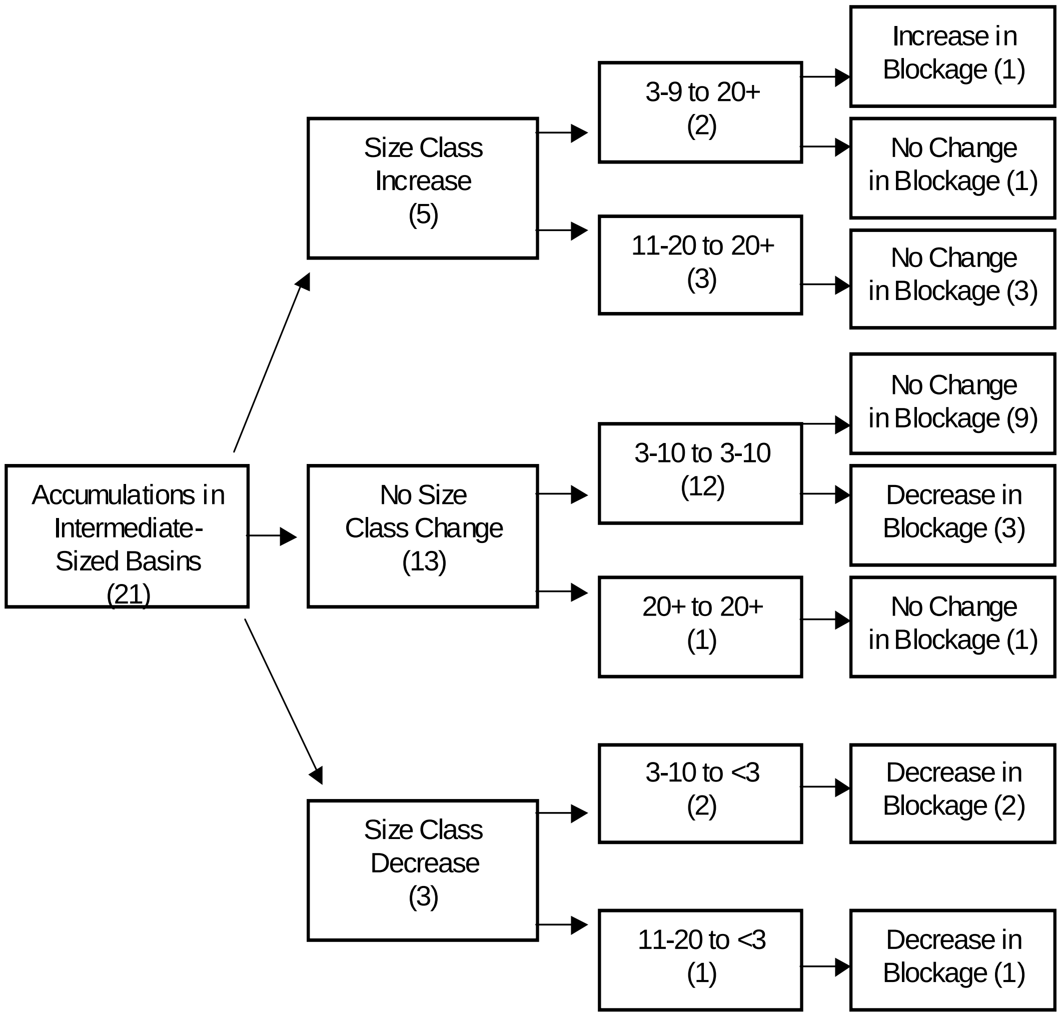



**Figure 10-7: Changes in the size class and channel blockage by wood accumulations in Mack and Upper Lookout sites between 1975 and 2002. Addition or loss of pieces was used to determine size class changes. The number in parentheses indicates the number of accumulations.**

In Mack and Upper Lookout the likelihood of change was associated with the extent of blockage observed in 1975 (Table 10-7). Accumulations that blocked 50-85% of the channel were twice as likely to have reduced channel blockage in 2002 as those that occupied more than 85% of the channel width. Accumulations that occupied 15-50% of the channel width in the 1970’s showed no change in how much of the channel they occupied in 2002.

**Table 10-7: Changes in blockage of channel width by wood accumulations in Mack and Upper Lookout sites between 1975 and 2002.**

| Blockage in 1975 | Blockage in 2002: 0-15% | 15-50% | 50-85% | 85-100% | Total |
|---|---|---|---|---|---|
| 0-15% (n=1) | 0 | 1 | 0 | 0 | 1 |
| 15-50% (n=7) | 0 | 7 | 0 | 0 | 7 |
| 50-85% (n=6) | 4 | 0 | 2 | 0 | 6 |
| 85-100% (n=7) | 2 | 0 | 0 | 5 | 7 |
| Total | 6 | 8 | 2 | 5 | 21 |

## 10.7.3 Lower Lookout

Comparisons of accumulations in Lower Lookout between 1977 and 2002 suggest only modest changes occurred (Figure 10-8). Two of the four accumulations that had been present in 1977 had lost enough pieces to cause a decreases in size class and no change in channel blockage was observed as all remaining accumulations from 1977.

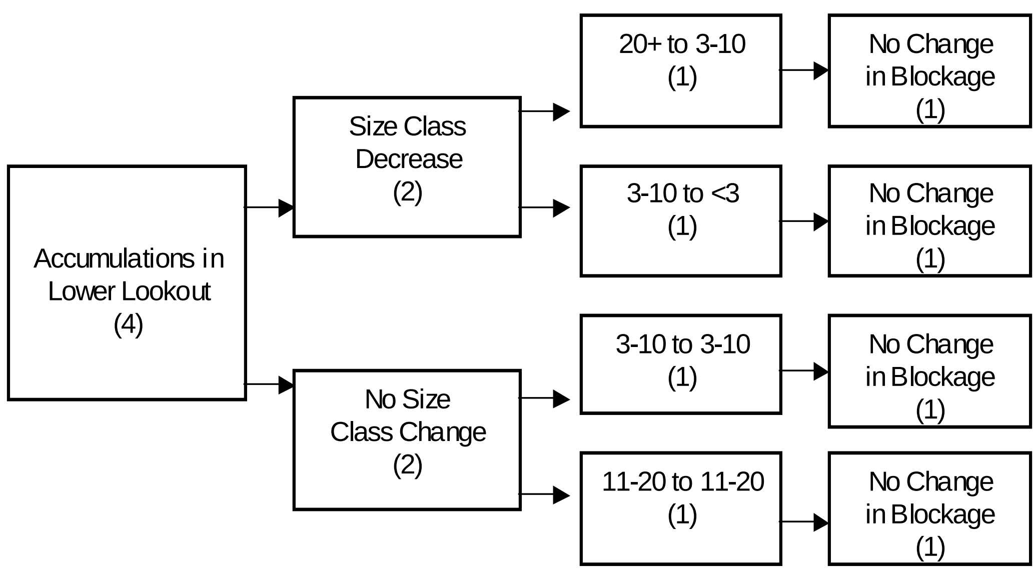



**Figure 10-8: Changes in the size and extent of channel blockage by wood accumulations in Lower Lookout between 1977 and 2002. The number in parentheses indicates the number of accumulations.**

In contrast, an inspection of maps from the intervening years shows that accumulations in Lower Lookout were highly changeable during this period of time (Figure 10-9). Formation of channel-spanning accumulations followed by trapping and release of wood resulted in significant fluctuation in the volume and number of large pieces (Figure 10-10).

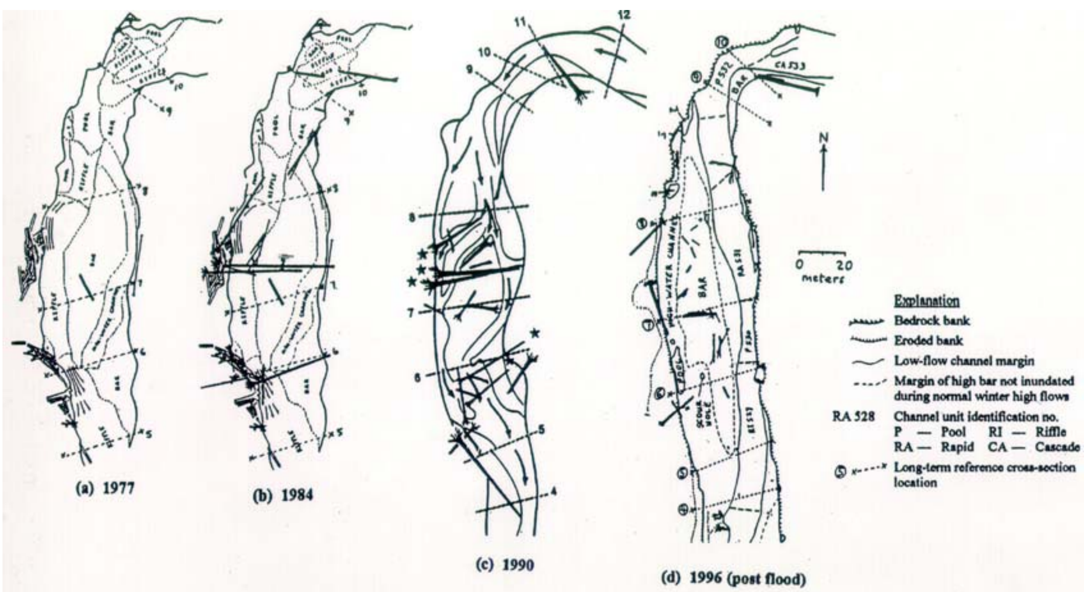



**Figure 10-9: Time series map of in-channel wood and channel features in the Lower Lookout (Faustini 2001).**

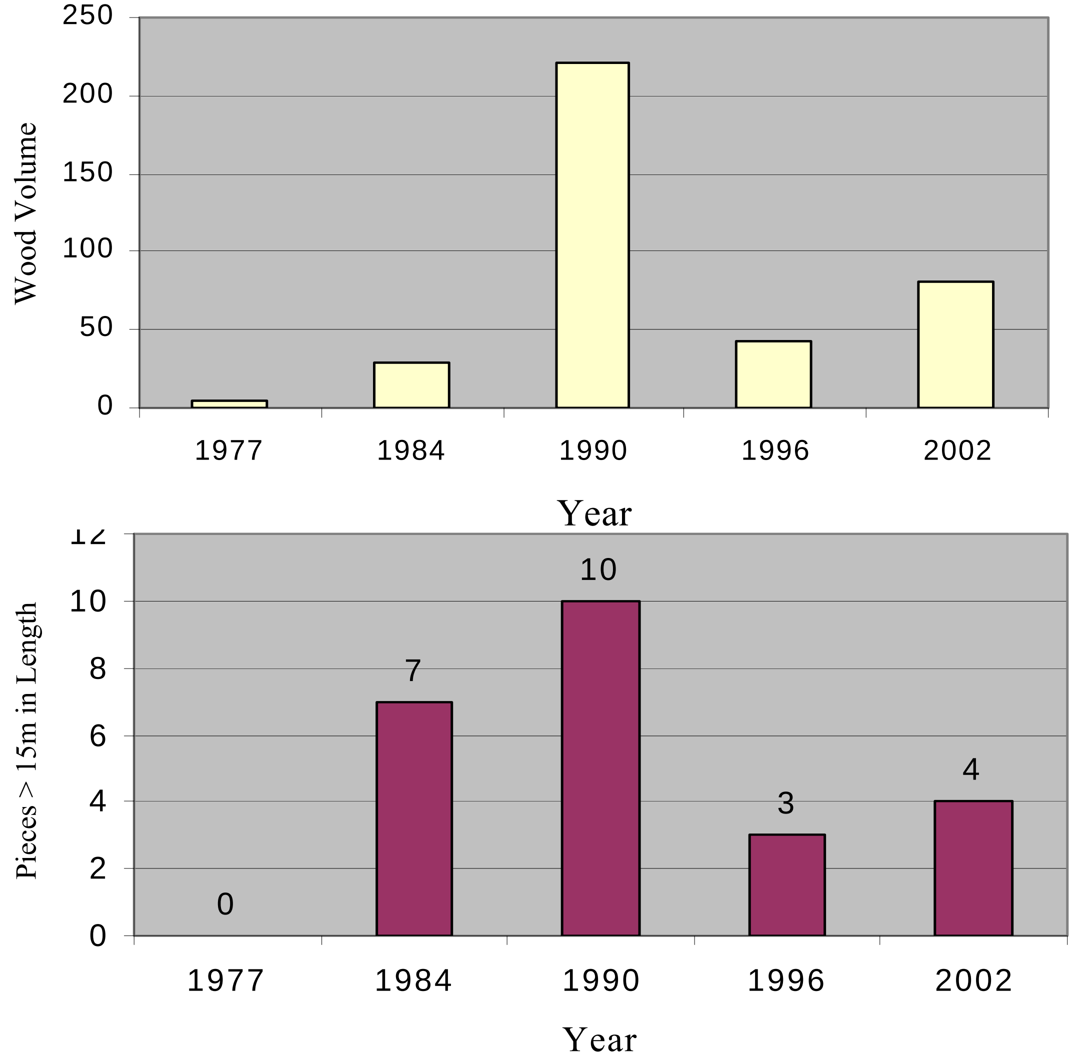



**Figure 10-10: The number of pieces greater than 15 meters in length and the in-channel wood volume in cubic meters for the Lower Lookout site from various dates between 1977-2002. In addition to Lienkaemper and Swanson (1987), data come from Lienkaemper (unpublished data), Nakamura and Swanson (1993), and Faustini (2001).**

Changes in accumulations in Lower Lookout between 1977 and 1984 resulted from the addition of three pieces that extended more than 50% across the channel (Figure 10-11b). Two of these large pieces entered the stream via windthrow and became associated with an accumulation that was present on the 1977 map (LLO1). A windstorm in 1982 toppled the other large piece that, along with other smaller material, became incorporated into another accumulation that was present on the 1977 map (LLO2). These additions changed the percentage of channel width occupation from less than 15% of the channel to more than 85% for both accumulations (LLO1 and LLO2).

The second period of change in the accumulations in the Lower Lookout occurred during flooding in 1996. Much of the wood, including most of the large pieces, added between 1977 and 1996 was transported out of the site and a portion of the streambank near LLO2 was excavated (Figure 10-11d). The two accumulations (LLO1 and LLO2) that had previously extended over 85% of the channel width were both reduced to less than 15% (Figures 10-11d).

The long gravel bar that formed along much of the length of the study site during the 1996 flood caused the primary channel to move against the east bank, which has affected the arrangement of wood in the site since 1996. Small accumulations that formed on top the bar in 1996 (Figure 10-11d) have not been affected by subsequent floods. Another small accumulation formed at the head of the bar between 1996 and 2002. Alteration in flow pattern caused by the bar has resulted in less erosion of the stream bank where the four log levee accumulations along the periphery of the channel had been present in 1977. The remaining portions of two accumulations from 1977 were covered over by riparian vegetation in 2002 and the wood is not holding other pieces or sediment in place.

Figure 10-11 is attached at end.

The only other notable change in the arrangement of wood in 2002 is the formation of a channel-spanning accumulation at the downstream end of the site. This accumulation was formed in 1999 as the result of a wind event that toppled the very large key piece in this accumulation (Figure 10-11e). This accumulation represents the majority of the increase in wood over the post-1996 flood period.

### 10.8 Comparison of mapped sites to basin-wide wood inventory

Because the maps used to measure change cover very limited amount of stream length, we asked whether these sites were representative of the general population of stream channels in the watershed, by comparing them to a basin-wide wood inventory conducted in 2002 (see Part 1 of this thesis). Each mapped site was compared to other segments that had similar transport capability and influence from redistribution processes.

Wood volumes in the Lower Lookout site between 1977 and 2002 fell within the observed range of variability of wood volume in 31 inventoried segments in 2002 that were comparable, high transport channels (Figure 10-12). Wood volumes mapped in Upper Lookout and Mack Creek mapped sites in 1975 and observed in 2002 also were within the range of variability of wood volume observed in 81 inventoried segments in 2002 that were intermediate-sized channels influenced by floods only during the last 50 years (Figure 10-13).

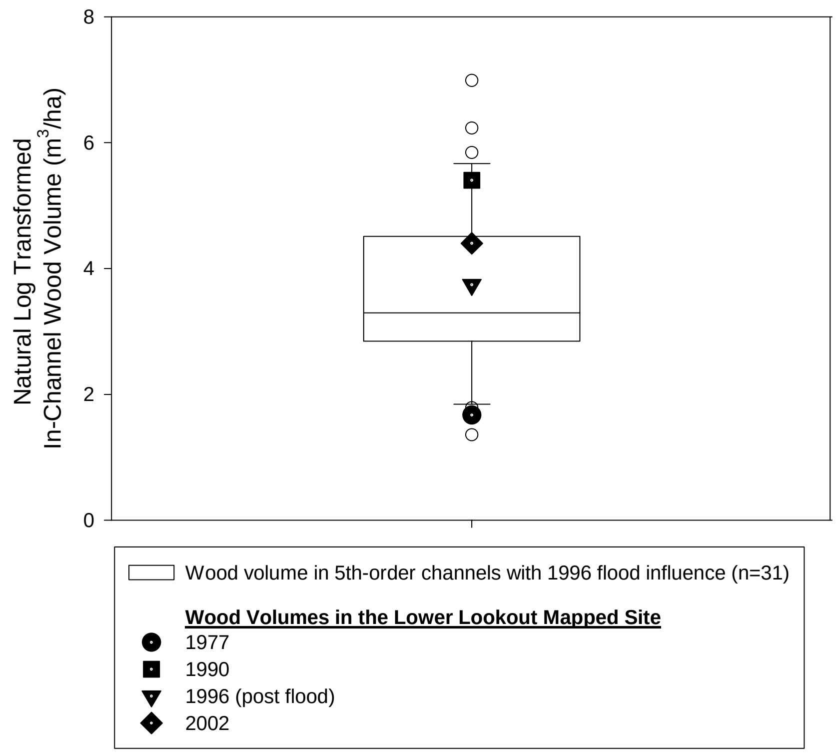
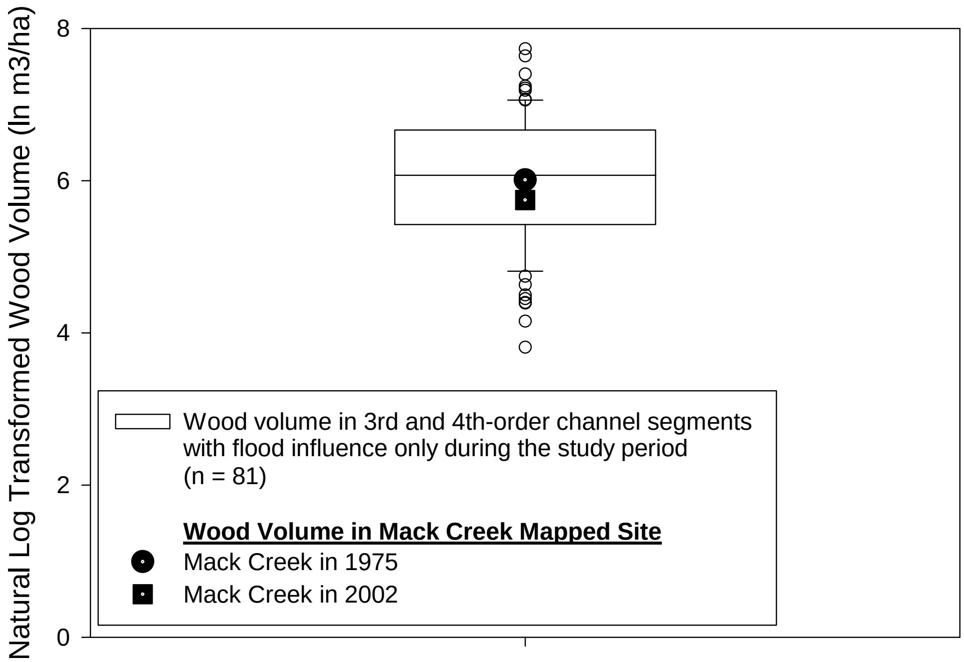
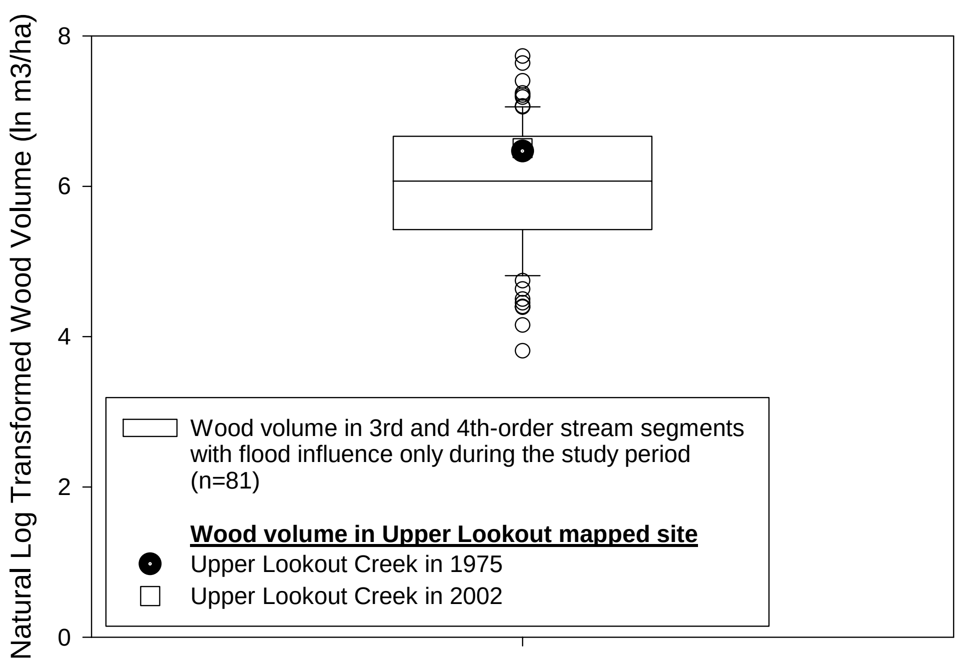



**Figure 10-12: Box plot of wood volume in 50-m stream segments with high transport capability (n=31) that only likely to be affected by floods during the study period. Wood volumes found in the Lower Lookout study site at various times between 1977 and 2002 are superimposed on the box plot.**




a.




b.

**Figure 10-13: Box plot of wood volume in 50-m stream segments with intermediate transport capability (n=81) that only likely to be affected by floods during the study period. Wood volumes found in the Mack Creek (a) and Upper Lookout (b) mapped study sites in 1975 and 2002 are superimposed on the box plot.**

# 11. DISCUSSION

## 11.1 Measurement errors

Errors in the estimates of change in wood could arise from: (1) missing small pieces, (2) incorrectly estimating large piece size, (3) missing pieces in accumulations. An error in measuring the number of small pieces is much more likely than an error in measuring the number of large pieces, but both types of measurements may have resulted in positive or negative errors in volume and piece counts. Small pieces are more likely to have been missed in places such as Upper Lookout where there were more large pieces of wood; although the methods used in 2002 probably counted more small pieces than were mapped in the 1970s. Because of their substantial size, large pieces would rarely have been missed. However, their volume could have been incorrectly estimated (see discussion about counting obscured pieces in accumulations below).

In addition to the error types described above, estimates of the volume and number of pieces in accumulations may have been underestimated. It is more likely that there would be volume errors associated with pieces in accumulations than with single pieces. This is due to the fact that, while single pieces are generally completely visible, portions of pieces in accumulations can be either partly or wholly obscured. If a piece was entirely obscured in 2002, it would not have been counted, and that would have reduced estimated volume and number of pieces. Additionally, in 2002 and on the maps from the 1970s, if pieces were partially obscured such that only one end of the piece was visible, its length class was likely to have been underestimated, reducing the volume estimate only.

Estimates of measurement error for each site were calculated for all sites assuming counting errors of 3 pieces and volume estimation errors of 5 $m^3$ (Table 11-1). Relative change for each site was defined as significant if an increase or decrease of 10% occurred after measurement error was accounted for. For example, if three pieces with a total volume of 5 $m^3$ were missed in Watershed 2, it would have resulted in a per hectare error of 39 pieces/ha and 64 $m^3$/ha. This results in an estimated error that is 60% of the net change in the number of pieces and 11% of the relative change in volume.

**Table 11-1: Estimates of measurement error for net change in volume and number of pieces by site based on a counting error of +/-3 pieces and volume calculation error of +/-5 $m^3$**

| | Error | | Absolute Difference | | % error | % error |
|---|---|---|---|---|---|---|
| Site | (number/ha) | (volume/ha) | number/ha | volume/ha | for number | for volume |
| WS9 | +/- 49 | +/- 81 | 618 | 12 | +/- 8 | +/- 678 |
| WS2 | +/- 39 | +/- 64 | 64 | 587 | +/- 60 | +/- 11 |
| MACK | +/- 8 | +/- 14 | 50 | 24 | +/- 17 | +/- 58 |
| ULO | +/- 9 | +/- 16 | 113 | 201 | +/- 8 | +/- 8 |
| LLO | +/ -9 | +/- 15 | 60 | 80 | +/- 15 | +/- 19 |

Using this system, significant changes in overall wood conditions occurred in Lower Lookout, in terms of both volume and number of pieces, and in Upper Lookout, in terms of the number of pieces. Significant changes in large pieces occurred in Upper Lookout and Lower Lookout, in terms of both volume and number of pieces, and in Watershed 2, in terms of volume. Significant changes in small pieces occurred in

Lower Lookout, in terms of volume and number, and in Upper Lookout and Watershed 9, in terms of number. Significant changes in single pieces were observed in Upper Lookout and Lower Lookout, in terms of both volume and number of pieces, and in Watershed 9, in terms of number of pieces. Changes in accumulations were significant in all sites in terms of the number of pieces only (WS9, Mack, ULO), volume only (LLO), or both (WS2). Significant changes occurred in all sites for wood located both in the channel and out of the channel. In Watershed 9 and Mack, significant changes were observed in terms of number of pieces only. Changes in Watershed 2 were significant for in terms of volume only. Changes in volume and number were significant in Lower Lookout. In Upper Lookout, wood out of the channel changed significantly in terms of both volume and number while significant changes in wood located in the channel occurred in terms of number of pieces only.

### 11.2 Measurement of changes in wood conditions

In this study we measured net changes in wood amount. However, net changes are generally less than changes to pieces are considered individually instead of in aggregate (i.e. gross changes). Our knowledge of the gross changes in wood that occurred in Lower Lookout between 1977 and 2002 highlights how gross changes in wood can be very substantial while net changes can be rather unsubstantial. Other basins similar to Lower Lookout could have similar levels of net change but little in the way of gross change and we would be misled into concluding that changes in wood conditions were minor in basins of this size.

Using techniques that measure gross changes in wood conditions may not necessarily resolve the issue. Documenting gross changes in wood requires substantial time and resources that includes frequent surveys that involve the use of tags or other methods to that allow the tracking of particular pieces from the time they enter until the time they leave a site. These methods of tracking gross changes can also have substantial measurement uncertainty. For example, pieces may enter and leave site between successive inventories and be completely undocumented. Documenting gross changes to accumulations are also particularly difficult. New pieces added to an existing accumulation may obscure pieces that were there previously as well as other newly added pieces.

### 11.3 Effect of size, arrangement, and location on changes in wood, 1970s - 2002

We expected large pieces would generally be stable, especially in smaller basins, based on earlier studies of fluvial transport of wood in the Pacific Northwest (Keller and Swanson 1979, Lienkaemper and Swanson 1987, Bilby and Ward 1991, Nakamura and Swanson 1994). These studies showed that pieces with lengths greater than channel width were more persistent and less likely to move than pieces that were shorter than channel width. However, we found that while net changes in large pieces were minor in Mack and Upper Lookout, they were substantial in the two smallest basins. Differences in the amount of wood added by toppling led to more net change in large pieces in Watershed 2 and Watershed 9 than in Mack and Upper Lookout.

Inputs from toppling in Watershed 2 and Watershed 9 were 6 to 40 times greater in terms of volume/ha and 7 to 19 times greater in terms of number of pieces/ha than inputs to the other three sites.  While toppling may vary by basin location, stand age, and species composition, it is somewhat unlikely that the differences observed are the result of these factors because forests adjacent to the study sites are fairly similar. It is more likely that differences from toppling are an artifact of the relatively short amount of time and limited spatial extent of our study area.

As expected, there was greater change among small pieces than large pieces over the study period.  Relative change in the number of small pieces was substantial and comparable or greater than net change in large pieces for all sites except Watershed 2. As noted above, toppling of large pieces in Watershed 2 contributed to more change in larger pieces than in other sites. While only limited research has been conducted on the transport of small pieces it does suggest that, because of their greater mobility, small pieces are subject to more changes in location (Braudrick and Grant 2000, Haga et al. 2002).

We expected pieces in accumulations to change less than single pieces because pieces in accumulations would have additional stability created by the association with pieces within accumulations that would not exist for single pieces.  The limited research examining wood mobility as a function of arrangement suggests that pieces in accumulations are less likely to move than single pieces.  Keim et al. (2000) found that accumulations were effective trapping sites. Additionally, Lienkaemper and Swanson (1987) noted that small pieces in accumulations, which might be considered unstable if isolated in the channel, were stabilized by one or more larger pieces. Our results add support to this idea as the net changes in volume for accumulations were generally small in Watershed 9, Mack and Upper Lookout, but net changes in the number of pieces were substantial for all sites. This suggests that, in all sites except Lower Lookout, floods can move smaller pieces into and out of accumulations, but other processes are necessary to mobilize larger pieces and create substantial alteration of accumulations. (See the discussion of congested wood movement associated with dam-break flood pulses and debris flows in Part 1 of this thesis.)

Net changes in the number of single pieces were substantial in all sites. However, the changes in single pieces were not consistently greater than changes in pieces in accumulations. This finding is inconsistent with our expectation that single pieces would be less stable than pieces in accumulations. In Watershed 2, Mack and Upper Lookout, net changes in volume and number of single pieces were all negative between the 1970s and 2002 while net changes in pieces in accumulations were all positive. This suggests that single pieces may have been incorporated into accumulations during floods that occurred between the 1970s and 2002.

Pieces located out of the channel were expected to be largely unchanged because flows capable of mobilizing these pieces would be more infrequent than flows that could mobilize wood located in the channel. However, we found relative changes in pieces located out of the channel to be substantial in almost all sites and commonly comparable to those for pieces located in the channel. Channel maps of Lower Lookout show wood along the channel margin was significantly altered by the flood of 1996. Several other factors may have also influenced these results. In Watershed 2 and Watershed 9 relative increases in volume accompanied by relative decreases in number of pieces resulted from the addition of a few large pieces created by toppling, which could inflate volume, combined with decomposition among smaller pieces, which could reduce the number of pieces. Additionally, most of the large pieces that toppled into Watershed 2 and Watershed 9 were categorized as "out of the channel" because more than half the total length located out of the channel. Only if a large piece toppled roughly parallel to the stream would it have been categorized as "in the channel" given the narrow channel width.

### 11.4 Influence of fluvial transport, toppling, and decomposition on changes in wood, 1970s - 2002

The hypothesis that fluvial transport would cause more change in larger basins than smaller basins was supported by the results of this investigation. However, increased fluvial transport of wood into and out of the study sites in larger basins did not necessarily affect all aspects of the wood conditions examined equally. Large pieces were less prone to change in smaller basins and more prone to change in larger basins. This is understandable given that changes in channel character, such as increased channel width, increase the likelihood of larger pieces being mobilized by

floods. Increases in fluvial transport also resulted in single pieces becoming increasingly prone to change. In areas with low fluvial transport, single pieces are more numerous than pieces in accumulations and transport of any piece is likely to be infrequent resulting in a situation where net change in single pieces is likely to be smaller. In areas where fluvial transport is more influential, the proportion of single pieces is less and pieces in accumulations may be more difficult to mobilize because of the additional stabilization provided by other pieces in accumulations.
Increases in fluvial transport associated with larger basin size did not appear to have a significant influence on large pieces in accumulations or pieces located outside of the channel except in Lower Lookout. This suggests that the existence of a basin area threshold for large piece by flood transport is unlikely (Figure 3-5, Grant and Swanson 1995). Instead, substantial changes to accumulations in 3$^{rd}$- to 4$^{th}$-order channels within the region are only likely to occur if other processes, such as debris flows, produce congested wood movement.

Input of wood from toppling was found to be responsible for more change in wood conditions in smaller basins than larger basins. It was hypothesized that inputs from toppling would be similar among all sites because the forests adjacent to the stream were of similar age. It is likely that analyzing net, rather than gross, change contributed to an underestimation of toppling for the sites in larger basins. For example, wood that toppled into Lower Lookout between 1977 and 1996 that was transported by the flood is missed by the net change analysis but would have been captured by an analysis of gross change.

Similar levels of decomposition were not observed among all sites as was hypothesized. Instead, decomposition was found to be responsible for more change in wood conditions in smaller basins than larger basins. Again, it is likely that analyzing net changes resulted in the underestimation of decomposition in the larger sites, but the greater amount of active channel area in larger basin sites may also be influencing the results. When the area of active channel per unit of channel length increases, it becomes increasingly unlikely that pieces will come to rest in a location where they will decompose before being moved.

### 11.5 Effect of increasing fluvial transport on changes in accumulations, 1970s - 2002

Changes to accumulations were related to basin size. In Lower Lookout between 1977 and 2002, channel-spanning accumulations formed and were removed. In Upper Lookout and Mack, accumulation change was more modest and tended to occur when key pieces were oriented against the direction of flow or extended well into, but not completely across, the channel. Accumulations changed very little in Watershed 2 and Watershed 9.

The changes in accumulations observed in Lower Lookout suggest that the residence time of the channel-spanning accumulations in 5$^{th}$-order channels may be shorter than estimates of decades to centuries reported by other researchers (Swanson and Lienkaemper 1978, Swanson et al. 1984, Lienkaemper and Swanson 1987, Gregory 1991). Two factors may explain this finding. First, Lower Lookout experienced a 50-year return period flood in 1996; this was a much larger event than was included in the other studies. Also, the width of the channel in Lower Lookout is great enough to allow movement of the longest pieces within the wood population, and it is also at least twice as wide as the channels examined by Swanson and Lienkaemper (1978), Swanson et al. (1984), Lienkaemper and Swanson (1987), and Gregory (1991).

### 11.6 Management implications

Based on our experiences conducting this study we have a number of suggested elements for monitoring programs

- Establish marked, stable reference points that delineate site boundaries.
- Schedule annual inventories in larger basins.
- Adopt digital video technology as a replacement for tape and compass surveying techniques. This would allow for greater spatial coverage and facilitate comparisons of wood conditions in reaches at different points in time.
- Incorporate features such as size and number of key pieces in accumulations, locations of accumulations with respect to the active channel, as well as classifications of the numbers of pieces and extent of channel width blocked in order to facilitate assessments of changes in individual accumulations.

The variable effect of fluvial transport on wood in the channel complicates the implementation of management strategies that seek to manipulate wood in streams to meet habitat objectives. Because general fluvial transport (as opposed to congested wood movement that is likely to be associated with mass movement processes) does not appear to be sufficient to move larger pieces in intermediate-sized, 3rd – and 4th-order streams, placing large pieces of wood into these portions of the stream network would be a generally effective strategy. Even if pieces placed do move it is likely they will become incorporated into new accumulations in relatively close proximity.

## 12. CONCLUSIONS

This study investigated factors that could affect the amount of change in in-stream wood over time in the Lookout Creek watershed in the western Cascade Range. We utilized detailed map records that permitted us to compare wood conditions over a 25-year period, which is longer than most other field-based wood dynamics studies. Our findings support the following conclusions:

- Changes in in-stream wood were greater among small pieces than large pieces, although substantial changes in large pieces did occur in larger channels as a result of fluvial transport and in smaller basins as a result of toppling.
- Changes in in-stream wood were greater among single pieces than pieces in accumulations. Floods are responsible for decreases in single pieces

accompanied by increases in pieces in accumulations that were observed in most sites.

- Changes in in-stream wood occurred among pieces located both in and out of the channel suggesting recent flooding, particularly in larger channels, was able to affect wood located along the margins of the channel.
- Changes in in-stream wood resulting from fluvial redistribution systematically increased with channel size. Decomposition and toppling were the dominant processes of changes in smaller channels, while fluvial transport was the dominant redistribution process in larger channels.
- Change in accumulations was generally minor in all sites except the $5^{th}$-order channel site. This suggests that congested wood transport is necessary for extensive alteration of accumulations in $3^{rd}$ and probably $4^{th}$-order channels in the western Cascade Range.

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# APPENDICES

Appendix 1: Characterizing accumulations during field inventory

Explanations of the variables used to characterize accumulations are explained in this section.

Number of pieces in an accumulation

Five classes were utilized: 1) 3-9 pieces, 2) 10-20 pieces, 3) 21-50 pieces, 4) 51-100 pieces, 5) >100 pieces

Emplacement process for pieces in an accumulation

We visually estimated the percentage of the pieces in the accumulation that were emplaced by the following processes.

Fluvial transport: water moved the wood for some distance, or shifted the wood from its original fall location by at least 1 meter.

Windthrow: piece fell in due to toppling of a tree by wind

Bank erosion: piece in the stream was still attached to the bank, bar, or island where it had been rooted and/or evidence of localized bank cutting prompted the destabilization of the piece in question.

Debris flow: debris flow was inferred as the cause of emplacement if it was buried in sediment, had excessive physical damage that could have been cause by transport with other large pieces of wood, or was located in very dense accumulations.

Earthflow: pieces that were associated with larger (>1 m in width) streamside slides.

Timing of emplacement for pieces in an accumulation

We visually estimated the percentage of the pieces in the accumulation that were emplaced prior to 1996, in 1996, and after 1996.

Prior to 1996: A piece was inferred to have been emplaced prior to 1996 if there was vegetation (saplings, moss) growing on it or if it was in a more advanced state of decay.

1996: Pieces inferred to have been emplaced in 1996 showed relatively recent signs of physical abrasion such as broken limbs that were slightly weathered.

After 1996: A piece was inferred to have been added after 1996 if freshly broken ends and/or fine woody material such as needles, leaves, and twigs were present.

Extent of channel blockage by an accumulation

This variable was used to indicate how far across the active channel the accumulation reached. Four classes were used: 0 (0-15%), 1/3 (26-50%), 2/3 (51-75%) or 1 (76-100%).

Orientation of accumulation

This variable characterized how the primary axis of the accumulation was oriented with respect to inferred direction of high flow in the channel
0-30 degree angle from parallel to high flow direction
30-60 degree angle from parallel to high flow direction
60-90 degree angle from parallel to high flow direction

Location of accumulation with respect to the active channel

Visual estimation of the percentage of pieces in an accumulation that was located in Zones 1, 2, 3 or 4 as described by Robison and Beschta (1990).

Accumulation type

The following categories were used to denote the general configuration, location within the channel, and process responsible for emplacing key pieces of the accumulation.

Log levee: wood pieces were deposited along the channel margin by flood flow and generally stacked parallel to the direction flow and occupying very little of the active channel.

Side channel: All pieces are located in a side channel off of the main, active channel and appear to have been moved by flood.

All in channel: All pieces are located in the active channel and were deposited there by flood transport. Typically formed as the result of pieces shorter than channel width stopping because of contact with the streambank, boulders or other streambed feature and then catching others.

Fall in: Pieces that initiated the formation of the accumulation fell in as a result of windthrow or bank erosion. Other pieces may have been added as the result of flood transport. Overall pieces are loosely associated with eac hother.

Head of island: Pieces are stacked as a result of flood transport and are located at the head of an island or bar feature. Typically most pieces have a similar orientation that is against or between the flow direction.

Terrace/Island: Most pieces are located outside of the active channel and show evidence that they were emplaced by flood transport.

Mass movement: Pieces are stacked in a generally tight, but haphazard manner and show evidence of downstream transport such as abrasion.

Appendix 2: Determining average volumes for diameter.length classes.

The process used to estimate the average volume of pieces in each of the "diameter.length" classes is explained below. The general process involved selecting a representative group of wood pieces, measuring their length and diameter, calculating average length and diameter for each of the length and diameter classes, and using average length and diameter values to compute average volumes for each diameter.length class.

At several locations dispersed through the Lookout Creek watershed pieces of in-channel wood were measured exactly to provide a calibration set for reach-scale volume calculations. At each location we spent an hour measuring any pieces that could be safely and accurately measured. If 40 pieces had not been measured after 1 hour we continued to measure pieces until 40 were measured. A total of 412 pieces were measured.

Diameter measurements were taken at each end and the midpoint of each piece using calipers for each piece. The length of each piece was measured using a laser surveying device or a tape. Untransformed average values for each diameter and length class based on these measurements are shown in Table 1 and box plots of the data are show in Figure 1.

**Table 1: Untransformed values for mean and standard deviation (SD) within each diameter and length class**

| Diameter Class | Mean (cm) | SD (cm) | N |
|---|---|---|---|
| 1 | 17.94 | 6.13 | 236 |
| 2 | 43.11 | 8.62 | 127 |
| 3 | 78.35 | 13.70 | 49 |

| Length Class | Mean (m) | SD (m) | N |
|---|---|---|---|
| 1 | 2.76 | 1.15 | 279 |
| 2 | 6.91 | 1.35 | 89 |
| 3 | 12.85 | 2.42 | 28 |
| 4 | 27.56 | 6.89 | 15 |

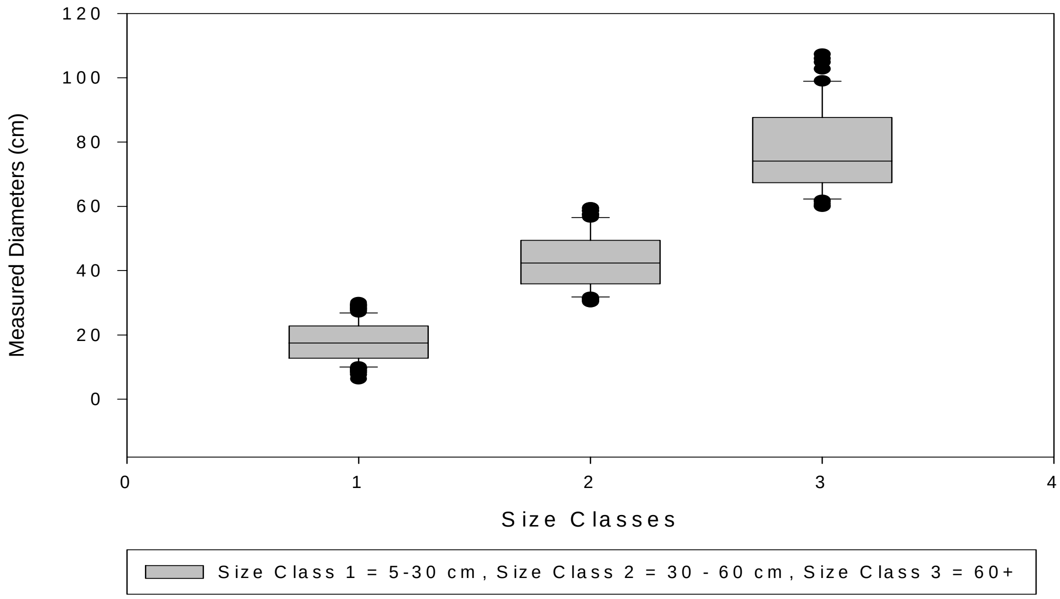
Data were normalized using a natural log transformation. Box plots created with transformed data are shown in Figure 2. Average values for each class were back transformed and used in volume calculations. The volume of each piece was calculated using the equation for the volume of a cylinder with average values for each diameter ($d_{av}$) and length ($l_{av}$) class.

$$\text{Volume} = (\pi(d_{av}/2)^2)^* \, l_{av}$$

Table 2 shows the average volume of pieces in each diameter and length class.

**Table 2: Average diameter and length within each class following back transformation.**

| Diameter Range (cm) | Diameter Class | Average in Diameter Class (m) | Length Range (m) | Length Class | Average in Length Class (m) |
|---|---|---|---|---|---|
| 10 –30 | 1 | 0.18 | 1.0-5.0 | 1 | 2.8 |
| 31-60 | 2 | 0.43 | 5.1-10.0 | 2 | 6.9 |
| >60 | 3 | 0.78 | 10.1-20.0 | 3 | 12.9 |
| | | | >20.0 | 4 | 27.6 |



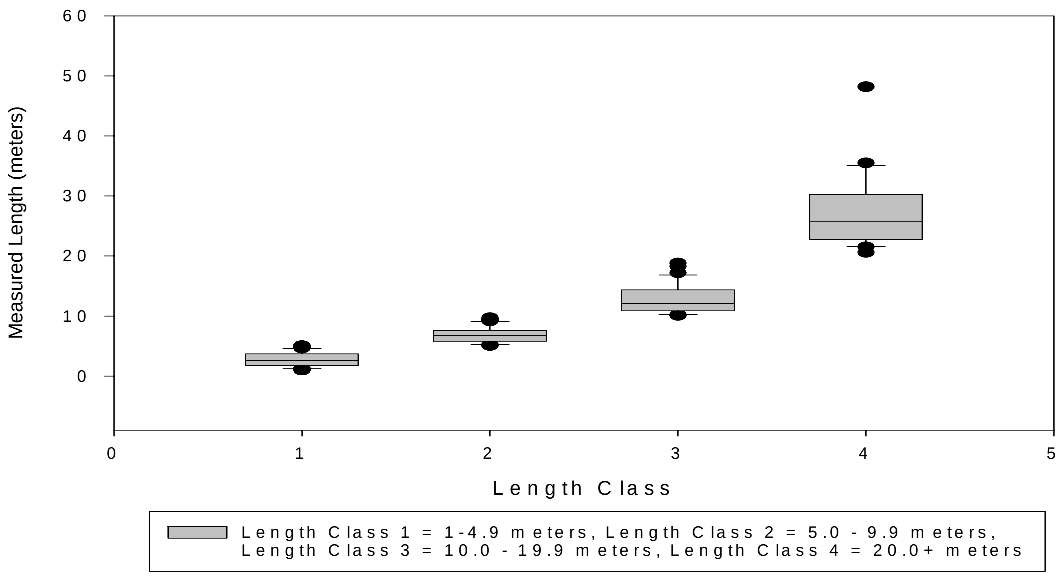




**Figure 1: Box plot of untransformed values for mean and standard deviation (SD) within each diameter (size) and length class**

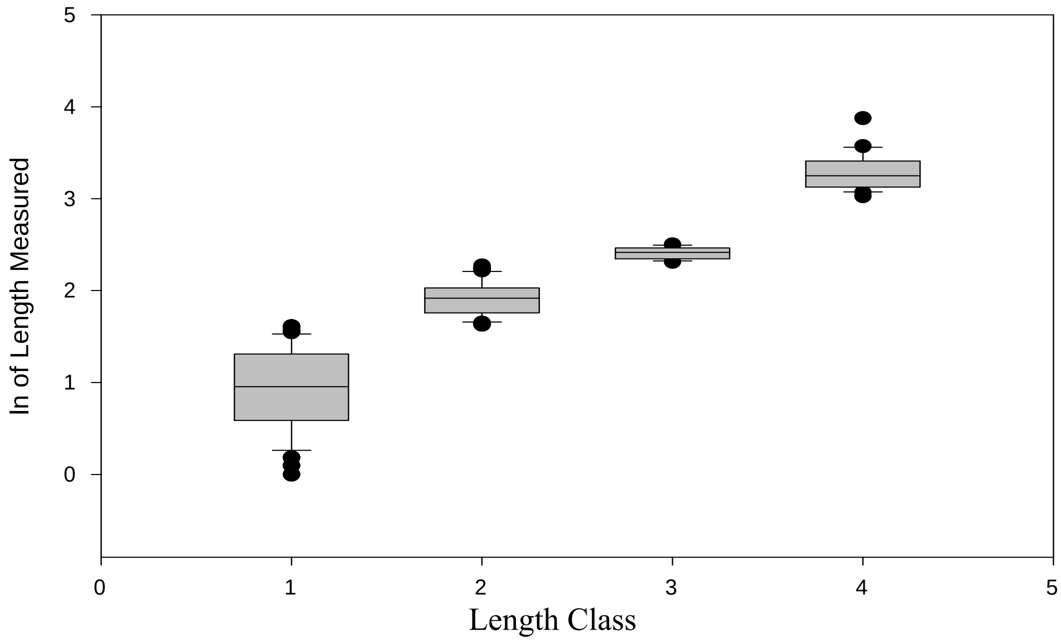



**Figure 2: Box plot of natural log transformed values for mean and standard deviation (SD) within each diameter (size) and length class**

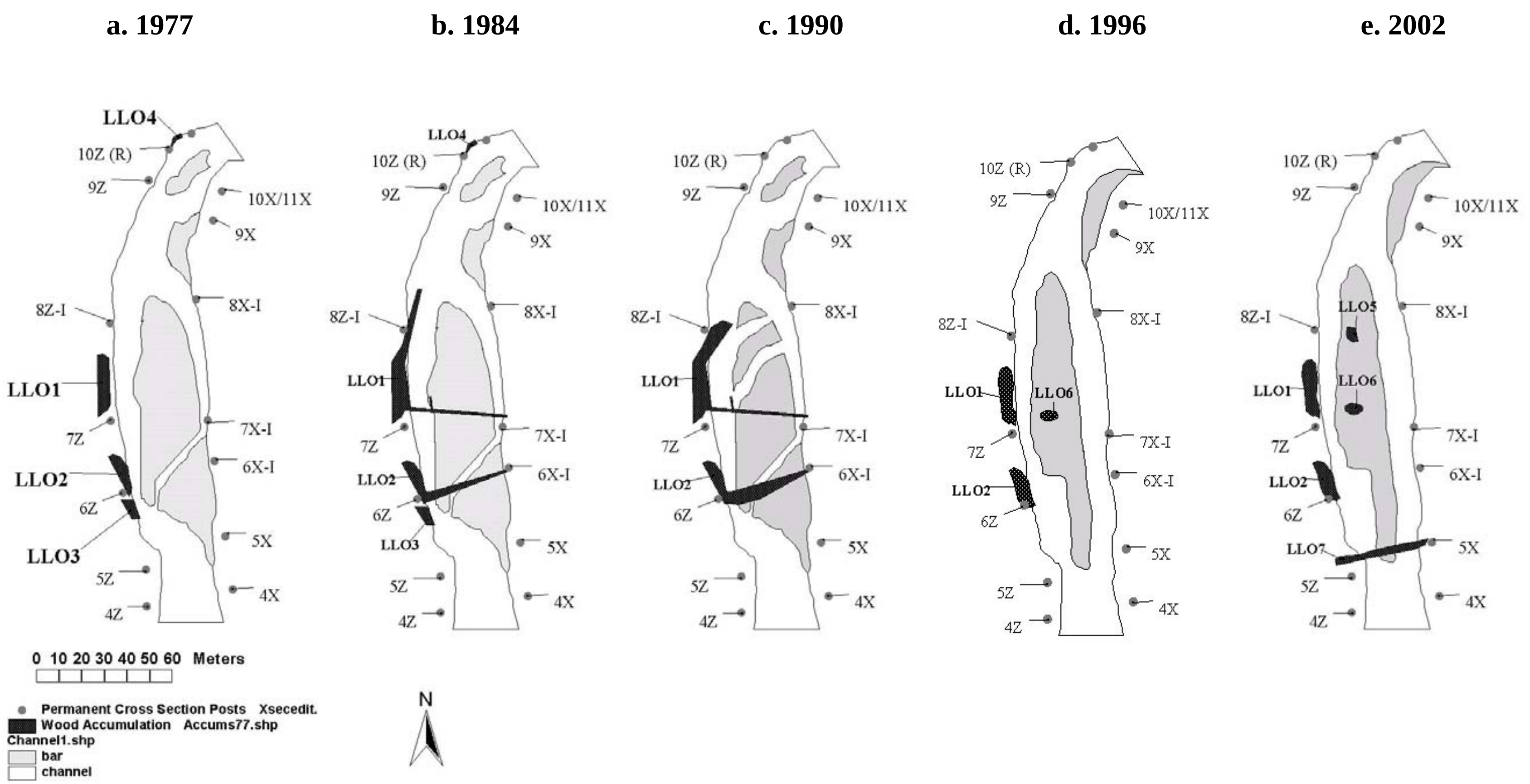



**Figure 10-11: Changes in accumulations observed in Lower Lookout site between 1977 and 2002.**