COOPERATIVE MONITORING EVALUATION AND RESEARCH 03-308

Review of the Available Literature Related to Wood Loading Dynamics in and around Streams in Eastern Washington Forests

DOCUMENT PACKAGE

OCTOBER 2004

SUBMITTED BY
HERRERA ENVIRONMENTAL CONSULTANTS INC.
#PSC 03-134

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TECHNICAL MEMORANDUM

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Prepared for

State of Washington
Department of Natural Resources
Forest Practices Division

October 2004

Note:
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Review of the Available Literature Related to Wood Loading Dynamics in and around Streams in Eastern Washington Forests

Prepared for

State of Washington
Department of Natural Resources
Forest Practices Division
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October 4, 2004

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1.0 Introduction

1.1 Background

New forest practice rules recently established and based on the Forests and Fish Report (F&FR 1999) are subject to monitoring to evaluate their effectiveness. Monitoring and determination of the effectiveness of the new rules is the responsibility of the Department of Natural Resources' (WDNR) Cooperative Monitoring, Evaluation, and Research (CMER) committee made up of representatives from tribes, state and federal agencies, and industry. CMER has designated a standing committee, called the Scientific Advisory Group – Eastside (SAGE) to develop study approaches and implement evaluations regarding eastside riparian rules. SAGE initiated this project to identify the current state of knowledge regarding instream wood, wood recruitment and fluxes, and the function of wood in streams of eastern Washington. The project focus is to assess available quantitative information for eastern Washington on 41 research questions (provided in Appendix A) that pertain to the following nine topics:

- Wood loading (channel wood characteristics)
- Wood distribution in streams
- In-stream manipulation of wood
- Decay rates of wood in streams
- Transport of wood in streams
- Role of wood in pool formation in streams
- Role of wood in bedload transport and sediment sorting
- Riparian and channel conditions
- Wood recruitment and mortality.

Herrera Environmental Consultants, Inc. (Herrera) assembled a consultant team that was selected by WDNR and SAGE to conduct the study. Herrera has prepared a Technical Report presenting the results of the study effort. This report is in partial fulfillment of Task 5 (Table 1-1).

1.2 Methodology

Collection of Literature and Data

The Herrera team contacted a wide array of institutions and individuals, in addition to searching numerous databases of potentially relevant literature. Herrera developed a source tracking log to document databases collected and searched (Appendix B-1), individual scientists and land managers possibly involved in eastern Washington research (Appendix B-2), and institutions included in the search for available information (Appendix B-3). Herrera contacted 47 institutions, 43 individuals, and searched or obtained 39 databases to obtain information pertaining to this project. Table 1-1 outlines the project tasks that were undertaken by Herrera for completion of this literature review.

Table 1-1. Project tasks.

No.	Task	Description	Date
1	Team workshop	Project kick-off project workshop with SAGE members to refine the project scope of work, discuss research priorities and level of effort to be expended for each question, present the conceptual model and its relationship to the analysis of literature, and define criteria for determining quality of numeric information.	8/28/03
2	Literature search and acquisition	Assemble the available literature related to question topics for eastern Washington forest streams and their associated ecosystems, including the Eastern Cascades, Northern Glaciated Mountains, and the Blue Mountain Ecological Reporting Units and other similar and relevant ecosystems. Technical staff was to collect sources from university libraries and agency libraries. Types of sources that were to be contacted include published peer-reviewed literature, non peer-reviewed literature (gray literature, including monitoring results, pilot projects, resource assessments, conference proceedings, etc.), and master's and doctoral research. Technical staff was to obtain unpublished resources by calling resource managers, government scientists and academic investigators, and by consulting on-line sources of gray literature.	4/7/04
3	Mid project workshop	Workshop with DNR, SAGE, and CMER representatives in order to reassess the project plan and provide a preliminary review of the sources and available numeric information. The workshop included a discussion of the preliminary draft literature database and answers to four (4) questions for DNR and SAGE's review.	11/14/03
4	Review & catalog literature sources	Resources compiled in Task 2 will be reviewed and catalogued using ProCite™ library software.	5/21/04
5	Technical report	Herrera team will prepare a report that summarizes and synthesizes existing information for each of the nine topic areas provided in Appendix A. Answers will include text integrating the findings of studies on the given subject, numeric summaries of reported results (including information on range, standard deviation, means, effects of controlling variables, where reported within the reviewed documents), citations and descriptions of each data source and confidence in the answers and applicability of the information across regions of eastern Washington, where possible. The technical report addressing all 41 questions will build on this preliminary draft report prepared for the mid-project workshop.	5/21/04

The general approach to obtaining literature for this research project was to first compile a database of readily available informational sources potentially relevant to the nine topics and eastern Washington. This information was collected into a set of master databases of over 5,000 references. These master databases were searched for each question and the information sorted into the following categories: 1) research that was conducted in eastern Washington, 2) relevant research that was conducted in an analogous ecoregion (e.g., similar ecosystem regions in the

Rocky Mountains to that in eastern Washington), and 3) literature that was not from analogous ecoregions of eastern Washington, but provides useful information regarding study methodologies or data linked to physical processes relevant to the question. A discussion of the ecoregions and the definition of analogous is discussed under the Ecoregions sections below.

The Herrera Team obtained 12 watershed analyses for the eastern Washington region (listed in Appendix C) from SAGE members. An initial assessment of these watershed analyses determined that most of the information documented is qualitative and little quantitative data is presented. Approximately 38 additional watershed analyses that follow Washington Department of Natural Resources protocols (listed in Appendix C) have been conducted for eastern Washington. These additional watershed analyses may have useful data, but significant effort would be necessary to distill the information; they were not procured because it was beyond the scope of this literature review.

In compiling and evaluating quantitative data it is essential to understand the methodology used to collect data, the context of the study, and assumptions made during any part of the study. For example, for studies comparing unmanaged and managed lands, it is not valid to assume particular sites are representative of either category without establishing specific objective criteria for defining the categories. A site that has been clearcut two times and in its third harvest rotation and a site which has been selectively cut just once represent very distinct antecedent conditions even if the current forest is of similar age and both are managed sites. Likewise, unmanaged sites may have been subjected to very different histories of natural disturbance.

Interpretation and conclusions often depend on important assumptions. For example, interpretations or assumptions regarding historical data depend on a clear understanding of what was measured and the historical context. Measurements as simple as channel width mean little without an explicit definition of what was measured; was it wetted width at a certain discharge, was it the unvegetated width, did it include side channels, was it based on topographic criteria (e.g., top of bank), or some other criteria? Other questions about historical activities in streams are also important for interpretation and comparison between studies. For example, was a stream ever cleared of wood debris? Stream clearing was widely practiced and still occurs in many areas. Has the fire history in a region been influenced by historic fire management practices? If so, are recent fires representative of "natural" fires? Have riparian buffers been part of historical management?

The Herrera team has attempted to address these issues in evaluating reports and data. It is clear that an assessment of the assumptions, methodology, and data quality of each study is a critical part of being able to compare results between studies. This type of evaluation is important to assembling a database and drawing conclusions about eastern Washington forests.

Response to Research Questions

A list of the research questions is provided in Appendix A. The approach to responding to each of these questions is described below.

Summary of Literature Sources. A short summary of the literature search is included in each answer. Literature sources are categorized into the three categories: 1) studies conducted in eastern Washington, 2) studies conducted in analogous regions, and 3) studies that are not in analogous regions but are relevant to the question's topic. This section includes a brief discussion and summary table consisting of the following elements for the study area of each study: location, drainage area size, slope, general geologic type, presence of riparian management, and type of data (original data, quantitative, or qualitative).

Summary of Quantitative Data. A summary of quantitative information directly related to the question and eastern Washington is provided. Each relevant literature source that contains quantitative data is briefly discussed. Where appropriate, a list of all data parameters used in the study to arrive at final results is provided. Then, the results that pertain to the question from each study are presented. The Herrera team did not conduct numeric or statistical analyses of these studies; however, the team reported an example of the numeric results from the relevant studies. If appropriate, analysis results were provided that were relevant to the question, but did not specifically answer the question.

Herrera has also completed a preliminary assessment of whether data collected for the question responses covers all of eastern Washington stream channel sizes and forest types. Drainage areas in eastern Washington range from approximately 0.1 square kilometers to 10,000 square kilometers in size. Where possible, the Herrera team portrayed the data for a question by drainage area in order to identify which drainage basin sizes were covered by the existing studies. This additional analysis illustrates the stream channel sizes (or drainage areas) that were addressed in the available literature for a particular question and reveals which stream sizes have not been addressed in the literature.

For questions where no studies within eastern Washington were found or additional information from analogous regions were pertinent to answering the question, a summary of the quantitative data and results from these studies was also provided. Since these studies were not conducted in eastern Washington, they can provide a preliminary answer for their respective research questions; however, further analysis would be needed to determine if these studies are statistically similar to similar conditions in eastern Washington.

For questions where no information from eastern Washington or analogous regions was available, a summary of quantitative information from relevant topical studies was provided. Studies that are relevant by topic were used to illustrate methodologies that could possibly be applied to eastern Washington in future studies.

Qualification of Literature Sources. Question responses were then qualified as follows:

1. **Question can be answered now for a particular region (e.g., Blue Mountains) of eastern Washington.**

2. **Question can be answered with additional quantitative analysis of existing data. There is a sufficient source of scientific data to answer question for particular region in eastern Washington. However, in order to answer the question, numerical analysis of the data would be needed. A suggested numeric analysis would be provided for resource management guidelines.**

3. **Question can be answered based on studies in analogous regions but there is not sufficient data from a region within eastern Washington to sufficiently answer the question. Next step is collection of eastern Washington data set identical to existing data set from analogous regions and comparison of data. If correlation is sufficiently close, numerical analysis of existing information can provide basis for resource management guidelines.**

4. **Question cannot be answered with the information currently available. Insufficient data from eastern Washington or analogous regions is available. Development of a scientific protocol and collection of additional data is necessary to answer the question. Where possible, the Herrera team provided a suggested protocol for conducting a study to answer this question.**

Summary and Recommendations. The Summary and Recommendations section contains a summary of the findings from the question response and a recommendation for further study. Where relevant and possible an example methodology for further study is briefly discussed.

References. References for each question are provided after each question reponse. An electronic file of all the references in a ProCite data will be provided with this report.

Ecoregions

There are five ecologically-physiologically-defined regions of eastern Washington used to separate regions for this literature review: Northeast Cascades, Southeast Cascades, Columbia Basin, Okanogan Highlands, Northeast Corner, and Blue Mountains that were used for this literature review (Figure 1-1) (University of Washington 2003)[1]. Each ecoregion has similar characteristics including: annual precipitation, soils, native vegetation, topography, and land use. The Herrera team uses these ecoregions in order to determine the coverage of studies for eastern Washington and to define characteristics on which to define analogous regions outside of eastern Washington. When no data were available specific to eastern Washington, then data for

[1] University of Washington. 2003. University of Washington, School of Aquatic and Fisheries Sciences Washington Gap Analysis project Ecoregions map obtained from web site on 10/3/03: <http://www.fish.washington.edu/naturemapping/ecoregion_zone.html>.

analogous regions were obtained and Herrera attempted to determine to which ecoregion in eastern Washington the analogous studies applied.

University of Washington (2003) defined six ecoregions in eastern Washington. The approximate locations of these ecoregions are provided below and depicted in Figure 1.0-1.

- Northeast Cascades – south to Lake Chelan
- Southeast Cascades – southeast Cascades from American Ridge south to the Columbia River
- Columbia Basin – steppe vegetation up to the lower timberline, but excluding the Blue Mountain Steppe zone to the north and east of the Blue Mountains
- Blue Mountains – Blue Mountains, including the Blue Mountain Steppe to the north and east of the forested Blue Mountain zones
- Okanogan Highlands – from the eastern foothills of the Okanogan valley to the crest of the Kettle Range; south to the Columbia Basin
- Northeast Corner – northeastern Washington; west to the Kettle Range; south to Cheney.

Eastern Washington Forest Types

A subset of the ecoregions defined above includes forest community types. It is important to identify forest community types in eastern Washington to determine if the literature has covered all forest types throughout the project area. Forest community types were also used to define characteristics on which to define analogous regions outside of eastern Washington, where ecoregions were not specified. Forest community types in eastern Washington typically have been defined by precipitation, elevation, and temperature parameters (Agee 1993; Franklin and Dyrness 1973; USFS. 1992)[2]. Using these parameters, the following forest community types are categorized for eastern Washington: 1) subalpine fir zone, 2) grand fir zone, and the 3) Douglas-fir/ponderosa pine zone. United States Forest Service (1992) has used additional parameters such as slope and species dominance to define a large set of forest community types. USFS (1992) categorizes forest community types for eastern Washington as follows: 1) fir-spruce, 2) larch, 3) lodgepole pine, 4) hemlock-Sitka spruce, 5) Douglas-fir, 6) oak-pine, 7) ponderosa pine, 8) western white pine, and 9) western hardwoods (Table 1-2). In the following question responses, where the forest types from the literature are consistent with USFS (1992) categories, the USFS names were used; otherwise forest types from the literature were provided. The literature also called out species and not necessarily forest community types.

[2] See references under Question 1 below for full citations of these references.

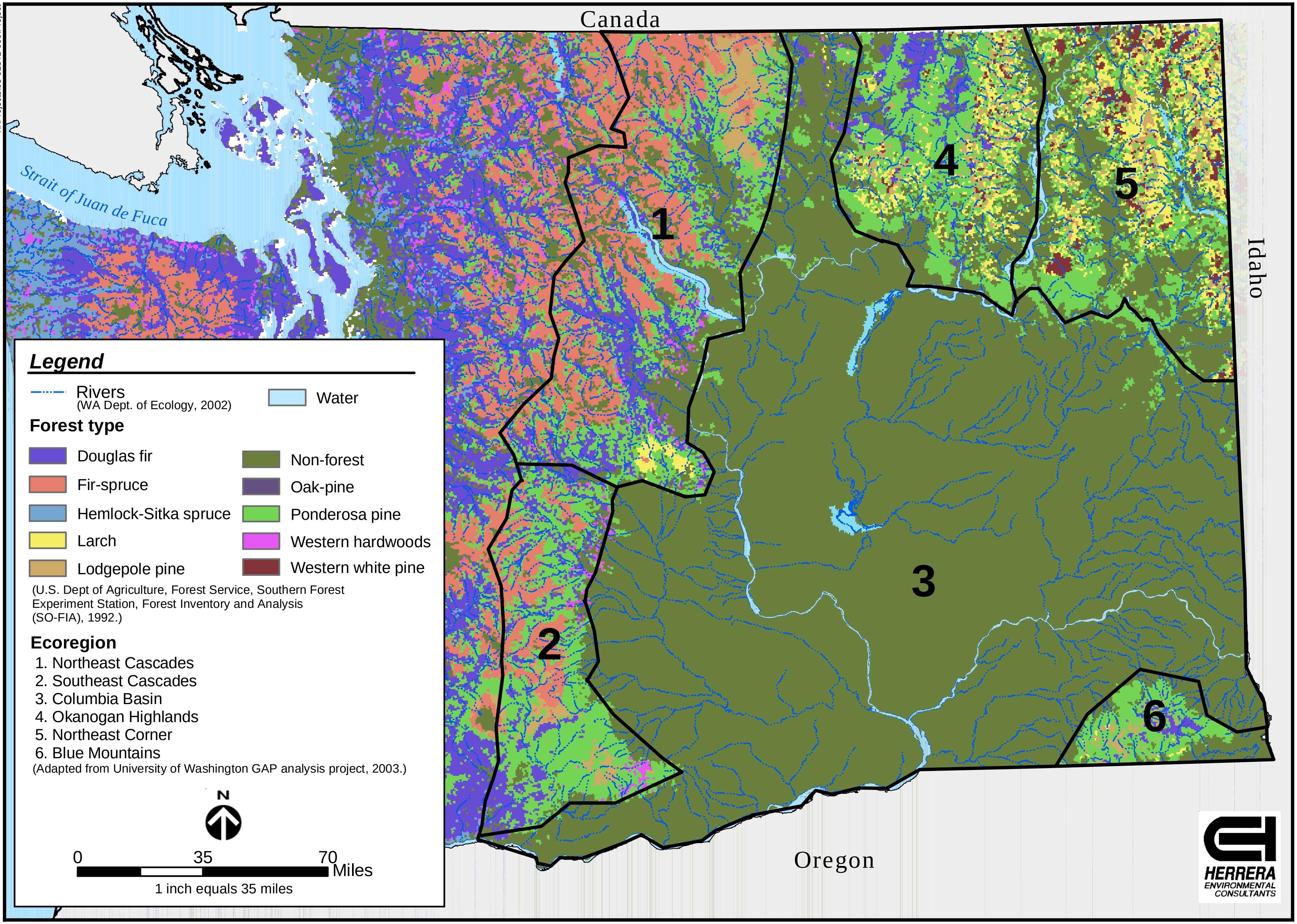


Figure 1-1. Ecoregions and forest types of eastern Washington.

Table 1-2. USFS (1992) vegetation zones within ecoregions in eastern Washington.

Ecoregion (University of Washington 2003)	Vegetation Zones (USFS 1992)
Northeastern Cascades	Fir-spruce, lodgepole pine, hemlock-sitka spruce, Douglas-fir, ponderosa pine, western white pine, and western hardwoods
Southeastern Cascades	Fir-spruce, lodgepole pine, hemlock-sitka spruce, Douglas-fir, oak-pine, ponderosa pine, western white pine, and western hardwoods
Columbia Basin	Steppe
Okanogan Highlands	Fir-spruce, larch, lodgepole pine, hemlock-sitka spruce, Douglas-fir, oak-pine, and ponderosa pine
Northeast Corner	Fir-spruce, larch, lodgepole pine, hemlock-sitka spruce, Douglas-fir, oak-pine, ponderosa pine, western white pine, and western hardwoods
Blue Mountains	Ponderosa pine, fir-spruce, larch, lodgepole pine, and Douglas-fir

2.0 Wood Loading

2.1 Question 1 Response

Is there a correlation between wood volume and/or number of pieces of wood in the stream and the adjacent riparian community? If so, quantify the relationship.

Summary of Literature Sources

Of the references reviewed, a total of 14 were found that had quantitative and/or descriptive information relating to wood volume. Of these, eight had information relevant to eastern Washington and six contained data from analogous regions. Table 2.1-1 provides a summary of these references.

Summary of Quantitative Data

Riparian forests exhibit various characteristics that influence instream wood loads. These can be the result of stand attributes or regional differences. These are described as follows:

Stand Attributes

Riparian characteristics are a viable predictor for instream wood loads. In unmanaged[3] riparian forests of Washington, Fox (2001) found a positive correlation between LWD volume and adjacent riparian characteristics of mean tree height ($P<0.001$), mean tree diameter (dbh) ($P<0.001$), and mean basal area ($P<0.001$). In terms of numbers of LWD, Fox (2001) found a positive correlation to riparian basal area ($P=0.007$), but not to riparian characteristics of mean stem density, tree height, or diameter (at breast height-dbh). For 18 CRSN (unmanaged) and WISSP (managed) sites (CRSN n=7, WISSP n-11), chesney (2000) found that wood loading was greater in streams within unmanaged forests than within managed forests. In unmanaged stands (n=7), he found 2.42 LWD pieces per bankfull width (bfw) whereas in managed sites (n=11), only a mean of 0.98 LWD pieces per bfw were present. The mean number of SWD pieces per bfw was 12.3 for unmanaged sites compared to 6.64 for managed sites. The unmanaged stands contained more trees per acre than the managed stands, including 2.9 times the number of stems greater than 20 inches dbh. Furthermore, these unmanaged stands were typically older than managed stands. chesney (2000) also provides wood volume for particular locations or zones in the channel (defined in detail in section 3.1). Mean volume of wood in zone 1 was 3.0 times greater in unmanaged sites, zone 2 was similar, and wood volume in zone 4 was 2.4 times greater in unmanaged sites than managed sites. Baldwin (unpublished) studied correlations between LWD characteristics and riparian forest stand parameters in eastern Washington. Data collected include forest stand inventory; tree height and age; bankfull width and depth; canopy cover and

[3] Defined as unlogged, and unroaded, with minimal anthropogenic disturbance albeit with a potential history of fire suppression.

Table 2.1-1. Summary of literature sources containing data relevant to question 1.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1	SC	Pacific silver fir, Douglas-fir/ponderosa pine	5 – 30%	Alluvial	Both	S,O	Yes
Fox 2001, 2003	Tributaries to the Naches, Cle Elum, Wenatchee, Methow, and Stehekin River basins	0.9 – 186	SC, NC, CB	Subalpine fir, grand fir, Douglas-fir/ponderosa pine	0.2 – 47%	Alluvial and bedrock	Unmanaged	S	Yes
Baldwin unpublished	LeClerc, Priest River, and Lost Creek basins		NE	Riparian species: western redcedar, Englemann spruce, subalpine fir, Douglas-fir, western hemlock	1.97 – 6.59	Silt-loam, channel beds made up of boulder, cobble, gravel	Unmanaged	S	No
Camp et al. 1996	Swauk basin	1 – 50	CB	Douglas-fir/ponderosa pine	Unavail.	Forest uplands	Unmanaged	S	Yes
Keller et al. 1982	Redwood Creek basin, CA	1.5 – 27.2	California	Redwood	0.016 – 0.12	Alluvial	Both	S	Yes
Knight 1990	Ochoco	15	E. OR	Unavailable	3 – 6%	Unavail.	Both	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

topographic shading; and large woody debris characteristics. A regression analysis was performed to determine significant correlations. The analysis revealed that LWD piece quantity is positively correlated with core trees/acre ($p<0.001$, $R^2=0.45$) and core basal area/acre ($p=0.004$, $R^2=0.29$). Core trees/acre refers to the number of trees per acre in the region 30 feet beyond bankfull width.

Characteristics of Forest Zones

The distribution of tree species, tree heights, diameters, and stem densities in distinct ecoregions often differ due to variation in elevation, aspect, precipitation /soil moisture, and temperature (Henderson et al. 1992; Agee 1993; O'Hara and Latham 1996). In eastern Washington, coniferous forests occupy the dry interior regions of the eastern slopes of the Cascades and extend across the northern portion of the state to the Rocky Mountains in the extreme northeast corner of Washington. More than nine climax species have been identified in the forest associations of eastern Washington due to the diverse ranges of climate and elevation (Franklin and Dyrness 1973). The more significant forest zones of eastern Washington are the *Abies lasiocarpa* (**subalpine fir [SAF]**), *Abies grandis* (**grand fir [GF]**), *Pseudotsuga menziesii* (**Douglas-fir [DF]),** and the *Pinus ponderosa* (**ponderosa pine [PP]**) forest zones.

The subalpine fir forests are generally found along the Cascade crest, and the interior of the Pasayten Wilderness in the north Cascades at elevations above 1,300 m amsl. The prolonged winter snow-pack (often between 7-8 m in wetter zones), along with the coldest winter temperatures of all Pacific Northwest forests, limits growth as compared to trees in lower elevation forests (Agee 1993). Subalpine fir (SAF) and co-dominants are not well-adapted to surviving fires (Agee 1993) and fire return intervals, estimated to be around 250 years (Fahnestock 1976), or 109 to 137 years (Agee 1990), are often points of stand origin.

Grand fir are typically found at elevations between 1,100-1,500 m east of the Cascade crest, although populations of grand fir can be found at low elevations of inland western Washington (Agee 1993). Rarely is grand fir the late-successional dominant species.

Douglas-fir/ponderosa pine forests are typically found in dry, lower elevation (1,200-1,800 m) sites east of the Cascades (Franklin and Dyrness 1973). Douglas-fir is always the co-dominant species in this forest type, and is typically suppressed by fire (Agee 1993; Lehmkuhl and Everett 1994; Everett et al. 2000). Agee (1993) reported natural fire-recurrence intervals of these forests to be typically between 11-24 years. Due to frequent burns, fires are typically of low intensity; therefore, the older ponderosa pines are rarely killed due to their thick bark unless fires are fueled by excess wood build-up in the under-story (Franklin and Dyrness 1973; Agee 1993). Furthermore, Camp et al. (1996) found that late-successional fire refugia were more commonly found on north-aspect facing slopes. As a result, these forests typically have a diverse array of seral stages.

Fox (2001) described the riparian characteristics of stem density, stem diameter, tree height, and basal area pertaining to forest types of Washington, including those described for eastern Washington. These are presented in Figure 2.1-1.

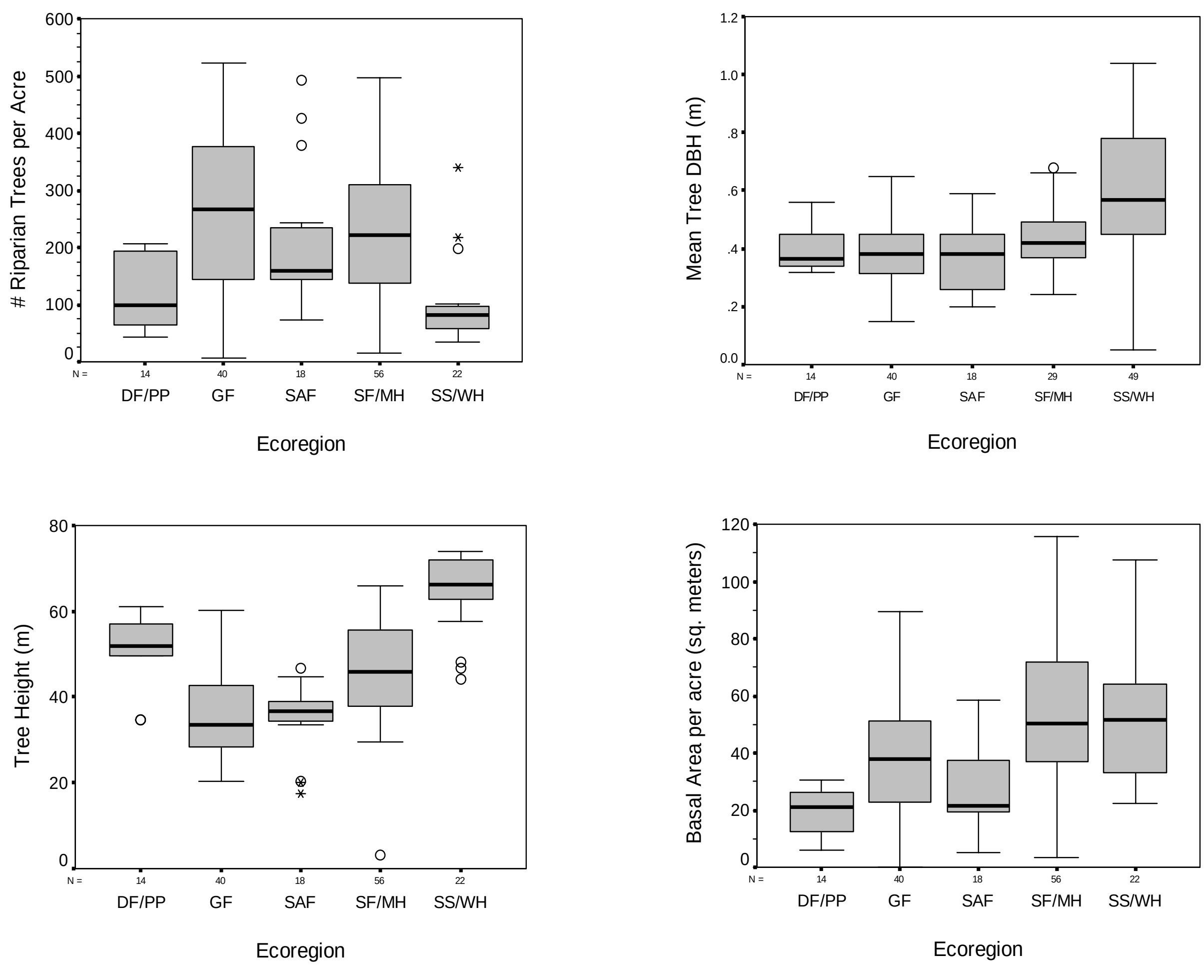


Figure 2.1-1. Box plots of A) mean riparian tree stem density, B) mean riparian tree diameter (m) at breast height (dbh), C) mean tree height in the site-adjacent riparian stands, and D) mean riparian basal area, as grouped by Forest Zone.
SS/WH= Sitka spruce / western hemlock, SF/MH=silver fir / mountain hemlock, SAF=subalpine fir, GF=grand fir, DF/PP=Douglas-fir/ponderosa pine. Source: Fox (2001).

Fox (2001) quantified the number of pieces and volume of woody debris for forest zones including subalpine fir, grand fir, and Douglas-fir/ponderosa pine forests. The quantities from 72 study sites show that there are similarities between the subalpine fir and grand fir forest types, but that the Douglas-fir/ponderosa pine forests are significantly different. Furthermore, Fox determined that, for several ecoregions, the number of LWD pieces per channel width increases with increases in bankfull width (Figure 2.1-2). The LWD volumes and piece numbers for distinguishable channel sizes for each these forest types are presented in Figures 2.1-3 through 2.1-6.

The study sites in Baldwin (unpublished) are unmanaged, and each study site was categorized based on WDNR site class delineation. Site classes are determined by soil profiles and potential growth productivity. The study sites fell into two sites classes; the first (SCII) was dominated by Englemann spruce and the second (SCIII) was dominated by western redcedar. SCIII, dominated by western redcedar, has an average of 7.1 pieces of LWD per bankfull width, as compared to 4.1 pieces per bfw for SCII. Two sample t-tests revealed a significant difference between total volume of LWD between SCII and SCIII (p=0.034), but total volume per bankfull width was not significantly different between SCII and SCIII. The LWD volume in SCIII is $3.4m^3$ larger than the volume in SCII. Regression analysis found the best predictor of total LWD volume to be dominant conifer species (p=0.012, R^2=0.23).

Knight (1990) studied forest harvest impacts on coarse woody debris and channel form in the Ochoco and Blue Mountains of central Oregon. The studies were performed in managed and unmanaged watersheds. In-stream wood with diameter>10cm and length>1m, were included in the study. Figure 2.1-7 displays total wood volume per 100m channel reach and drainage area for four dominant riparian species for both managed and unmanaged sites. Considering stands dominated by fir or pine tend to have lower stand basal areas than stands dominated by spruce (Figure 2.1-1), there appears to be a positive correlation between stand basal area and wood volume (Figure 2.1-7). The data from Knight (1990), in Figure 2.1-7, show higher wood loading volumes in smaller channels than Fox (2001) found looking at both alpine and fir/pine riparian forests (Figure 2.1-3 and Figure 2.1-4). Data from Knight (1990) also indicate a positive correlation between the total wood volume per 100m channel reach and the number of trees per adjacent hectare (Figure 2.1-8).

Despite the correlations linking LWD to adjacent riparian areas, the majority of instream wood is infrequently associated to an adjacent riparian source. McDade et al. (1990) found that less than 50 percent of all identified wood in the channel could be attributed to an adjacent source. Fox (2003) found that this percentage of instream wood attributable to adjacent riparian stands decreases with increasing stream size. This suggests that more than half of the wood in a stream at a given point comes from upstream sources when wood is mobilized at higher flows and routed through the system. The observation that adjacent riparian characteristics are a poor predictor of local instream wood loads led Fox (2003) to conclude that basin-scale management, and not just the management of adjacent riparian areas, are necessary to ensure adequate wood loading within a given riparian community.

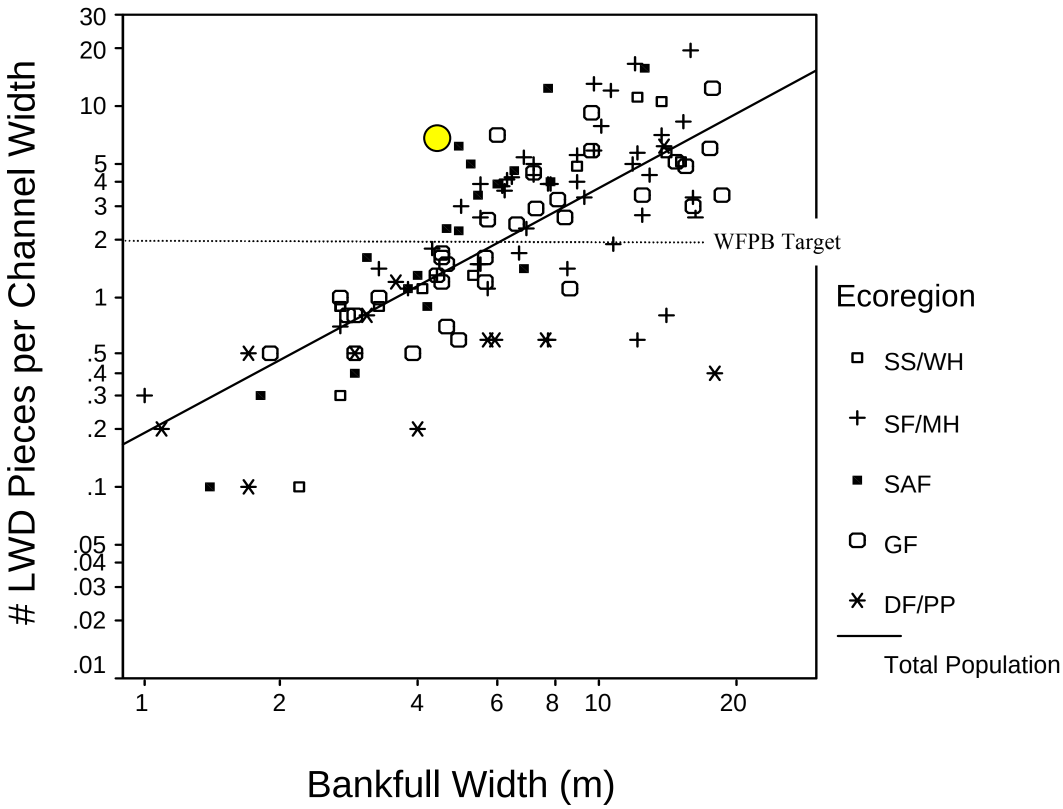
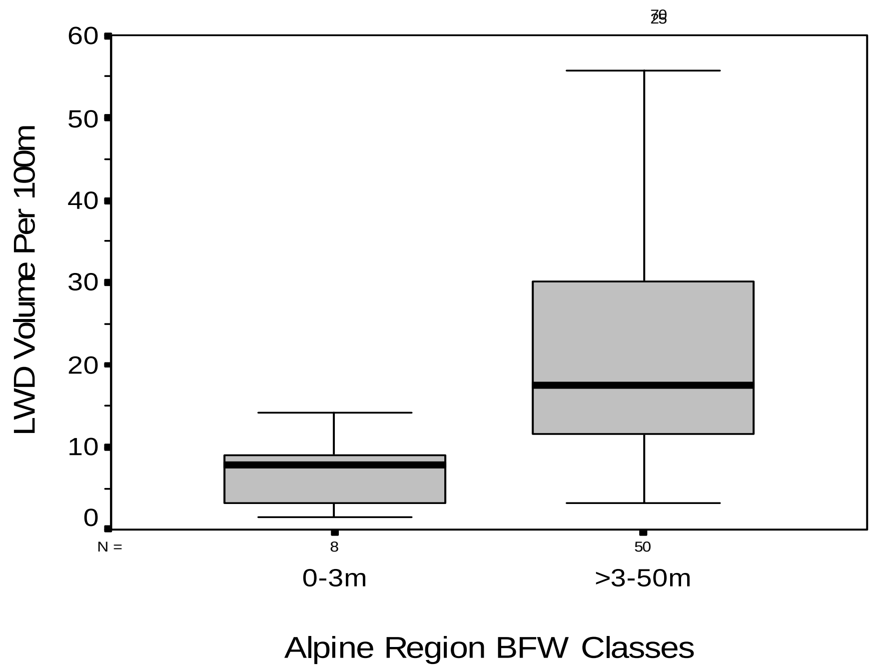


Figure 2.1-2. The number of LWD pieces per channel with by bankfull width for channels <20m in bfw.

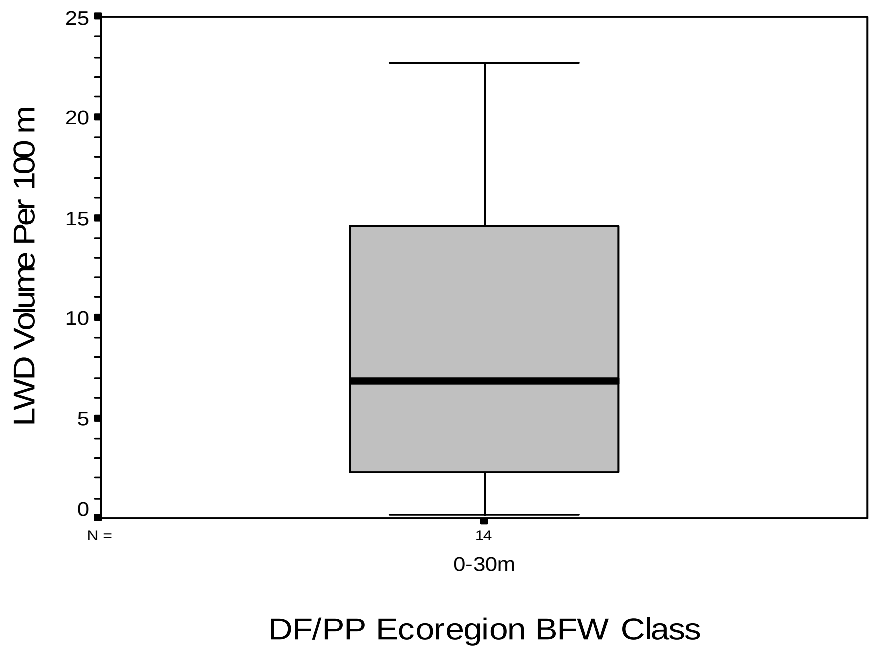
The target index of two pieces of LWD per channel width (WFPB 1997), as indicated by the horizontal line, is the quantity indicating “Good” habitat quality. Each data point represents the mean quantity per sample, labeled to identify discrete ecoregions. The slope of the regression through the points is significant ($p<0.001$). R^2 (adjusted) = 0.536, n=121. Source: Fox (2001). Additional dot represents number of wood pieces per bankfull width from Baldwin (unpublished) in the Northeast Corner region.



Bankfull Width Class

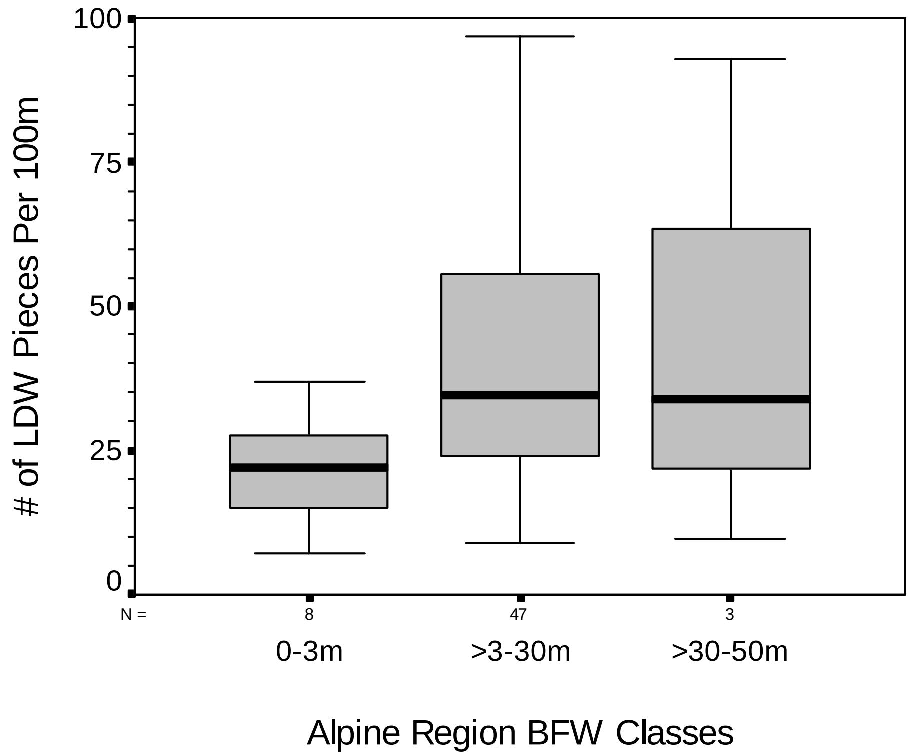
Bankfull Width	Alpine Region Volume LWD/100m						
	Mean	**Median**	**Percentile 25**	**Percentile 75**	**Variance**	**Count**	**Range**
0 – 3m	7.1	8.3	3.1	9.8	17.5	8	12.7
>3 – 50m	24.5	18.0	11.4	30.2	482.7	50	101.3

Figure 2.1-3. The percentile distribution of the volume of LWD per 100m for the Alpine Region, which statistically groups eastern Washington forest zones of grand fir and subalpine fir forest types.
Source: Fox (2001).



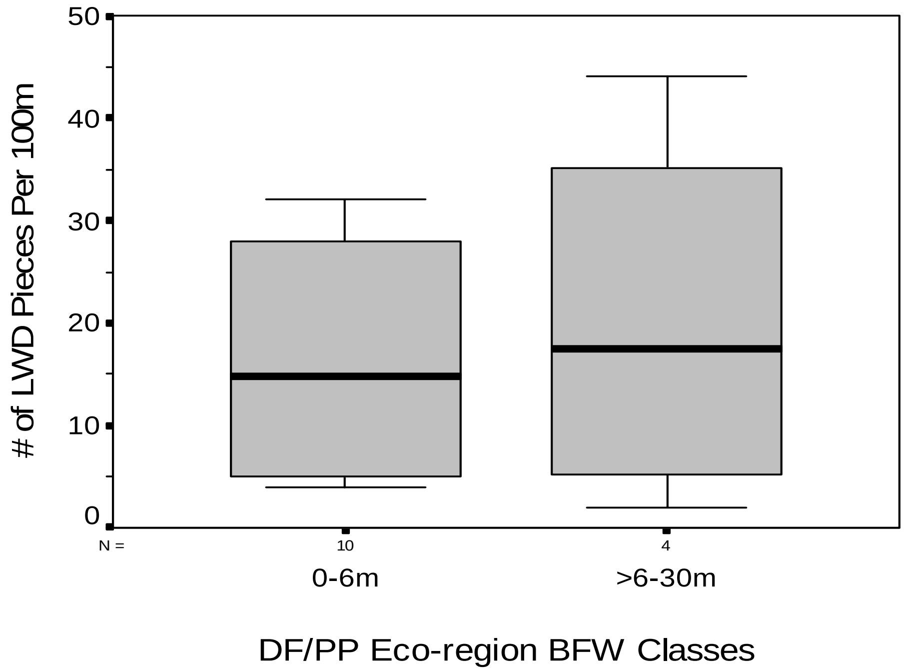
Bankfull Width	DF/PP Forest Zone Volume LWD/100m						
	Mean	**Median**	**Percentile 25**	**Percentile 75**	**Variance**	**Count**	**Range**
0-30m	12.0	6.9	2.3	14.7	235.3	14	59.0

Figure 2.1-4. The percentile distribution of the volume of LWD per 100m for the DF/PP Forest Zone.
Further delineations of bfw groups could not be statistically identified (Fox 2001).



Bankfull Width	Alpine Region # of LWD/100m						
	Mean	**Median**	**Percentile 25**	**Percentile 75**	**Variance**	**Count**	**Range**
0 – 3m	21.7	22.3	14.9	27.9	93.9	8	30.0
>3 – 30m	45.6	35.1	24.5	55.5	1134.8	47	150.0
>30 – 50m	45.5	34.2	21.6	63.3	1839.5	3	83.3

Figure 2.1-5. The percentile distribution of the quantity of LWD per 100m for the Alpine Region.
bfw classes are distinguished by significant differences between either the means or the variances (Fox 2001).



Bankfull Width	DF/PP Forest Zone # of LWD/100m						
	Mean	Median	Percentile 25	Percentile 75	Variance	Count	Range
0-6m	16.4	15.0	5.0	28.6	116.2	10	28.0
>6-30m	20.2	17.4	5.1	35.1	357.4	4	42.0

Figure 2.1-6. The percentile distribution of the quantity of LWD per 100m for the DF/PP Forest Zone.
Source: Fox (2001).

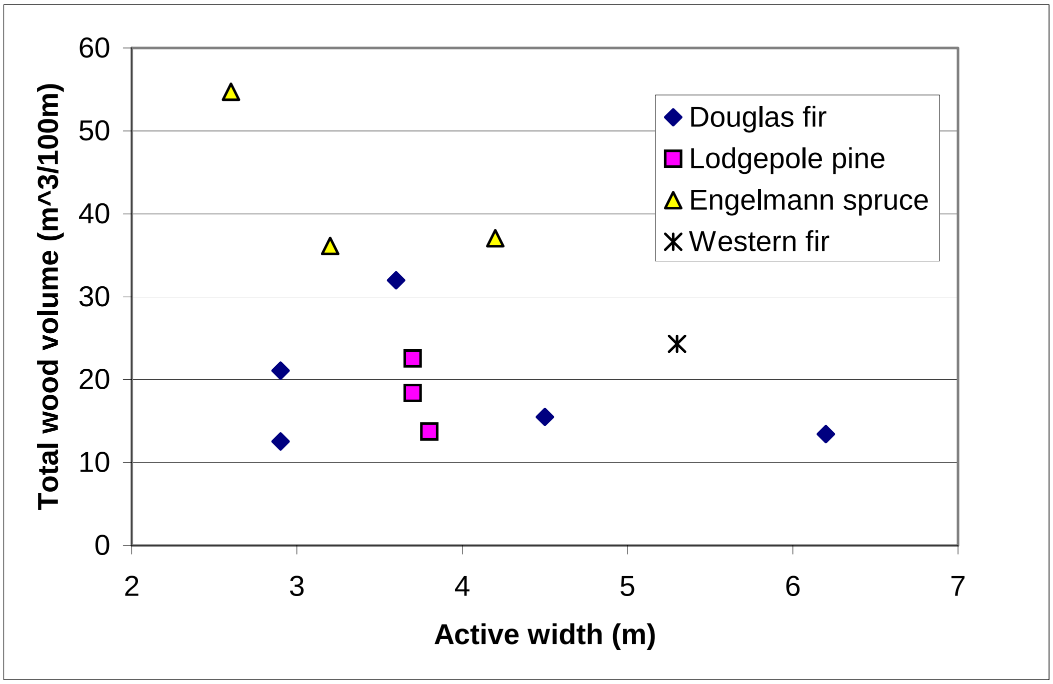


Figure 2.1-7. Relationship between total wood volume per 100m and active channel width for 4 dominant riparian species.
Source: Knight (1990).

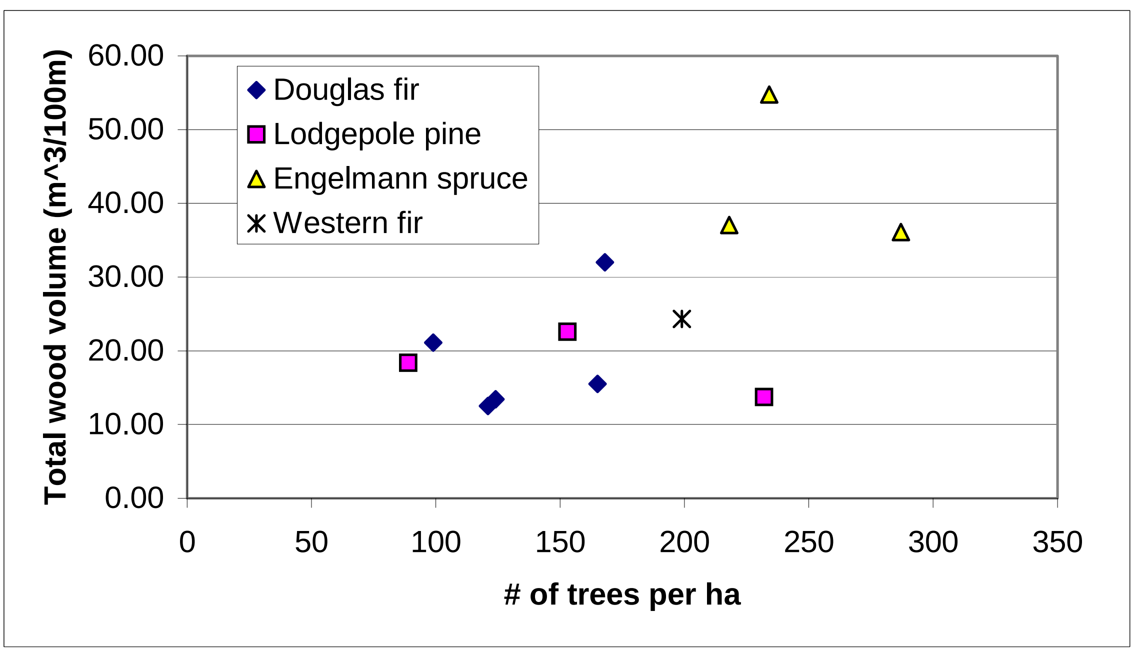


Figure 2.1-8. Relationship between total wood volume per 100m stream reach and number of trees per adjacent hectare.
Source: Knight (1990).

Qualification of Literature Sources

This question can be answered now for the Northeast Cascades, Southeast Cascades, Columbia Basin, and Northeast Corner regions, based on existing information (#1).

Summary and Recommendations

Literature exhibiting the correlation between riparian stands and instream wood loading in eastern Washington is incomplete but some significant relationships have been determined. In unmanaged[4] riparian forests of Washington, Fox (2001) and Baldwin (unpublished) provide a linkage between riparian attributes and instream wood loads. chesney (2000) also provides quantitative numbers of channel wood, which can be attributed to age classes and stem diameter classes. chesney (2000) assessed trees per unit area and number of trees per given diameter classes to instream wood loads. Assessing other stand characteristics such as basal area and tree height, however, may provide additional insight to drivers of wood loading. Knight (1990) provides a comparable dataset relating wood loading to dominant riparian species between managed and unmanaged basins. Further analysis of these data sets may provide additional conclusions.

The instream wood conditions found in Fox (2001) are reported as a range representative of the forest zones; however, wood loads are not explicitly linked to riparian stand characteristics. The relationship between forest zones and instream wood loading from Fox (2001) can be extrapolated to other regions containing similar forest types in eastern Washington. Most instream wood, however, could not be attributed to an adjacent source (McDade et al. 1990; Fox 2003), and the correlations of instream wood to the adjacent riparian stands reported by Fox (2001) likely represent basin processes rather than reach-scale processes. Therefore, perhaps regional riparian characterizations rather than local riparian characteristics best represent the range of instream wood loads found in a system. Indeed, Fox (2001) found that instream wood load (volume and number of pieces) were best represented by regional stand characteristics, as distinguished by forest zone, as well as the width of the channel. However, in small, steep channels in Eastern Washington, the monitored sites used in chesney (2000) will yield information on terrestrial wood inputs to channels and channel wood fluxes.

References

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[4] Defined as unlogged and unroaded with minimal anthropogenic disturbance albeit with a potential history of fire suppression.

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2.2 Question 2 Response

What is the range of current wood loads in eastside forested streams (by wood size class if possible)? Quantify mean, median, range, and standard deviation to the extent possible. Discuss effects of variations in sample methods on results and the range of results found in various investigations.

Summary of Literature Sources

Of the references reviewed, a total of four were found that had quantitative information related to the range of current wood loads in eastside-forested streams. Table 2.2-1 provides a summary of these references.

Summary of Quantitative Data

The available literature on eastern Washington wood loading is limited to a few studies for both managed and unmanaged stands. chesney (2000) found 2.42 LWD[5] pieces per bankfull width in unmanaged streams (n=7) and 0.98 pieces per bankfull width in managed streams (n=11) in eastern Washington just east of the Cascade crest. Similarly, chesney found that the mean number of SWD pieces per bankfull width was 12.3 for unmanaged sites compared to 6.64 for managed sites. Fox (2001) quantified piece numbers and volumes in unmanaged basins for the forest types of subalpine fir, grand fir, and Douglas-fir/ ponderosa pine forests. The quantities from 72 study sites in Fox (2001) distinguished similarities between the subalpine fir and grand fir forest types, but the Douglas-fir/ponderosa pine forests were significantly different. The LWD volumes and piece numbers for distinguishable channel sizes for each these forest types are presented in Figures 2.1-3, 2.1-4, 2.1-5, 2.1-6.

Knight (1990) found an average of 83.2 m^3 (standard deviation=46.6) of LWD[6] volume per 300 m of stream in managed streams of central Oregon. Based on six managed sites and seven unmanaged sites, Knight (1990) concluded that there was no significant difference between sites based on management, but provides insufficient information to document site management history. The managed sites were chosen based on forest harvesting, but without an influence of debris removal, fish habitat enhancement, road influence, or excessive cattle grazing. He does not provide information regarding natural disturbances for either the managed or unmanaged sites, thus it is difficult to make a thorough comparison between the sites.

[5] In this study, LWD was defined as a piece greater than 10 cm diameter at the mid-length and 2 m in length.
[6] In this study, LWD was defined as a piece greater than 10 cm diameter at the small end and 1 m in length.

Table 2.2-1. Summary of literature sources containing data relevant to question 2.

Data Source	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1.	SC	Subalpine fir, Douglas-fir/ ponderosa pine	5 – 30%	Alluvial	Both	S	Yes
Fox 2001	Tributaries to the Naches, Cle Elum, Wenatchee, Methow, and Stehekin River basins	0.9 – 186	SC, NC, CB	Subalpine fir, grand fir, Douglas-fir/ponderosa pine	0.2 – 47%	Alluvial and bedrock	Unmanaged	S	Yes
Knight 1990	Ochoco	15	E. OR	ND [c]	3 – 6%	ND	Both	S	Yes
McIntosh et al. 1994	Grande Ronde, Methow, Wenatchee, and Yakima basins	3000, 4641, 3437, 15,942	BM, NC, SC	ND	ND	Medium rubble	Both	S	No

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

McIntosh, et al. (1994) investigated current amounts of LWD (diameter > 0.1m, length > 2.0m) in managed and unmanaged basins in eastern Oregon and Washington. They report wood load as number of pieces per kilometer and number of LWD complexes per kilometer for each basin and for each subbasin sampled (Table 2.2-2). McIntosh et al. found on average 42.2 pieces/km in the managed basins and 61.8 pieces/km in the unmanaged basins. The authors did not report bankfull width related to each sampling reach and thus the data cannot be compared to other studies without further information.

Table 2.2-2. Current amounts of LWD in managed and unmanaged basins of eastern Oregon and Washington.
(Data from McIntosh et al. 1994)

Basin Name	Length (km)	LWD (#/km)	LWD complexes (#/km)
Managed Streams			
Grande Ronde Basin	148.7	40.0	5.9
Yakima River Basin	8.1	32.8	5.8
Wenatchee River Basin	33.6	26.7	3.5
Methow River Basin	146.1	69.2	12.3
Total	**336.5**	**42.2**	**6.9**
Unmanaged Streams			
Yakima River Basin	18.8	72.7	13.8
Wenatchee River Basin	80.0	72.5	11.9
Methow River Basin	30.3	40.2	8.1
Total	**129.1**	**61.8**	**11.3**

Qualification of Literature Sources

This question can be answered now for the Northeast Cascades, Southeast Cascades, Columbia Basin, and Blue Mountains based on existing information (#1).

Summary and Recommendations

Although the literature depicting the ranges of wood loading in eastern Washington is limited, the existing studies are reasonable to provide inferences to this question. For streams draining natural[7] or unmanaged forests, the data from Fox (2001) provide the range of wood numbers and volumes for three forest types in eastern Washington, as grouped by discrete channel sizes (Figures 1-4). Extrapolation of the subalpine fir, grand fir, and Douglas-fir/ponderosa pine forests from Fox (2001) can enable applications to other regions containing similar forest types in eastern Washington. chesney (2000) and McIntosh et al. (1994) provide quantitative numbers

[7] Defined as unlogged and unroaded and minimal anthropogenic disturbance albeit potential fire suppression.

of LWD pieces, both for managed and unmanaged stands. chesney (2000) has measured multiple wood size classes, their zonation, and piece type.

Some disparities exist among studies, and data for other regions is missing. For example, chesney (2000) found that LWD pieces per channel width remains constant with increasing channel size for small drainage areas (up to 8.1 km^2 in size). However, Fox (2001) illustrated that the number of pieces per channel width increase with increasing stream size, mainly due to the fluvial organization of wood into large jams as streams become larger. This phenomenon should be assessed for eastern Washington streams to cover a broad range of stream sizes to verify instream wood loading rates. Furthermore, studies from regions not assessed in Fox (2001) or chesney (2000) should also be conducted to verify or illustrate differences from the loads observed in these studies. McIntosh et al. (1994) should be contacted to get basin size and bankfull width information or specific locations or study sites. Furthermore, specific characteristics of management history need to be documented and addressed when comparing sites and studies (number of rotations, years since a rotation, type of buffers, etc.).

A study to document the quantity of LWD in larger channels can be done using aerial photographs and field surveys to determine if the aerial extent of LWD can be correlated to the number of pieces and volume collected from field surveys.

References

chesney, c.j. 2000. Functions of Wood in Small, Steep Streams in Eastern Washington: Summary of Results for Project Activity in the Ahtanum, Cowiche, and Tieton Basins. TFW Effectiveness Monitoring Report. TFW-MAG1-00-002. Olympia, Washington.

Fox, M.J. 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington State. Master of Science thesis. College of Forest Resources, University of Washington.

Knight, S.M. 1990. Forest harvesting impacts on coarse woody debris and channel form in central Oregon streams. M.S. Thesis. Oregon State University, Corvallis, Oregon.

McIntosh, B., J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke, G.H. Reeves, and L.A. Brown. 1994. Management history of eastside ecosystems: Changes in fish habitat over 50 years, 1935 to 1992. USDA Forest Service PNW-GTR-321.

2.3 Question 3 Response

Recognizing that fire suppression activities, beaver removal, and livestock introduction have influenced almost all areas of eastern Washington, how do wood loads in the streams adjacent to unlogged forest stands differ from stands which have been logged within the last 40 years? Is there data available regarding the quantity of wood in streams adjacent to stands where no harvest, fire suppression, beaver removal, or livestock grazing has occurred?

Summary of Literature Sources

Of the references reviewed, three were found that had quantitative and/or descriptive information relating to wood volume. Of these, two had information relevant to eastern Washington and one contained data from eastern Oregon. Table 2.3-1 provides a summary of these references.

Summary of Quantitative Data

chesney (2000) performed a study on the functions of wood in small, high-elevation streams in managed and unmanaged forests in eastern Washington. Woody debris characteristics were measured at 18 sites (seven unmanaged, 11 managed). Woody debris volume was sampled using Ambient Monitoring Program Manual (Schuett-Hames et al. 1994). Results indicate increased wood volumes per bankfull width in unmanaged sites versus managed sites (Table 2.3-2).

McIntosh et al. (1994) collected data on current amounts of LWD (diameter >0.1m, length > 2.0m) in managed and unmanaged basins in eastern Oregon and Washington (Grande Ronde, Yakima, Wenatchee, and Methow Basins), to quantify the effect of management activities on wood loading. They found that the frequency of LWD and debris complexes is about 50 percent greater in unmanaged streams than in managed streams (Table 2.3-3).

Several additional wood loading studies have been performed in eastern Washington, but only include wood loading data from unmanaged streams (Fox 2001; Baldwin unpublished). Fox (2001) quantified the number of pieces and volume of woody debris in 72 unmanaged study sites located in the Southeast Cascades, Northeast Cascades, and the Columbia Basin (presented in Question 1 response). Baldwin (unpublished) has wood loading data from unmanaged streams in the Northeast Corner region. The data includes LWD characteristics and riparian forest stand parameters.

Knight (1990) studied forest harvest impacts on coarse woody debris and channel form in the Ochoco and Blue Mountains of central Oregon. The studies were performed in managed and unmanaged watersheds. In-stream wood with diameter greater than 10 meters and length greater than 1 meter, were included in the study. Knight found no significant difference between wood loads in managed and unmanaged streams (Table 2.3-4).

Table 2.3-1. Summary of literature sources containing data relevant to question 3.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1.	SC	Pacific silver fir, Douglas-fir/ponderosa pine	5 – 30%	Alluvial	M: (n=11), U: (n=7)	S	Yes
McIntosh et al. 1994	Grande Ronde, Methow, Wenatchee, and Yakima basins	3000, 4641, 3437, 15,942	BM, NC, SC	ND [c]	ND	Medium rubble	Both	S,Q	No
Fox 2001	Tributaries to the Naches, Cle Elum, Wenatchee, Methow, and Stehekin River basins	0.9 – 186	SC, NC, CB	Subalpine fir, grand fir, Douglas-fir/ponderosa pine	0.2 – 47%	Alluvial and bedrock	U	S	Yes
Baldwin unpublished	LeClerc, Priest River, and Lost Creek basins	ND	NE	Western redcedar, Englemann spruce, subalpine fir, Douglas-fir, western hemlock	1.97 – 6.59	Silt-loam, channel beds made up of boulder, cobble, gravel	U	S	No
Studies in Analogous Regions (Eastern Oregon, Idaho, etc.)									
Knight 1990	Ochoco	3.7 – 36.9	E. OR	ND.	3 – 6%	ND.	Both	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

Table 2.3-2. Summary statistics of total wood volume and number of pieces per bankfull width for unmanaged and managed sites.

	Total Wood Volume per Bankfull Width (m^2)		LWD Pieces per Bankfull Width (m^{-1})	
	Mean	StdDev	Mean	StdDev
Unmanaged sites (n=7)	5.20	3.69	2.42	0.96
Managed sites (n=11)	2.25	1.69	1.01	0.71

Source: chesney (2000).

Table 2.3-3. Current amounts of LWD in managed and unmanaged basins of eastern Oregon and Washington.

	Length (km)	LWD (#/km)	LWD complexes (#/km)
Managed Streams			
Grande Ronde Basin	148.7	40.0	5.9
Yakima River Basin	8.1	32.8	5.8
Wenatchee River Basin	33.6	26.7	3.5
Methow River Basin	146.1	69.2	12.3
Total	**336.5**	**42.2**	**6.9**
Unmanaged Streams			
Yakima River Basin	18.8	72.7	13.8
Wenatchee River Basin	80.0	72.5	11.9
Methow River Basin	30.3	40.2	8.1
Total	**129.1**	**61.8**	**11.3**

Source: McIntosh et al. (1994).

Table 2.3-4. Summary statistics of total wood volume per 300 meters for unmanaged and managed sites.

	Total Wood Volume per 300m (m^2)	
	Mean	StdDev
Unmanaged sites (n=5)	65.2	27.8
Managed sites (n=10)	83.2	46.6

Source: Knight (1990).

A detailed history of the unmanaged basins, in the studies mentioned above, was not addressed; therefore the assumption cannot be made that the streams in these unmanaged basins had no influence of harvesting, fire suppression, beaver removal or livestock grazing.

Qualification of Literature Sources

This question can be answered with additional quantitative analysis of existing data (#2). There is a sufficient source of scientific data for small channels in the Southeast Cascades region; however, in order to answer the question, further numerical analysis of available data is needed. Limited results are available for other regions but none have wood loading data available from both managed and unmanaged streams.

Summary and Recommendations

The work of chesney (2000) and McIntosh et al. (1994) together indicate that unmanaged streams in the Southeast Cascades region have higher wood loading than managed streams. These conclusions are drawn from a combined total of 10 unmanaged sites and 15 managed sites. In order increase the population of unmanaged study sites and the confidence in these results, further analysis of data from Fox (2001) should be completed. Fox (2001) presents wood loading data for unmanaged streams in the format of number of pieces and LWD volume per 100 meter reaches (see Question 1 response for details). The methodology used for these studies can be applied to future research efforts to address wood loading in managed and unmanaged streams in other regions of eastern Washington.

Baldwin (unpublished) includes data from 44 plots from three watersheds of unmanaged streams in the Northeast Corner region. Future research into wood loading within managed streams in this region could provide the complementary data necessary to complete a comparison between unmanaged and managed streams in the Northeast Corner. McIntosh et al. (1994) presents results from a number of managed streams in the Blue Mountains.

We recommend compiling a list of study sites representing relatively undisturbed conditions within a range of channel sizes in each of the eastern Washington ecoregions. We also recommend developing a formal field protocol for consistent and reproducible data collection. The list of potential study sites and field protocol can then be used to document and compare wood loading throughout eastern Washington.

References

Baldwin, T. unpublished. Riparian Condition and Site Characterization Pilot Study. UCUT: TFW/F&F Program Draft Report.

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McIntosh, B., J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke, G.H. Reeves, and L.A. Brown. 1994. Management history of eastside ecosystems: Changes in fish habitat over 50 years, 1935 to 1992. USDA Forest Service PNW-GTR-321.

Schuett-Hames, D., A. Pleus, L. Bullchild, and S. Hall. 1994. Timber-Fish-Wildlife Ambient Monitoring Program Manual. Report #TFW-AM9-94-001. Northwest Indian Fisheries Commission, Olympia, Washington.

2.4 Question 4 Response

How do wood loads in streams differ between those with clear-cuts adjacent to the riparian buffer zone and those with partial cuts adjacent to the riparian buffers?

Summary of Literature Sources

Of the references reviewed, one study was found that had quantitative and/or descriptive information differentiating the effects of clear-cutting and partial-cutting on wood loads. Several additional studies are presented that may provide guidelines for further research. Table 2.4-1 provides a summary of these references.

Summary of Quantitative Data

Work by chesney (2000), introduced in the Question 1 response, addresses the functions of wood in small, high-elevation streams in managed and unmanaged forests in eastern Washington. Several of the managed sites have been logged next to the channel. Table 2.4.2 presents the wood volume for three managed sites with differing logging activity. The site with thinning occurring in the riparian zone (trees per hectare (TPH)=2,542) had higher wood volume (0.24 m^3/bfw), than the other two sites with clearcut and heavy thinning (TPH=741, 998; wood volume=0.02, 0.04 m^3/bfw). Additional data is available from chesney (2000) but would require additional data analysis to obtain results pertinent to this question.

Qualification of Literature Sources

This question can be answered with additional quantitative analysis of existing data (#2). There is a sufficient source of scientific data for small channels in the Southeast Cascades region; however, in order to answer the question, further numerical analysis of available data is needed.

Summary and Recommendations

Although there was only one study found directly comparing wood loads in streams within clear-cut forests versus streams within partial-cut forests, there are several studies performed in eastern Washington and analogous regions (Knight 1990; chesney 2000) that could be extended to include several additional elements and subsequent analysis. Knight (1990), introduced in the Question 1 response, studied wood loads in eastern Oregon streams with riparian zones that were either unharvested or selectively harvested, cutting less than 90 percent of the original basal area. Additional data collection using similar methodology for streams with clear-cut harvesting may provide insight into this question. The feasibility of using the methodology and results from this study would need to be assessed to establish additional research.

Additionally, the methodology used in analogous process-based studies could be used as model studies for further research in eastern Washington streams. Bilby and Ward (1991) investigated

Table 2.4-1. Summary of literature sources containing data relevant to question 4.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1.	SC	Pacific silver fir, Douglas-fir/ ponderosa pine	5 – 30%	Alluvial	Both	S,O	Yes
McIntosh et al. 1994	Grande Ronde, Methow, Wenatchee, and Yakima basins	3,000, 4,641, 3,437, 15,942	BM, NC, SC	ND [c]	ND	Medium rubble	Both	S,Q	No
Studies in Analogous Regions (Eastern Oregon, Idaho, etc.)									
Knight 1990	Ochoco	15	E. OR	ND	3 – 6%	ND	Both	S	Yes
Analogous Process-based Studies									
Bilby and Ward 1991	Southwest WA	0.4 – 137	WW	Western redcedar, Douglas-fir, western hemlock, red alder, bigleaf maple	ND	ND	Both	S	Yes
Beechie et al. 2000	Northwest WA- model	N/A	WW	Red alder, Douglas-fir	N/A	N/A	N/A	Q	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

the characteristics and functions of LWD in streams adjacent to old-growth, clear-cut, and second-growth forests in Southwest Washington (Cascades Range and Willapa Hills). Beechie et al. (2000) modeled LWD recruitment and pool formation in northwestern Washington streams after simulated stand-clearing disturbances using two computer models: Forest Vegetation Simulator for stand development and Riparian-in-a-Box for LWD recruitment, depletion, and pool formation. A similar methodology could provide insight into eastern Washington wood loading scenarios if calibrated with empirical data.

Table 2.4.2. Wood volume for three managed sites with differing logging activity. Source: chesney (2000).

Stream	Logging Activity	Slope (%)	Width (m)	Trees per Hectare (TPH)	Wood Volume (m^3/bfw)
Gray	Clearcut	20.6	2.4	741	0.02
Cultus	Heavy thinning	11.1	4.1	998	0.04
Darla	Thinning	17.5	2.9	2,542	0.24

References

Beechie, T.J., G. Press, P. Kennard, R.E. Bilby, and S. Bolton. 2000. Modeling recovery rates and pathways for woody debris recruitment in northwestern Washington streams. North American Journal of Fisheries Management 20:436-452.

Bilby, R.E. and J.W. Ward. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. Canadian Journal of Fisheries and Aquatic Sciences 48:2499-2508.

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Knight, S.M. 1990. Forest harvesting impacts on coarse woody debris and channel form in central Oregon streams. M.S. Thesis. Oregon State University, Corvallis, Oregon.

McIntosh, B.A., J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke, G.H. Reeves, and L.A. Brown. 1994. Management history of eastside ecosystems: Changes in fish habitat over 50 years, 1935 to 1992. USDA Forest Service PNW-GTR-321.

2.5 Question 5 Response

Do wood loads vary with the species of tree (Douglas-fir, cedar, ponderosa pine, larch, etc.) in the adjacent riparian stands? How?

Summary of Literature Sources

Of the references reviewed, three were found that had quantitative and/or descriptive information relating wood loads to specific tree species. Of these, two contained data from eastern Washington and one contained data from eastern Oregon. Table 2.5-1 provides a summary of these references.

Summary of Quantitative Data

The study sites observed by chesney (2000) are, except for three sites, categorized as Pacific silver fir forest type. Although differences in wood loading among forest types are possible with these data, they were not analyzed as such in this study. Fox (2001), introduced in the Question 1 response, quantified LWD pieces numbers and volumes for the forest zones of subalpine fir, grand fir, and Douglas-fir/ponderosa pine forests, where these species were the late successional dominant or most prevalent co-dominant. Although these data was not analyzed pertaining to specific species in the riparian area (Figure 2.1-3-6), these data were collected by species and therefore could be queried and analyzed in this manner.

Knight (1990), introduced in the Question 1 response, found species composition of the riparian stand to be a strong indicator of both stand basal area and stream debris volumes. Knight (1990) reported that stands dominated by Douglas-fir and lodgepole pine tended to have low stand basal areas and correspondingly low debris volumes. The presence of larch in the stand did not affect this relationship since larch generally composed only and minor component of the stand basal area. Knight (1990) also found that streams flowing though stands dominated by spruce contained significantly greater debris volumes than in streams dominated by fir or pine. This relationship is attributed to an apparent positive correlation between increased basal area and instream wood loading (see Figure 2.1-1 and Figure 2.1-7). Knight (1990) also reported that stands dominated by Douglas-fir contained the fewest number of trees and contributed the least number of debris pieces to the streams, and stands dominated by spruce exhibited a greater number of trees and a greater density of debris pieces in the stream.

Qualification of Literature Sources

This question can be answered with additional quantitative analysis of existing data (#2). Preliminary data indicates that the dominant of adjacent riparian stands does influence instream wood loading.

Table 2.5-1. Summary of literature sources containing data relevant to question 5.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1.	SC	Subalpine fir, Douglas-fir/ponderosa pone	5 – 30%	Alluvial	Both	S	Yes
Fox 2001	Tributaries to the Naches, Cle Elum, Wenatchee, Methow, and Stehekin River basins	0.9 – 186	SC, NC, CB	Subalpine fir, grand fir, Douglas-fir/ponderosa pine	0.2 – 47%	Alluvial and bedrock	Unmanaged	S	Yes
Studies in Analogous Regions (Eastern Oregon, Idaho, etc.)									
Knight 1990	Ochoco	15	E. OR	ND [c]	3 – 6%	ND	Both	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

Summary and Recommendations

Further analysis of data collected by Fox (2001) may result in conclusive evidence for the relationship between adjacent riparian species and wood loading for the Southeast Cascades, Northeast Cascades, and Columbia Basin regions. This analysis may also determine that a clear relationship may not be established, at which point additional data collection, using similar methodology, would be necessary.

Despite the correlations LWD has to the adjacent riparian area, the majority of instream wood is infrequently linked to an adjacent riparian source. McDade et al. (1990) found that less than 50 percent of all identified wood in the channel could be attributed to an adjacent source. Fox (2003) found that this percentage decreases with increasing stream size. This suggests that more than half of the wood in a stream at a given point comes from upstream sources; wood is mobilized at higher flows and routed through the system. These sources likely stem from disturbances such as debris flows, dam-break floods, mass wasting, as well as from competitive and non-competitive forms of tree mortality within the riparian community. Furthermore, Fox (2003) observed that due to the patchiness of species in riparian stands, the attributes of instream wood loads stemming from variations in species composition an the adjacent riparian area were difficult to quantify. Because of the observation that adjacent riparian characteristics are a poor predictor of local instream wood loads, Fox (2003) concluded that instream wood must be managed at the basin scale rather than merely the adjacent riparian timber. Indeed, Hemstrom (2001) notes that the lack of species diversity is detrimental to creating aquatic habitats and maintaining forest health. Therefore, management might be better served to manage for heterogeneity of riparian species similar to distributions provided in natural systems, and manage for the ranges of stand characteristics (e.g., Figure 2.1-1).

Chesney (personal communication 2004) asserts that long-term monitoring of channel wood and riparian characteristics would reveal more information about the correlation between these two parameters. The study sites discussed in chesney (2000) are currently being studied under a long-term monitoring program.

References

chesney, c.j. 2000. Functions of Wood in Small, Steep Streams in Eastern Washington: Summary of Results for Project Activity in the Ahtanum, Cowiche, and Tieton Basins. TFW Effectiveness Monitoring Report. TFW-MAG1-00-002. Olympia, Washington.

chesney, c. 2004. Personal communication (comments on draft report received by Diane Hennessey, Herrera Environmental Consultants, Inc.). SAGE committee member. August 6, 2004.

Fox, M.J. 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington State. M.S. Thesis. College of Forest Resources, University of Washington, Seattle, Washington.

Knight, S.M. 1990. Forest harvesting impacts on coarse woody debris and channel form in central Oregon streams. M.S. Thesis. Oregon State University, Corvallis, Oregon.

2.6 Question 6 Response

What was the historical (pre-harvest, pre-fire suppression pre-beaver removal, and pre-livestock introduction) conditions of streams with regard to wood loads in eastside forested streams?

Summary of Literature Sources

Of the references reviewed, five studies were found with information on the historic conditions of wood loading in streams in eastern Washington. All together, however, there is little quantitative data to report. Table 2.6-1 provides a summary of these references.

Summary of Quantitative Data

Information on instream wood loading prior to all forms of anthropogenic alteration is extremely limited. Historical riparian and forest structure has been assessed, however, and may provide inferences on the quantities of historic instream wood loads. Ohlson and Schellhaas (unpublished) found that modern forest stands currently have more trees per acre and more basal area than were found historically. In their study, overall stand density has increased 307 percent for Douglas-fir, 81 percent for ponderosa pine and 138 percent for Engelmann spruce (*Picea engelmannii*), while western larch (*Larix occidentalis*) was the only tree species that decreased in density (-48 percent). Average basal area has also increased 81 percent above historical levels found in this study.

Smith (1993) performed a historical analysis of changes in stream habitat between 1935 and 1990 on two eastside streams. She used historic Bureau of Sport Fisheries (BOF) stream data from 1935 and 1936 along with current stream surveys (1990) and aerial photos to analyze changes in habitat and channel conditions. Her study reach may not be considered pristine due to land use activity dating back to 1880 (intensive grazing and small-scale selective harvest).

Other authors have assessed instream wood loads in streams draining modern unmanaged forests of eastern Pacific Northwest streams (chesney 2000; Fox 2001; Knight 1990). The natural fire disturbance patterns may or may not have been altered in these authors' study sites due to fire suppression over the last 100 years, therefore, these stands may or may not reflect similarities to the historic wood loading characteristics in these streams. However, disturbances such as landslides, stem suppression, disease and insect mortality, non-competitive tree mortality, and other factors that contribute to wood loading mechanics are not likely to have changed significantly in these forests since the onset of fire suppression. Based on this assumption as well as the paucity of historic data, inferences drawn on wood loading characteristic from streams in these forests may be reasonable as well as practical. The data from these authors is summarized in *Question 1 Response* above, and may provide the best alternative in lieu of the short supply of historic wood loading data from this region.

Table 2.6-1. Summary of literature sources containing data relevant to question 6.

Data Source	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1	SC	Pacific silver fir, Douglas-fir/ponderosa pine	5 – 30%	Alluvial	Both	S	Yes
Fox 2001	Tributaries to the Naches, Cle Elum, Wenatchee, Methow, and Stehekin River basins	0.9 – 186	SC, NC, CB	Subalpine fir, grand fir, Douglas-fir/ponderosa pine	0.2 – 47%	Alluvial and bedrock	Unmanaged	S	Yes
Knight 1990	Ochoco	15	E. OR	Pacific silver fir, Douglas-fir/ponderosa pine	3 – 6%	Unavailable	Both	S	Yes
Ohlson and Schellhaus (unpubl.)	E. slope Cascades	Unavail.	OH	Douglas-fir/ponderosa pine	30 – 50%	Unavailable	Unmanaged	S	No
Smith 1993	Little Naches River	398	SC	Ponderosa pine, lodgepole pine, Douglas-fir, grand fir, western hemlock, western redcedar, subalpine fir	Unavail.	Sandstone and basalt	Managed	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. Due to the lack of data and information pertaining to pre-disturbance in all forms, however, this question may remain unanswered.

Summary and Recommendations

One approach to addressing this question may be to use the methodology and resources presented in Smith (1993) for a relatively undisturbed basin.[8] Another alternative would be to analyze the historical riparian characteristics such as those from Ohlson and Schellhaas (unpublished) and establish relationships with instream wood loads. Another reasonable alternative would be to assess the studies regarding instream wood loading that come closest to meeting these pre-human disturbance criteria. In basins that have had no logging or roads, and where the extent of fire suppression is unclear as to whether or not it affected a particular stream or instream wood loads, perhaps using those data will provide the most credible information to which inferences can be drawn. For example, Knight (1990) found an average of 65.2 (stdev 27.8) m^3 of LWD volume per 300 m of stream in unmanaged streams of central Oregon. chesney (2000) found 2.42 LWD pieces per bfw and 12.3 SWD pieces per bfw in unmanaged streams (n=7) of eastern Washington just east of the Cascade crest. chesney (2000) also provides wood volume for particular locations or zones in the channel (defined in detail in section 3.1). Mean volume of wood in zone 1 was 3.0 times greater in unmanaged sites, zone 2 was similar, and wood volume in zone 4 was 2.4 times greater in unmanaged sites than managed sites. Further, the quantities reported in Fox (2001) describe conditions in unmanaged forests; however, it is unclear as to what extent fire suppression (if conducted in the study sites) has had upon altering instream wood loads. Therefore, the ranges provided in Knight (1990), chesney (2000), or Fox (2001) (see Figures 2.1-3 through 2.1-6) might be the most tangible source to draw from based on the lack of historical information.

References

chesney, c.j. 2000. Functions of Wood in Small, Steep Streams in Eastern Washington: Summary of Results for Project Activity in the Ahtanum, Cowiche, and Tieton Basins. TFW Effectiveness Monitoring Report. TFW-MAG1-00-002. Olympia, Washington.

Fox, M.J. 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington State. M.S. Thesis. College of Forest Resources, University of Washington, Seattle, Washington.

[8] The basin was relatively undisturbed because intensive grazing and small-scale selective harvest occurred in the late 1800s to the early 1900s.

Knight, S.M. 1990. Forest harvesting impacts on coarse woody debris and channel form in central Oregon streams. M.S. Thesis. Oregon State University, Corvallis, Oregon.

Ohlson, P. and R. Schellhaas. 2000. Historical and current stand structure in Douglas-fir and ponderosa pine forests. Unpublished report. USDA Forest Service, Wenatchee, Washington.

Smith, J.E. 1993. Retrospective analysis of changes in stream and riparian habitat characteristics between 1935 and 1990 in two eastern Cascades streams. M.S. Thesis. University of Washington, Seattle, Washington.

2.7 Question 7 Response

Did the historical abundance of riparian and in-stream wood vary with stand type (dry ponderosa pine forests, Douglas-fir/grand fir forests, subalpine forests, etc.) and ecoregions? If so, how?

Summary of Literature Sources

Of the references reviewed, three were found that had quantitative and/or descriptive information relating to wood loads. Of these, two were specific to eastern Washington and one was specific to eastern Oregon. Table 2.7-1 provides a summary of these references.

Summary of Quantitative Data

As discussed in the Question 6 response, information on instream wood loading prior to all forms of anthropogenic alteration is extremely limited. The only potentially useful information found to characterize historical wood loads can be found in chesney (2000), Fox (2001), and Knight (1990). These authors have assessed instream wood loads in streams draining modern unmanaged forests of eastern Pacific Northwest streams. Specific information regarding how in-stream wood loads varied with stand type is summarized in the Question 5 response.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. Due to the lack of data and information pertaining to pre-disturbance in all forms, however, this question may remain unanswered.

Summary and Recommendations

Recommendations to answer this question and Question 6 are included in the Question 6 response.

References

chesney, c.j. 2000. Functions of Wood in Small, Steep Streams in Eastern Washington: Summary of Results for Project Activity in the Ahtanum, Cowiche, and Tieton Basins. TFW Effectiveness Monitoring Report. TFW-MAG1-00-002. Olympia, Washington.

Table 2.7-1. Summary of literature sources containing data relevant to question 7.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1.	SC	Subalpine fir, Douglas-fir/ ponderosa pine	5 – 30%	Alluvial	Both	S	Yes
Fox 2001	Tributaries to the Naches, Cle Elum, Wenatchee, Methow, and Stehekin River basins	0.9 – 186	SC, NC, CB	Subalpine fir, grand fir, Douglas-fir/ponderosa pine	0.2 – 47%	Alluvial and bedrock	Unmanaged	S	Yes
Studies in Analogous Regions (Eastern Oregon, Idaho, etc.)									
Knight 1990	Ochoco	15	E. OR	ND [c]	3 – 6%	ND	Both	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

Fox, M.J. 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington State. M.S. Thesis. College of Forest Resources, University of Washington, Seattle, Washington.

Knight, S.M. 1990. Forest harvesting impacts on coarse woody debris and channel form in central Oregon streams. M.S. Thesis. Oregon State University, Corvallis, Oregon.

3.0 Wood Distribution

3.1 Question 8 Response

What portions of the wood loads affect channel morphology? In other words, what portion of wood is of functional size to affect pool formation, sediment sorting, channel stability? How does this vary with stream size and/or channel morphology? Provide quantification of the findings of various studies. Discuss how variations in data collection methods may affect interpretation of study results.

Summary of Literature Sources

Of the references reviewed, ten were found that had quantitative and/or descriptive information relating to wood volume; of these, four had information relevant to eastern Washington, one had information relevant to eastern Oregon, and five were analogous process-based studies. Table 3.1-1 provides a summary of these references.

Summary of Quantitative Data

Portion of Wood Loads Affecting Channel Morphology

Many studies from across the country indicate that woody debris affects channel morphology, although studies in eastern Washington are limited. Woody debris plays an important role in affecting channel morphology including pool formation, sediment sorting, and channel stability. Large wood creates habitat heterogeneity by forming pools, back eddies, and side channels, and by increasing channel sinuosity and hydraulic complexity.

In order to understand how woody debris affects channel morphology, it is important to explain woody debris distribution and function within streams. Abbe and Montgomery (2003) provide a description of the distribution of wood in streams using the example of the Queets River in western Washington; no similar studies for eastern Washington were found.

Wood recruited into streams have been classified by size and type (Abbe and Montgomery 2003). Ten types of woody debris (WD) accumulations are identified based on the mode of recruitment and the orientation of key, racked, and loose debris relative to the channel axis (Table 3.1-2). Individual pieces of debris (measured WD was >1 meter long and 0.1 meter in diameter) were classified relative to their inferred function in a jam: *key members* anchor other debris and functional pieces of wood in the channel, *racked members* are lodged against a channel obstruction (e.g., boulder, key member, or other debris) and *loose members* fill interstitial space, but add little physical integrity to the jam. Although some types of WD accumulation have few geomorphic effects, others form stable in-stream structures that influence alluvial morphology at both subreach- and reach-length scales ranging from less than 1 to greater than 10 channel widths. For example, in the Queets River, stable accumulations of WD directly

Table 3.1-1. Summary of literature sources containing data relevant to question 8.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
Baldwin unpublished	LeClerc, Priest River, and Lost Creek basins	ND [c]	NE	Riparian species: western redcedar, Englemann spruce, subalpine fir, Douglas-fir, western hemlock	1.97 – 6.59	Silt-loam, channel beds made up of boulder, cobble, gravel	U	S	No
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1.	SC	Pacific silver fir, Douglas-fir/ ponderosa pine	5 – 30%	Alluvial	Both	S	Yes
Curran and Wohl 2003	E. and W. Central Cascades	<10 km^2/ stream studied	NC	Conifer/deciduous mix	0.06 – 0.18 m/m	Volcanic, metamorphic, glacial till	ND	S,Q	Yes
Studies in Analogous Regions (Eastern Oregon, Idaho, etc.)									
Knight 1990	Ochoco	15	E. OR	ND	3 – 6%	ND	Both	S	Yes
Analogous Process-based Studies									
Abbe 2000	Queets River, Olympic Peninsula WA; quantitative models	1,164	WW	Sitka spruce, Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple, black cottonwood	0.01 – 0.25	Tertiary marine sandstones and shales	Both	S,Q,O	YES
Abbe and Montgomery 1996	Queets River, Olympic Peninsula WA	1,164	WW	Sitka spruce, Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple, black cottonwood	0.01 – 0.25	Tertiary marine sandstones and shales	Both	S,Q,O	YES
Abbe et al. 2003	Olympic Peninsula, WA; Puget Sound lowlands	N/A	WW	N/A	N/A	N/A	M	Q	No
Beechie and Sibley 1997	Stilliguamish, Skykomish, and Snoqualmie Rivers	2.6 – 118.3	WW	Western hemlock (low); Pacific silver fir (high)	<0.04 m/m	Glacial/alluvial	Both	S	Yes

Table 3.1-1. Summary of literature sources containing data relevant to question 8 (continued).

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Analogous Process-based Studies (continued)									
Murphy and Koski	SE Alaska	Low flow channel widths: 8.2-31.4m		Western hemlock, Sitka spruce	0.4 – 3%	Alluvium and bedrock	U	S,O	Yes
Nakamura and Swanson 1993	Western Oregon	0.96 – 60.5	ND	Douglas-fir, western hemlock, western redcedar, Pacific silver fir	3 – 21%	ND	Both	S	Yes
Diehl 1997	Literature review of drift accumulations at bridges for various locations around the world			N/A	N/A	N/A	N/A	Q	No
Wallerstein et al.	Yazoo Basin, north Mississippi	9 – 388	N/A	ND	ND	ND	ND	S,Q	No

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

influence channel anabranching, planform geometry, flood plain topography, and establishment of long-term riparian refugia for old-growth forest development.

Table 3.1-2. Basic wood debris accumulation typology.

Types	Distinguishing Characteristics
In-situ (autochthonous)	Key member has not moved down channel.
Bank input	Some or all of key member in channel.
Log steps	Key member forming step in channel bed.
Combination	In-situ key members with additional racked WD
Valley	Jam width exceeds channel width and influences valley bottom.
Flow deflection	Key members may be rotated, jam deflects channel course.
Transport (allochthonous)	Key members moved some distance downstream.
Debris flow/flood	Chaotic WD accumulation, key members uncommon or absent, catastrophically emplaced.
Bench	Key members along channel edge forming bench-like surface.
Bar apex	One or more distinct key members downstream of jam, often associated with development of bar and island.
Meander	Several key members buttressing large accumulation of racked WD upstream. Typically found along outside of meanders.
Raft	Large stable accumulation of WD capable of plugging even large channels and causing significant backwater.
Unstable	Unstable accumulations composed of racked WD upon bar tops or pre-existing banks.

Source: Abbe and Montgomery (2003).

Woody debris that is stable (or "functional") within the channel are key members that affect channel-bed morphology, trap additional WD, or are unlikely to be transported downstream during bed-mobilizing flows. Log size relative to the channel size has been repeatedly reported as the principal factor controlling log stability in a given channel (Nakamura and Swanson 1993; Bilby and Ward 1989). A dimensionless plot of the ratio of basal bole diameter, D_b, to bankfull depth, h, versus the ratio of total tree or log length, L, to bankfull width, w, indicates distinct domains for loose, racked, and stable WD and that the relationship changes for different locations within the channel network (Abbe and Montgomery 2003) (Figure 3.1-1). Log stability is profoundly affected by the presence of a rootwad and multiple stems (Abbe et al. 2003; Diehl 1997; Wallerstein 1997).

Wood stability has been shown to be dependant on the size and shape of the wood and the substrate characteristics and these parameters influence how the wood interacts with the channel bed (Abbe 2000). Abbe (2000) evaluated the diameter necessary for a channel spanning log oriented orthogonal to flow to withstand rupture by a debris flow with a fluid density of 2000 kg/m3 and velocity of 10 m/s. Based on this study, a minimum diameter of 75 cm for a Douglas-fir log is required to withstand rupture in a 20 meter channel at those fluid density and velocity parameters. The results from this study are presented in Figure 4.1-1 in the Question 11 response.

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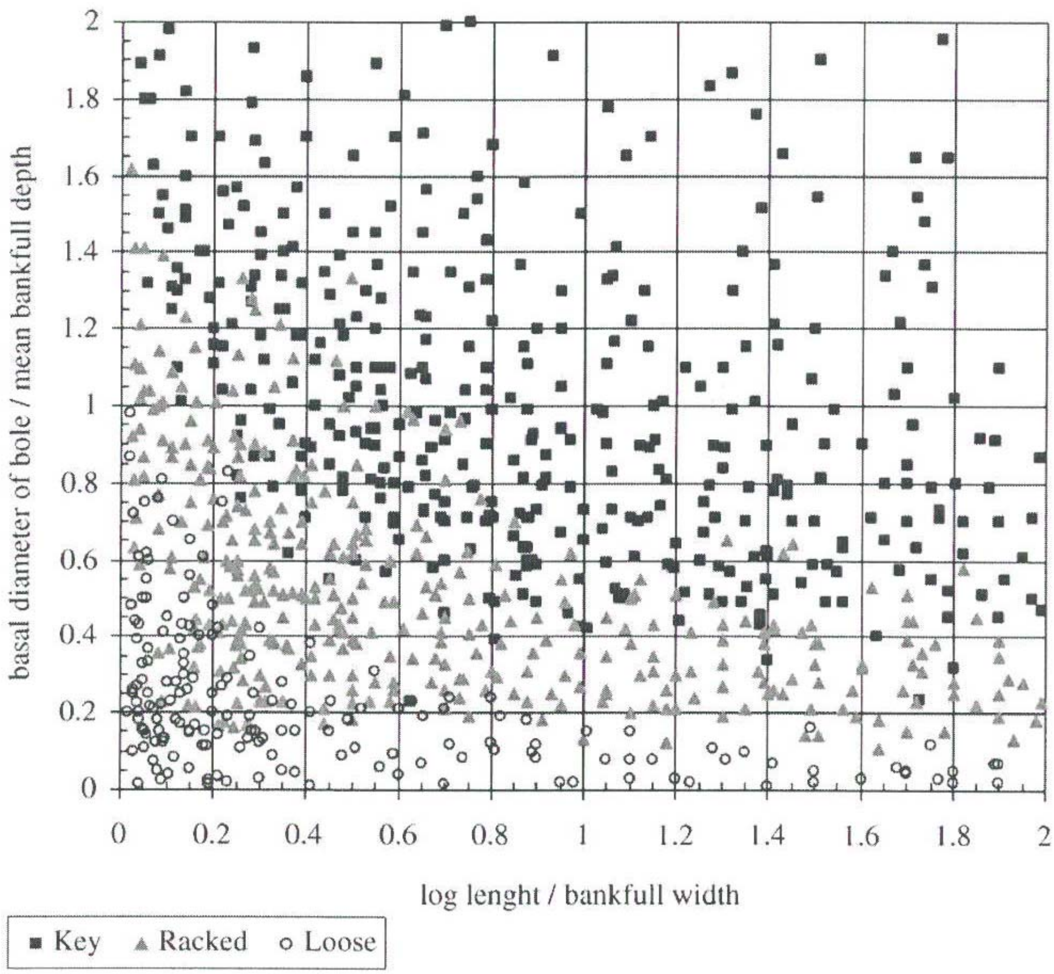

Figure 3.1-1. Dimensionless size plot of log stability thresholds for key, racked, and loose pieces in 32 jams located in five study reaches representing different portions of the Queets channel network.

Ratio of log basal diameter to bankfull depth is plotted versus ratio of log length to bankfull width. If log basal diameter is replaced with the rootwad diameter, the domain of key members is further separated from that of racked members.
Source: Abbe and Montgomery (2003).

Nakamura and Swanson (1992) analyzed effects of woody debris at five sites representing first order to fifth order streams in western Washington. They compared channel width in streams at locations of key coarse woody debris (CWD) and CWD-jams and bedrock outcrops. Channel widening and steepening due to CWD were observed (Figure 3.1-2). They found that mean channel widths at Upper Lookout Creek and Mack Creeks were 25 to 42 percent wider at key-CWD locations and 50 to 58 percent wider at CWD-jam locations than in areas where no CWD was present.

One eastern Washington study, chesney (2000), provides data on the distribution of wood within the stream channel and the portion of wood loads within distinct areas of the channel. chesney's (2000) study of small streams (D_A=0.8 km^2 to 8.1 km^2) indicates the volume and number of pieces of wood that occur in different zones of the streams (Table 3.1-2). The four zones of influence include:

- Zone 1 (Z1): wood is in contact with the channel bed and flowing or standing water
- Zone 2 (Z2): wood is located in Z1, within the bankfull channel and below the elevation of bankfull flow
- Zone 3 (Z3): wood is directly above the wetted perimeter of the bankfull channel
- Zone 4 (Z4): wood is near the wetted perimeter of the banfull channel but not above it.

The volumetric ratio of LWD to SWD in the streams ranged from 3.3 to 184.2, indicating a substantially larger portion of the wood volume is comprised of LWD. The volume of LWD per bankfull width is also substantially greater than the volume of SWD per bankfull width of stream.

Baldwin (unpublished) collected data on woody debris, number of pieces, diameter sizes and lengths in streams in the Northeast Corner region. The study sites in Baldwin (unpublished) are unmanaged, and each study site was categorized based on WDNR site class delineation. Site classes are determined by soil profiles and potential growth productivity. Key LWD pieces were determined after field data was collected. Table 3.1-4 summarizes the mean number of LWD pieces and the mean number of key LWD pieces, with standard deviations in parentheses.

Knight (1990) studied forest harvest impacts on coarse woody debris and channel form in Ochoco or Blue Mountains of central Oregon. All woody debris with diameter greater than 10 cm, length greater than one meter, and located within 10 meters of the streambank was measured in managed and unmanaged streams. Each piece was also classified by clump association: (1) single piece, (2) debris pieces loosely associated with one another, (3) single-tier jams, (4) multi-tier jams, and (5) debris jams consisting of large channel-spanning logs. Percent of total debris volume in each clump is presented in Table 3.1-5 and average number of wood pieces in each clump association per 300 meter reach is presented in Table 3.1-6.

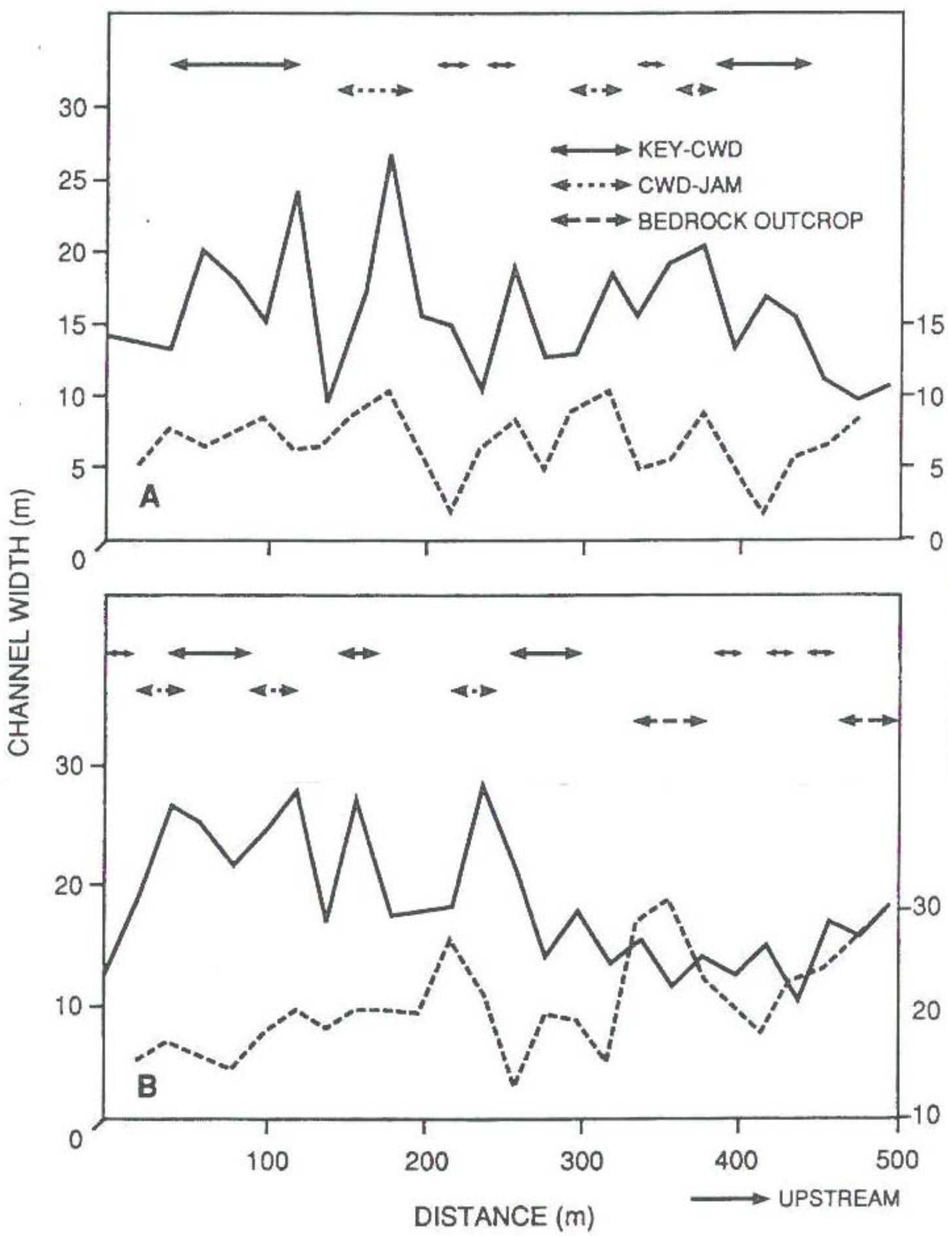

Figure 3.1-2. Variation of channel width and stream gradient in relation to key-CWD, CWD-jam and bedrock outcrop.
Solid and broken lines indicate channel width and stream gradient, respectively. (A) Upper Lookout Creek sit; (B) Mack Creek site. Source: Nakamura and Swanson (1992).

Table 3.1-3. Wood volume and location within zones in streams studied by chesney (2000).

Site Name	Gray	Tea	Meadow	Pine	Found	McClain	Darla	Trail	Cultus	Clover	Nass	Olds	Bear	Wren	Spruce	Cowiche	American	Kettle
Managed (M) or Unmanaged (U)	M	M	M	M	M	M	M	M	M	M	M	U	U	U	U	U	U	U
Bankfull width (m)	2.35	2.74	3.26	1.92	3.62	2.28	2.86	3.41	4.14	4.42	4.48	2.28	2.50	3.84	4.45	4.48	5.51	3.14
Total wood volume (m^3/bfw)	0.41	0.84	0.64	0.34	1.82	3.85	5.48	2.99	0.80	3.55	2.08	10.90	9.57	5.39	3.40	1.23	2.36	3.53
LWD volume (m^3/bfw)	0.31	0.00	0.58	0.32	1.79	3.76	5.31	2.96	0.77	3.53	2.03	10.64	9.45	5.37	3.31	1.21	2.30	3.14
SWD volume (m^3/bfw)	0.09	0.08	0.07	0.01	0.03	0.10	0.19	0.03	0.03	0.02	0.06	0.24	0.11	0.03	0.10	0.02	0.06	0.39
LWD:SWD volumetric ratio	3.3	10.1	7.9	35.1	54.9	37.9	28.5	94.4	22.97	166.7	33.33	43.9	88	184.2	34.6	49.6	35.4	8.1
Zones 1, 2, 3 volume (m^3/bfw)	0.02	0.06	0.06	0.01	0.13	0.08	0.24	0.10	0.04	0.16	0.20	0.28	0.22	0.35	0.23	0.06	0.12	0.18
Zone 4 volume (m^3/bfw)	0.01	0.01	0.00	0.01	0.06	0.17	0.21	0.19	0.05	0.28	0.06	0.43	0.46	0.23	0.20	0.09	0.24	0.13
Zone 1 volume (m^3/bfw)	0.01	0.00	0.00	0.00	0.02	0.00	0.03	0.03	0.01	0.08	0.00	0.00	0.05	0.11	0.09	0.01	0.01	0.08
Zone 2 volume (m^3/bfw)	0.01	0.06	0.05	0.01	0.07	0.05	0.18	0.02	0.01	0.03	0.19	0.08	0.08	0.14	0.08	0.03	0.04	0.06
Zone 3 volume (m^3/bfw)	0.00	0.00	0.00	0.00	0.04	0.03	0.02	0.05	0.03	0.05	0.01	0.19	0.08	0.10	0.06	0.01	0.08	0.04
Zone 4 volume (m^3/bfw)	0.01	0.01	0.00	0.01	0.06	0.17	0.21	0.19	0.05	0.28	0.06	0.43	0.46	0.23	0.20	0.09	0.24	0.13

Table 3.1-4. Mean number of pieces and number of key pieces of woody debris by site class for streams in the Northeast Corner region.

	SCII (n=11)	SCIII (n=16)
Mean number of pieces	18 (10.5)	34 (10.2)
Zone 1	4 (5.6)	5 (2.9)
Zone 2	9 (5.3)	11 (4.6)
Zone 3	4 (2.1)	6 (2.7)
Zone 4	2 (1.4)	4 (2.6)
Mean number of key pieces	1 (1.7)	3 (1.8)

Table 3.1-5. Percent of total debris volume in each clump association.
(1) single piece, (2) debris pieces loosely associated with one another, (3) single-tier jams, (4) multi-tier jams, and (5) debris jams consisting of large channel-spanning logs. Source: Knight (1990).

	Clump Association 1	2	3	4	5	Summation of clumps 3 to 5
Pristine Streams						
Allen	60.43	26.20	8.95	0.00	4.42	13.37
Bear	45.07	30.14	7.65	2.51	13.93	24.09
Canyon, East Fk.	58.23	14.21	0.00	27.62	0.00	27.62
Canyon, Middle Fk.	39.16	35.80	7.33	15.37	2.38	25.08
Little Crane	18.07	23.99	19.33	33.42	5.18	57.93
Petersen	42.22	53.16	2.98	1.35	0.41	4.74
South Fk Bear	65.06	11.06	10.50	13.33	0.00	28.83
Average	46.89	27.80	8.11	13.37	3.76	25.95
Std. Deviation	16.11	14.11	6.13	13.23	4.95	16.56
Managed Streams						
Allen	60.65	32.77	5.91	0.00	0.61	6.52
Clear	0.42	96.44	0.98	0.00	2.20	3.18
Clear, Dry Fk.	28.70	8.97	28.20	0.00	34.14	62.34
Howard East Fk.	56.15	25.91	17.40	0.00	0.49	17.89
Scotty	63.96	17.53	6.74	0.00	11.81	18.55
Wolf Middle Fk.	71.88	18.49	8.30	0.00	1.55	9.85
Average	46.96	33.35	11.25	0.00	8.47	19.72
Std. Deviation	27.13	31.94	9.88	0.00	13.29	21.76

Table 3.1-6. Average number of wood pieces in each clump association per 300m reach. (1) single piece, (2) debris pieces loosely associated with one another, (3) single-tier jams, (4) multi-tier jams, and (5) debris jams consisting of large channel-spanning logs. Source: Knight (1990).

	Clump Association 1	2	3	4	5
Pristine Streams					
Allen	94	65	14	0	3
Bear	45	57	16	6	17
Canyon, East Fk.	30	7	0	14	0
Canyon, Middle Fk.	45	35	9	16	4
Little Crane	61	38	23	11	13
Petersen	61	80	8	9	3
South Fk Bear	75	38	18	11	0
Average	58.71	45.71	12.57	9.57	5.71
Std. Deviation	21.30	23.83	7.57	5.32	6.63
Managed Streams					
Allen	136	90	17	0	2
Clear	1	325	7	0	4
Clear, Dry Fk.	30	25	29	0	7
Howard East Fk.	94	73	32	0	4
Scotty	102	25	20	0	5
Wolf Middle Fk.	63	17	10	0	5
Average	71.00	92.50	19.17	0	4.50
(w/o Clear)	85.00	46.00	21.60	0	4.60
Std. Deviation	49.72	117.69	9.99	0	1.64
(w/o Clear)	40.25	33.12	8.96	0	1.82

Woody Debris Effects on Pool Formation

Eastern Washington

Topic 7.0 Pool Formation discusses pool formation in streams and the Question 24 response discusses the relationship between LWD volume and pool characteristics. Most data available for eastern Washington that addresses pool formation are qualitative watershed studies that did not quantify the relationship between LWD and pools in streams (see question response 24).

One eastern Washington study provides quantitative data regarding the relationship between LWD, pool formation, and stream hydraulics. Curran and Wohl (unpublished and 2003) quantify the percent of steps in eastern and western Cascades streams that contain large (>10cm diameter, >1m length) woody debris, small (smaller than large debris) woody debris, and rock clasts. Average percent of steps that included large woody debris ranged from 5 to 60 percent for eastern Cascades streams. From 5 to 40 percent of steps in these streams included fine woody debris, while clasts were associated with 35 to 90 percent of steps in the streams. Figure 3.1-2 shows that LWD and fine woody debris (FWD) represent 29 percent and 16 percent of materials in step pools, respectively, for all pools in east and west Cascades streams. However, LWD and FWD comprise 50 percent and 30 percent respectively of the highest step pools per reach. Furthermore, Curran and Wohl's (2003) analysis show that clast size is correlated to average step height (not LWD), but LWD is important for formation of especially high steps (Figure 3.1-2). The implication of this relationship is that large woody debris may disproportionately lead to the formation of high steps that will dissipate large amounts of energy in step-pool channels. These results imply that an increase in the abundance of wood in a steep channel will have a stronger effect on flow resistance if that wood forms step risers than if it rests solely on step treads. Thus, it is the distribution and function, rather than the abundance, of wood that determines the influence of wood in step pool channels.

chesney (2000) studied woody debris effects on pool step formation in small streams in eastern Washington. Table 3.1-7 provides chesney's (2000) data on the variation in wood pieces in steps and step pool formation by stream size measured in bankfull width (stream size in this study varied between 0.8 km^2 and 8.01 km^2). The number of steps per bankfull width ranged from 0.48 to 3.25. Figure 3.1-3 shows the percentage of SWD and LWD in pool steps variation by bankfull width. The percentage of SWD is approximately 65 percent in most streams, while LWD comprises closer to 40 to 45 percent. In one stream, SWD makes up 100 percent of the steps, but in the larger streams is not present. LWD is not present in the steps in smaller two of the smaller streams.

Baldwin (unpublished) has raw numbers for pool widths and depths associated with instream wood, but this data needs to be further analyzed before its value can be determined.

Process-based Analogous Studies

Eastern Washington studies contained data regarding WD, pool formation and its variation by stream size, but did not provide an analysis of this relationship. Beechie and Sibley (1997) found that the size of LWD that formed pools increased with increasing channel width, but was not

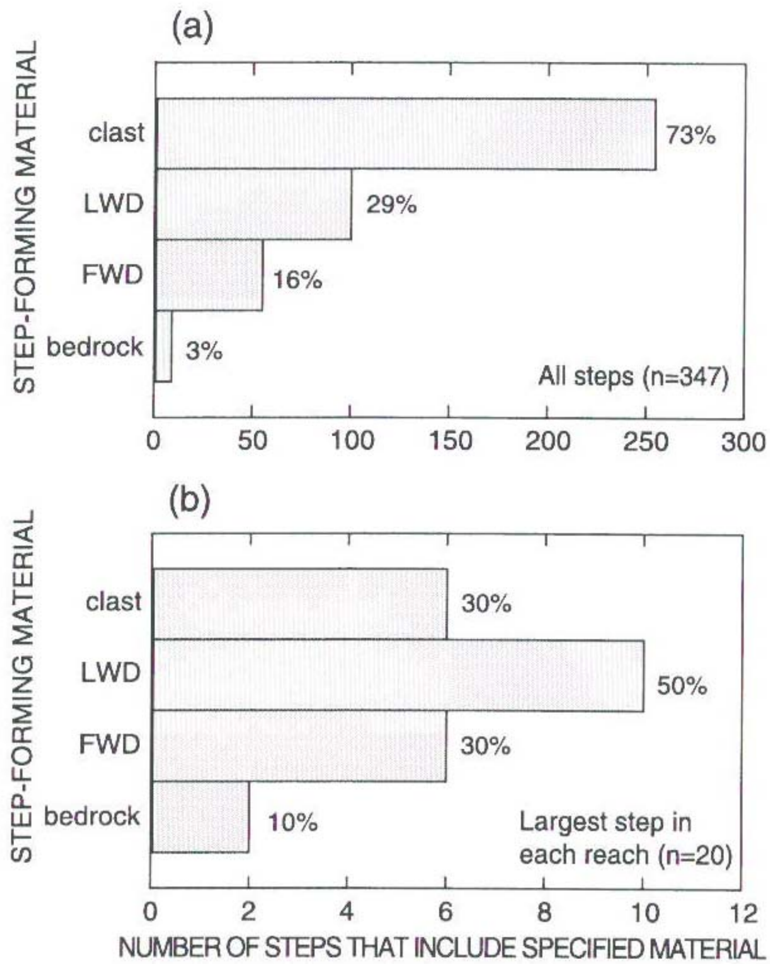

Figure 3.1-3. **Differences in step composition between (a) all steps and (b) a subset consisting of the highest step in each reach (east and west Cascades streams).** Source: Curran and Wohl (2003).

Table 3.1-7. Pool step data and woody debris in streams studied by chesney (2000).

Site Name	Gray	Tea	Meadow	Pine	Found	McClain	Darla	Trail	Cultus	Clover	Nass	Olds	Bear	Wren	Spruce	Cowiche	American	Kettle
Managed (M) or Unmanaged (U)	M	M	M	M	M	M	M	M	M	M	M	U	U	U	U	U	U	U
Bankfull width (m)	2.35	2.74	3.26	1.92	3.62	2.28	2.86	3.41	4.14	4.42	4.48	2.28	2.50	3.84	4.45	4.48	5.51	3.14
Total number of steps	25	14	14	0	8	15	21	17	11	20	16	22	28	12	23	7	22	25
Steps per bfw	3.25	1.56	1.31	0	0.67	2.00	2.23	1.52	0.81	1.38	1.09	2.93	3.41	0.95	1.58	0.48	1.22	2.43
Steps not meeting minimum height	4	4	7	0	1	3	4	2	4	5	2	2	8	4	3	2	0	0
Number of 100% wood steps	1	2	0	0	1	5	9	5	2	8	6	10	9	3	8	5	4	17
Number of 100% rock steps	11	1	0	0	1	3	2	6	2	1	0	1	4	2	6	0	10	0
Pieces of wood in steps	19	20	19	0	6	30	33	14	19	41	28	39	52	18	61	18	35	58
Percent of step face in SWD	84	65	100	0	17	60	64	36	68	68	71	54	72	44	72	56	0	0
Percent of step face in LWD	16	35	0	0	83	40	36	64	32	32	29	46	28	56	28	44	1	1
Wood decay state in steps	4.95	4.8	3.42	0	4.67	4.6	4.26	4.21	4.11	3.56	3.93	3.59	3.89	3.36	4.18	3.78	4.25	4.49
Percent of wood step faces	16.4	45.1	47.5	0	61	51	63.3	42.1	46	66	87.5	66	71.9	54	49.6	95	39.6	62
Percent of rock step faces	80.8	47.7	52.5	0	36	49	36.7	57.9	54	34	12.5	34	29.1	46	50.4	5	54.3	0
% of other materials in step faces	2.8	7.1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	6.1	38

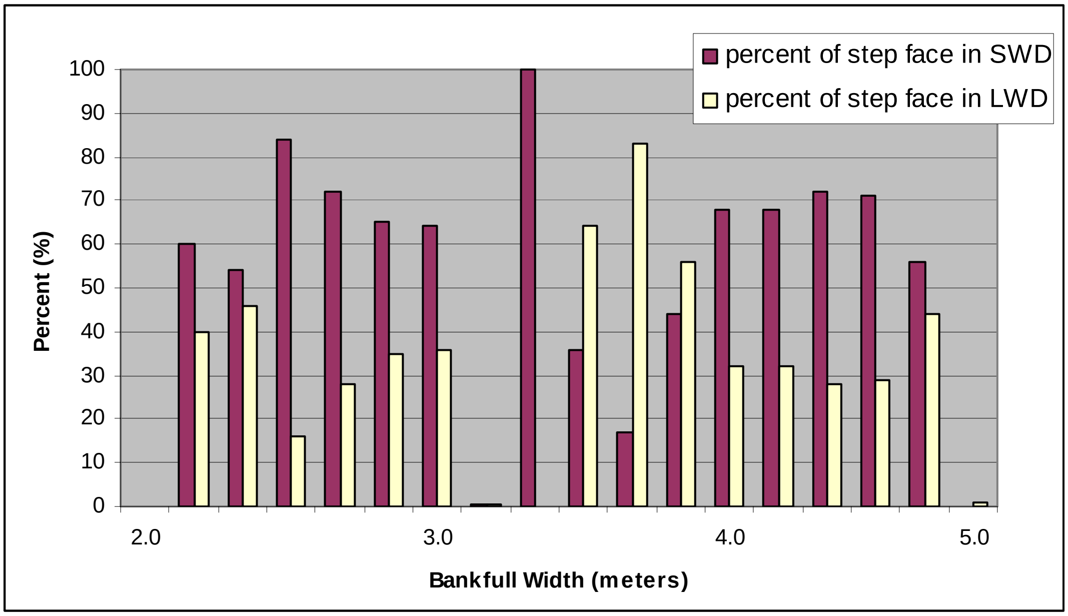

Figure 3.1-4. Percentage of steps composed of SWD and LWD by bankfull width. Study sites are grouped by bankfull width, exact bankfull widths are not represented in this chart. Adapted from chesney (2000).

related to channel slope for streams in second-growth forests in northwest Washington. They also observed that percent gravel (proportion of the bed in patches of gravel 16 to 64 mm in diameter) was best explained by channel slope and channel width, and there was no significant relationship between woody debris and percent gravel.

Murphy and Koski (1989) collected WD piece data on six different stream sizes, varying between 8.2 meters and 31.4 meters wide. Wood pieces were categorized into small, medium, large, and very large diameter sizes and the number of pieces in each study stream was provided. The percentage of each WD size class for each stream was calculated (Table 3.1-8). The percentage of wood pieces declines as wood size increases; so that fewer large to very large pieces are found in streams. Small wood pieces (10 to 30 cm) comprise 40 to 50 percent of the total number of pieces in these streams, compared to very large wood (>90 cm) pieces that comprise 1.5 to 6 percent of the number of pieces. Depending on the size of the stream, functional wood may be considered the larger key pieces in the stream, but the relationship between stream size and piece size was not analyzed. Generally, the mean total number of pieces increases with an increase in channel width, but this was not the case for stream class C2, where the mean number of pieces were approximately 50 percent of that for the smaller streams.

Woody Debris Effects on Sediment Sorting

Eastern Washington

chesney (2000) found that a range of 7 to 13 small woody debris (SWD)[9] pieces/bankfull width and a range of 1 to 2 LWD[10] pieces/bankfull width were required to retain sediment in small, steep streams. In terms of wood volumes, a range of 0.20 to 0.30 ft^3/bankfull width of SWD in both the channel and along the edge of the channel, and a range of 7 to 18 ft^3/bankfull width of LWD are necessary for sediment retention. For wood within the wetted channel only, data indicated a range of 3 to 5 ft^3/bankfull width provides functional sediment retention. No other eastern Washington studies were found that addressed woody debris effects on sediment sorting. This topic is further discussed in Section 8.0 Bedload Transport and Sediment, question responses 26 and 27; analogous studies are provided in that section.

Woody Debris Effects on Channel Stability

No studies were found that explicitly addressed the portion of wood loads that affect channel stability for eastern Washington. Several analogous and process-based analogous studies address this topic, but again do not explicitly address the portion of the wood load that affects channel stability. The effects of woody debris on channel stability are discussed in detail in Section 9.0 Riparian Channel and Condition (question responses 28, 29 and 30).

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[9] In this study, SWD was defined as channel wood greater than 2.5 cm and less than 10 cm mid-length diameter; and length greater than 30 cm and less than 2 cm.
[10] In this study, LWD was defined as channel wood greater than 10 cm mid-length diameter and greater than 2 m in length.

Table 3.1-8. Mean number of pieces and percent of mean total pieces in each size class for different stream types.

Stream Class	Stream Order	Channel Width (m)	Mean Number of Pieces (standard error) and Percent of Total Mean Pieces								
			Small (diam=10-30 cm)		Medium (diam=31-60 cm)		Large (diam=61-90 cm)		Very Large (diam>90 cm)		Total
B1	2nd-3rd	8.2	14.9 (2.8)	50.5%	9.4 (1.5)	31.9%	3.5 (0.8)	11.9%	1.7 (0.9)	5.8%	29.5 (4.5)
B6	2nd-3rd	9.5	16.9 (4.7)	51.5%	12.4 (1.6)	37.8%	2.9 (0.7)	8.8%	0.6 (0.4)	1.8%	32.8 (6.9)
B2	2nd-3rd	11.0	14.6 (1.8)	46.9%	10.8 (2.1)	34.7%	4.4 (0.9)	14.1%	1.3 (0.7)	4.2%	31.1 (3.9)
C2	3rd-5th	14.6	6 (2)	41.1%	5.8 (1.5)	39.7%	2.6 (0.7)	17.8%	0.2 (0.2)	1.4%	14.6 (4.1)
C1	3rd-5th	20.3	19.4 (4.6)	43.6%	17.2 (2.6)	38.7%	5.8 (1.6)	13.0%	2.1 (0.7)	4.7%	44.5 (8.3)
C3	3rd-5th	31.4	19.1 (4.5)	41.7%	17.3 (3.5)	37.8%	7.4 (1)	16.2%	2 (0.5)	4.4%	45.8 (8.2)

Adapted from Murphy and Koski (1989).

Qualification of Literature Sources

Part of this question (effects of woody debris on pool formation and sediment sorting) can be answered based on studies in eastern Washington (#2); however not all regions or stream sizes were covered by these studies.

The other part of this question (portion of wood loads on channel stability) cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

Variations in data collection methods may affect interpretations of results. Knight (1990), Curran and Wohl (2003), and Murphy and Koski (1989) characterize LWD as wood with diameter greater than 10 cm and length greater than 1 meter; while Baldwin (unpublished) and chesney (2000) characterize LWD as wood pieces with diameter greater than 10 cm and length greater than 2 meters. The discrepancy in sampling protocol results in analysis of inconsistent populations. We recommend developing a formal field protocol for consistent and reproducible data collection.

We also recommend field and aerial photography surveys to document the presence of wood in channels of various sizes in each of the eastern Washington ecoregions. Field surveys should focus only on functional wood that directly effects channel morphology, such as pool or bar formation. Field surveys should document the location, size, piece type, and species of wood that are responsible for directly affecting the channel or forming logjams that alter the channel.

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3.2 Question 9 Response

What is the normal distribution of sizes (length, volume) of functional wood in eastside streams? Provide quantification of the findings of various studies. Discuss how variations in data collection methods may affect interpretation of study results.

Summary of Literature Sources

Of the references reviewed, four were found that had quantitative and/or descriptive information relating to the sizes of functional wood. Of these, two contained data from eastern Washington, one contained data from eastern Oregon, and one was an analogous process-based approach. Table 3.2-1 provides a summary of these references.

Summary of Quantitative Data

Baldwin (unpublished) collected data on woody debris, number of pieces, diameter sizes and lengths in streams in the Northeast Corner region. LWD greater than 10 cm in diameter (at the midpoint) and greater than 2 meters in length was measured for each sample plot, following modified protocol developed by Schuett-Hames et al. (1999). Key LWD pieces were determined after field data was collected. Table 3.2-2 summarizes mean number of pieces, number of key pieces, piece diameter, and piece length. Mean piece diameter is also given for woody debris located in a specific zone. Zone classifications used in this study are similar to the zones used in chesney (2000), which was described in the Question 8 response.

chesney (2000) provides volume and number of LWD and small woody debris (SWD) within the stream channel (Table 3.1-2). LWD sampling methods, following Schuett-Hames et al. (1994), included measurement of wood pieces with lengths greater than two meters and mid-length diameters greater than 10 cm. SWD is characterized by lengths less than two meters but greater than 30 cm; and mid-length diameters less than 10 cm but greater than 2.5 cm.

Knight (1990) studied forest harvest impacts on coarse woody debris and channel form in the Ochoco and Blue Mountains of central Oregon. All woody debris with diameter greater than 10 cm, length greater than one meter and located within 10 meters of the streambank was measured. Diameter measurements were taken at the small end of the piece (no smaller than diameter of 10 cm) and at the large end of the piece (no longer than 10 meters). Length measurements were taken with any section outside the 10 meter limit disregarded. Each piece was classified by clump association (single piece, debris pieces loosely associated with one another, single-tier jams, multi-tier jams, and debris jams consisting of large channel-spanning logs). Mean piece diameter and length are presented by clump association in Table 3.2-3.

Murphy and Koski (1989) collected woody debris piece data on six different stream types. Study reaches were 100 to 600 meters long (20 times mean stream width). All wood pieces, with diameter greater than 10 cm and length greater than 1 meter, located within the annual high water area of the channel were counted and measured. Diameter was measured at the juncture of bole and root wad or at the widest point on the on the bole (Murphy et al. 1987). Wood pieces

Table 3.2-1. Summary of literature sources containing data relevant to question 9.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
Baldwin unpublished	LeClerc, Priest River, and Lost Creek basins	ND [c]	NE	Riparian species: western redcedar, Englemann spruce, subalpine fir, Douglas-fir, western hemlock	1.97 – 6.59	Silt-loam, channel beds made up of boulder, cobble, gravel	U	S	No
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1.	SC	Pacific silver fir, Douglas-fir/ponderosa pine	5 – 30%	Alluvial	Both	S	Yes
Studies in Analogous Regions (Eastern Oregon, Idaho, etc.)									
Knight 1990	Ochoco	15	E. OR	ND	3 – 6%	ND	Both	S	Yes
Analogous Process-based Studies									
Murphy and Koski	SE Alaska	Low flow channel widths: 8.2 to 31.4m		Western hemlock, Sitka spruce	0.4 – 3	Alluvium and bedrock	U	S,O	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

were categorized into four groups based on diameter size: small (10 to 30 cm), medium (31 to 60 cm), large (61 to 90 cm), and very large (>90 cm). The number of pieces per 100-meter reach for each diameter class are presented in Table 3.2-4.

Table 3.2-2. Mean number of pieces, number of key pieces, and piece diameter and length for woody debris by site class.

	SCII (n=11)	SCIII (n=16)
Mean number of pieces	18 (10.5)	34 (10.2)
Mean number of key pieces	1 (1.7)	3 (1.8)
Mean piece diameter (cm)	23 (3.6)	20 (4.3)
Zone 1	23 (5.3)	20 (5.3)
Zone 2	23 (3.6)	20 (4.3)
Zone 3	20 (7.9)	23 (9.4)
Zone 4	25 (8.6)	20 (6.6)
Mean piece length (m)	9 (6.4)	8 (1.2)

Standard deviation in parentheses. Adapted from Baldwin (unpublished).

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

Variations in data collection methods may affect interpretations of results. The four studies mentioned above use two different length limits in determining LWD pieces. Knight (1990) and Murphy and Koski (1989) characterize LWD as wood with diameter greater than 10 cm and length greater than 1 meter; while Baldwin (unpublished) and chesney (2000) characterize LWD as wood pieces with diameter greater than 10 cm and length greater than 2 meters. The location of diameter measurements may also cause discrepancies between studies. Many studies lack specific locations of wood pieces, which may lead to inaccurate conclusions.

Future field efforts to gather data to answer this question should incorporate a methodology that calls for detailed piece measurements (Murphy and Koski 1989) in addition to descriptions of the their functional role (Knight 1990). Work is currently being conducted using this methodology by chesney (personal communication 2004) and others under the Milan Project for small, steep streams.

References

Baldwin, T. unpublished. Riparian Condition and Site Characterization Pilot Study. UCUT: TFW/F&F Program Draft Report.

Table 3.2-3. Mean piece diameter and length for streams in managed and unmanaged streams by clump association.

Stream	D_A (km^2)	Active Width (m)	Average Piece Diameter (cm)						Average Piece Length (m)					
			Overall	Single Pieces	Loose Associations	Single Tier Jam	Multi Tier Jam	Debris Jam	Overall	Single Pieces	Loose Associations	Single Tier Jam	Multi Tier Jam	Debris Jam
Unmanaged Streams														
Allen	7.2	3.2	27.2	29.0	24.4	26.7	0.0	34.5	6.0	6.7	4.5	6.8	0.0	12.9
Petersen	8.0	3.6	22.5	21.2	24.7	16.1	19.4	17.7	5.3	5.3	5.7	6.3	2.5	2.3
MF Canyon	10.5	4.5	25.1	24.3	26.6	21.7	25.2	27.9	4.8	4.1	5.5	5.1	5.3	4.2
Bear	13.7	5.3	25.6	27.6	23.7	25.5	19.8	28.9	5.9	6.1	5.2	5.3	3.6	9
SF Bear	16.8	3.6	24.5	24.0	24.8	24.4	26.7	0.0	7.3	8.7	5.2	7.6	4.9	0
Little Crane	24.1	3.8	17.6	15.9	18.0	18.0	25.3	17.4	5.2	4.0	5.1	3.9	15.0	5.1
EF Canyon	36.9	6.2	29.9	25.5	29.5	0.0	40.3	0.0	4.9	4.0	4.9	0.0	7.0	0
Managed Streams														
EF Howard	3.7	2.6	33.7	36.8	30.5	33.2	0.0	22.8	6.3	7.4	4.8	7.2	0.0	3.9
MF Wolf	8.7	2.9	29.7	29.9	33.4	24.7	0.0	21.5	4.0	4.0	3.9	4.2	0.0	3.4
Allen	8.9	4.2	26.3	27.3	24.5	26.4	0.0	36.5	4.0	4.0	3.7	5.5	0.0	3
Clear	26.1	3.7	17.7	57.6	17.6	15.9	0.0	21.5	6.6	1.0	6.6	4.9	0.0	9.1
Scotty	27.1	3.7	23.0	23.2	20.6	20.9	0.0	39.3	5.7	5.8	6.5	3.7	0.0	7.2
DF Clear	41.4	2.9	35.9	36.3	30.9	35.1	0.0	20.9	4.5	4.8	3.2	4.2	0.0	5.6

Source: Adapted from Knight (1990).

Table 3.2-4. Mean number of pieces per 100-meter reach for each diameter class in six stream types.

	Stream Order	Channel Width (m)	Mean Number of Pieces (and Standard Error) per 100-meter Reach				
			Small (diam=10-30 cm)	Medium (diam=31-60 cm)	Large (diam=61-90 cm)	Very Large (diam>90 cm)	Total
B1	2nd-3rd	8.2	14.9 (2.8)	9.4 (1.5)	3.5 (0.8)	1.7 (0.9)	29.5 (4.5)
B2	2nd-3rd	11.0	14.6 (1.8)	10.8 (2.1)	4.4 (0.9)	1.3 (0.7)	31.1 (3.9)
B6	2nd-3rd	9.5	16.9 (4.7)	12.4 (1.6)	2.9 (0.7)	0.6 (0.4)	32.8 (6.9)
C1	3rd-5th	20.3	19.4 (4.6)	17.2 (2.6)	5.8 (1.6)	2.1 (0.7)	44.5 (8.3)
C2	3rd-5th	14.6	6.0 (2)	5.8 (1.5)	2.6 (0.7)	0.2 (0.2)	14.6 (4.1)
C3	3rd-5th	31.4	19.1 (4.5)	17.3 (3.5)	7.4 (1.0)	2.0 (0.5)	45.8 (8.2)

Source: Murphy and Koski (1989).

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3.3 Question 10 Response

Does size distribution vary with stream size, and/or channel morphology (e.g. Rosgen stream types)? If so quantify the relationship. Discuss how variations in data collection methods may affect interpretation of study results.

Summary of Literature Sources

Of the references reviewed, three were found that had quantitative and/or descriptive information relating to wood size distribution; of these, one contained data relevant to eastern Washington, one contained data from eastern Oregon, and one was an analogous process-based approach. Table 3.3-1 provides a summary of these references.

Summary of Quantitative Data

chesney (2000) provides data on the volume of LWD and SWD within stream channels in the Southeast Cascades. Figure 3.3-1 displays LWD and SWD volume per bankfull width. There appears to be no general trend between LWD and SWD and stream size, but further analysis would need to be performed to produce definitive conclusions.

Table 3.2-2 presents data from Knight (1990). Average piece diameter and piece length by clump association were measured. Overall mean piece diameter and piece length by drainage area are presented in Figure 3.3-2. Preliminary investigation reveals no apparent trend, but additional analysis would be needed to determine if a significant relationship exists between wood size distribution and stream size.

Murphy and Koski (1989), presented in Question 8 and 9 responses, collected woody debris piece data on six different stream types. Size distribution varying with stream size/type is presented in Table 3.2-4. Again, there appears to be no obvious trend between size distribution and stream size/type, but additional analysis would be needed.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

Initial results from chesney (2000) indicate that, within small streams in the Southeast Cascades region, the distribution of piece sizes is not dependant of stream size. Further data acquisition

Table 3.3-1. Summary of literature sources containing data relevant to question 10.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1.	SC	Pacific silver fir, Douglas-fir/ ponderosa pine	5 – 30%	Alluvial	Both	S	Yes
Studies in Analogous Regions (Eastern Oregon, Idaho, etc.)									
Knight 1990	Ochoco	15	E. OR	ND [c]	3 – 6%	ND	Both	S	Yes
Analogous Process-based Studies									
Murphy and Koski	SE Alaska	Low flow channel widths: 8.2 – 31.4m		Western hemlock, Sitka spruce	0.4 – 3	Alluvium and bedrock	U	S,O	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

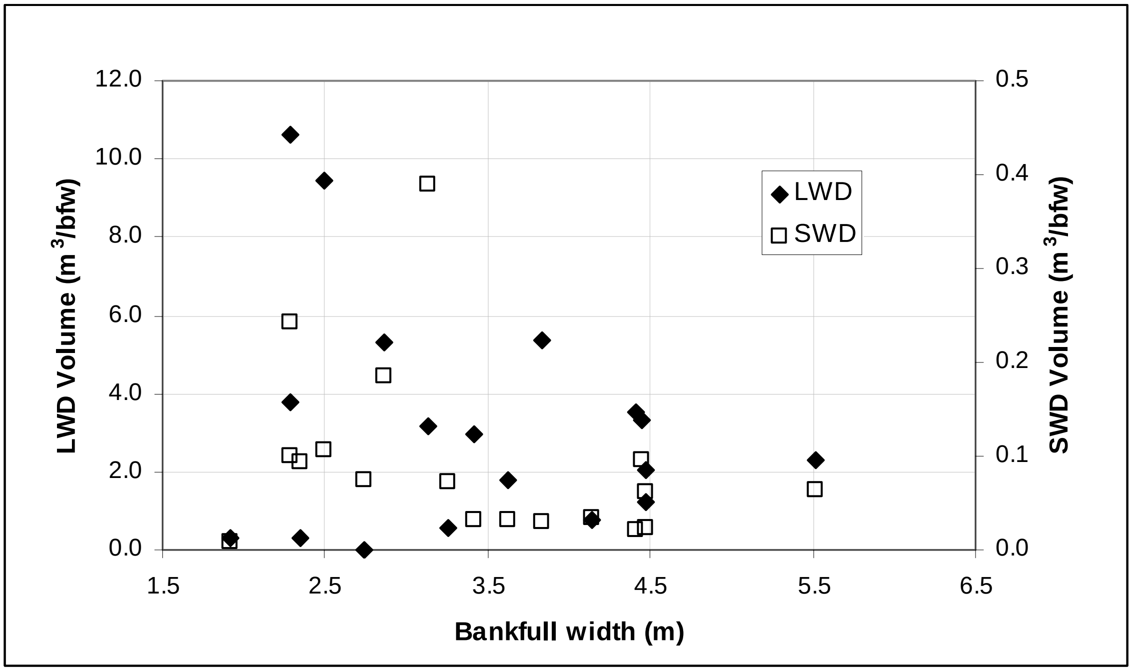

Figure 3.3-1. LWD and SWD volume per bankfull width.
Adapted from chesney (2000).

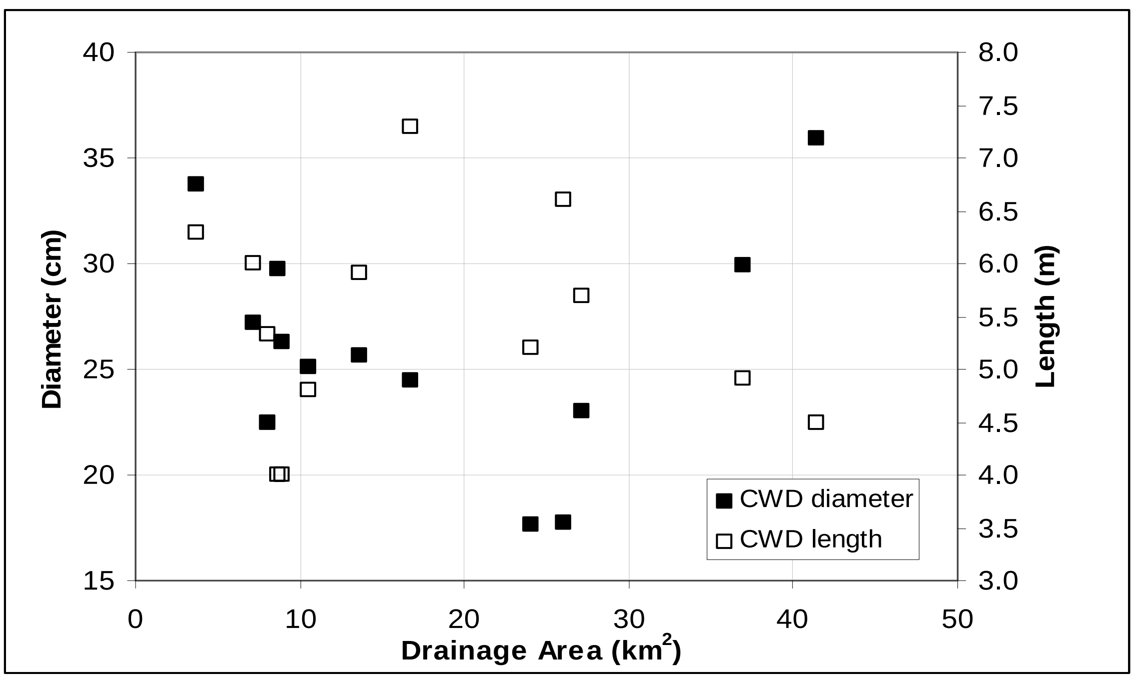

Figure 3.3-2. Overall mean CWD piece diameter and length by drainage area.
Adapted from Knight (1990).

and analysis over a greater range of stream sizes is necessary before this question can be answered. Future data collection efforts to address this question should also incorporate physical measurements of channel morphology. Such efforts could be incorporated with additional field reconnaissance to assess the relationship between stream sizes, channel morphology, and pool sizes (see Question 23 response).

A successful methodology to assess the variation in piece sizes based on stream size, and/or channel morphology should incorporate detailed protocols for piece measurement, measurements of bankfull width (stream size expressed in terms of normalized reach length), piece location in channel, and a means to describe reach morphology. Evaluations of the influence of channel morphology on the distribution of piece sizes must define the type and scale of morphological characteristics being evaluated and provide clear justification for the use of these features. A failure to utilize consistent methodologies, such as measurements that facilitate the comparison of datasets with either different contributing basin scales (bankfull width, drainage area, etc.) or different morphologic reach characteristics, may result in distinct populations which cannot be easily or meaningfully analyzed together.

References

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Knight, S.M. 1990. Forest harvesting impacts on coarse woody debris and channel form in central Oregon streams. M.S. Thesis. Oregon State University, Corvallis, Oregon.

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4.0 Instream Manipulation

4.1 Question 11 Response

What role has stream cleaning (removing wood to improve fish passage or prevent flooding) and harvest of firewood from streams played in the current wood loads in eastside streams? Has the effect of these activities on in-stream wood loads been quantified? If so, provide numeric summaries of information. Also, discuss assumptions made in studies conducted to estimate these effects and the potential implications of these assumptions on study results. If more than one method has been used to estimate these effects, discuss the effect of variations in methods on study results.

Summary of Literature Sources

Of the references reviewed, six were found that had quantitative and/or descriptive information relating to the effects of stream cleaning on current wood loads; of these, two had information relevant to eastern Washington and one contained data from an analogous region. Table 4.1-1 provides a summary of these references.

Summary of Quantitative Data

From the middle 1800s to around 1920, large- and intermediate-sized rivers in the Pacific Northwest were cleared of drift jams and snags to enable the navigation of steamboats and barge rafts down the rivers in order to transport supplies and agricultural products (Sedell and Swanson 1984). From the 1880s to 1915, small rivers and streams were also used to transport logs from the forest to the mills. Log driving involves the transportation of logs by floating them in loose collections by the natural or flushed streamflow (Sedell and Luchessa 1982). Before the logs could be driven, many of the streams had to be "improved" by blocking off side channels to constrict flow and cleaning out debris (boulders, leaning trees, sunken logs, obstructions of any kind) (Brown 1936, Sedell and Luchessa 1982). Many streams required splash dams to drive the logs downstream. Splash dams were temporary dams constructed primarily of timber that were used to form a reservoir where saw logs were stored. After a splash dam reservoir was filled with water and logs, the reservoir was catastrophically released by blowing up the dam. The resulting dam-break flood was the means for transporting the logs downstream to a larger river channel where they would be rafted to mills. Dam-break floods wreak immense damage on a stream by eroding banks, scouring the channel to bedrock, and destroying riparian vegetation. Streams with a history of splash damming are likely to take centuries to recover to conditions prior to logging.

Records of stream clean-up and "improvement" in the Northwest may be found in pioneer interviews, county court records, State court records, and U.S. Army Corps of Engineers reports (Sedell and Luchessa 1982). Over 130 incorporated river and stream improvement companies were operating in Washington by 1900 (Sedell and Luchessa 1982). During the 1930s most of the lowland streams were being cleared of brush, especially after major floods and particularly

Table 4.1-1. Summary of literature sources containing data relevant to question 11.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche, American, and Tieton River basins	0.8 – 8.1		Pacific silver fir, Douglas-fir/ponderosa pine	5 – 30%	Alluvial	Both	S,O	Yes
McIntosh et al. 1994	Grande Ronde, Methow, Wenatchee, and Yakima basins	3,000, 4,641, 3,437, 15,942	BM, NC, SC	ND [c]	ND	Medium rubble	M, U	S,Q	No
Abbe unpublished	Chiwawa, upper Yakima, Methow	441,487, 967	NC, SC	ND	ND	ND	N/A	Q	No
Studies in Analogous Regions (Eastern Oregon, Idaho, etc.)									
Bragg and Kershner 1997	Bridger-Teton NF, Wyoming [model]	4.14 – 99.65		Engelmann spruce and subalpine fir	1.5 – 3.5	ND	M	Q	No
Analogous Process-based Studies									
Abbe 2000	Queets River, Olympic Peninsula WA; quantitative models	1,164	WW	Sitka spruce, Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple, black cottonwood	0.01 – 0.25	Tertiary marine sandstones and shales	M, U	S,Q,O	Yes
Abbe et al. 2001	Ozette River, WA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No
Abbe et al. 2003a	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Q	Yes
Abbe et al. 2003b	Olympic Peninsula, WA; Puget Sound lowlands	N/A	WW	N/A	N/A	N/A	M	Q	No
Napolitano 1998	NF Caspar Creek, CA	0.7 – 27.2	N/A	Coast redwood forest	2	N/A	M, U		No

Table 4.1-1. Summary of literature sources containing data relevant to question 11 (continued).

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Analogous Process-based Studies (continued)									
Faustini and Jones 2003	Mack Creek, W. OR	5.8	N/A	Douglas-fir, western hemlock, western redcedar	N/A	N/A	M, U	Q,S	Yes
Gippel et al. 1996	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes
Shields and Gippel 1995	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes
Sedell and Luchessa 1982	Pacific Northwest	N/A	N/A	N/A	N/A	N/A	M, U	Q	No
Sedell and Swanson 1982	Pacific Northwest	N/A	N/A	N/A	N/A	N/A	M, U	Q	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

after the Federal Flood Control Act of 1936 where funds were made available to clean almost any size stream (Sedell and Luchessa 1982). Stream cleaning focused on fisheries benefits was initiated in the late 1940s and early 1950s in Washington and Oregon (Sedell and Luchessa 1982).

Removing large stable woody debris from small steep streams has long-term effects on wood transport and channel stability. Following the removal of large woody debris, smaller debris, no longer obstructed by stable pieces, becomes mobile during high flow events (Swanson and Lienkaemper 1978). After the initiation of small debris movement, the debris may gain enough mass and momentum to move larger debris and potentially initiate a debris flow (Swanson and Lienkaemper 1978). Abbe (2000) investigated the drag and impact loads associated with debris flows that fallen logs in steep low-order channels would have to withstand. The tensile strength of a log increases as a logarithmic function of log diameter (Figure 4.1-1). For logs extending orthogonally across a 20 meter channel, it would take a 75 cm diameter Douglas-fir in sound condition to withstand a debris moving at 10 m/s and a fluid density of 2000 kg/m^3 (Figure 4.1-1).

Clearing wood accumulations out of the Ozette River in the early 1950s had a pronounced effect on flow conditions, lowering low-flow stage in the river to less than half of the obstructed flow depth, and dramatically reducing the wetted area of the river (Abbe et al. 2001, 2003b). Large accumulations of wood still occur and in some cases, are increasing in frequency as a result of changes in land and river management (Abbe et al. 2003a,b). A recent logjam in the lower Deschutes River in western Washington significantly increased the wetted area of the channel, inundating numerous side channels and floodplain areas even during low flow events (Abbe et al. 2001, 2003a,b). Despite the positive ecological benefits provided by wood accumulations, conflicts with human perceptions and development can result in wood removal and a return to conditions associated with historically cleared channels, as in the case of the Deschutes River (Abbe et al. 2001, 2003a,b).

Several rivers in eastern Washington currently have large accumulations of wood that span most or all of the river channel, such as the upper Yakima (Figure 4.1-2), Chilliwack, and the upper Methow (Abbe unpublished data).

Shields and Gippel (1995) and Gippel et al. (1996) performed theoretical and empirical studies into hydraulic influences of wood debris on flow conveyance and backwatering. Results indicated that debris removal caused a decrease in bankfull friction (Darcy-Weisbach) by approximately 20 to 30 percent and an increase in bankfull capacity of approximately 5 to 20 percent (Shields and Gippel 1995). Gippel et al. (1996) found that when debris occupies 5 percent or less of channel's cross-sectional area it has no significant effect on flow conveyance, thus stream clearing is not necessary. When the debris occupies 10 percent or more of the channel's cross-sectional area the effect becomes significant.

There are several studies that discuss the effects of stream cleaning on wood loads, although only one of the studies reviewed occurs in eastern Washington (McIntosh et al. 1994). Although the CRSN and WISSP datasets used in chesney (2000) are yielding ongoing information to address this question for the Ahtanum, Cowiche, and Tieton River basins, several sites were influenced

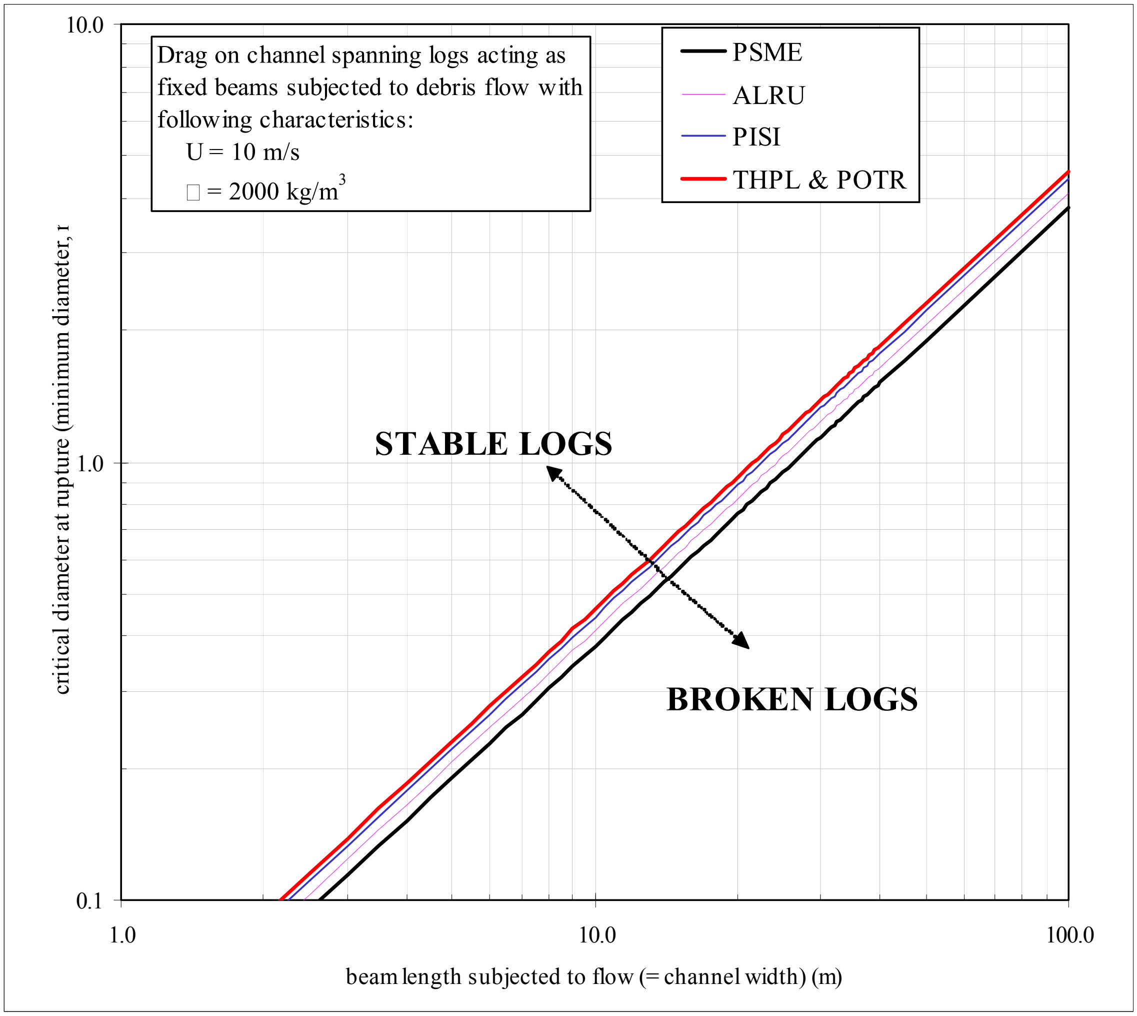


Figure 4.1-1. Analysis presented by Abbe (2000) evaluating the diameter necessary for a channel spanning log oriented orthogonal to flow to withstand rupture by a debris flow with a fluid density of 2000 kg/m3 and velocity of 10 m/s. For a channel 20 m in width it would take a 75 cm in diameter Douglas-fir (PSME). PSME - *Pseudotsuga menziesii*, ALRU – *Alnus rubra*, PISI – *Picea sitchensis*, THPL – *Thuja plicata* and POTR – *Populus trichocarpa*.

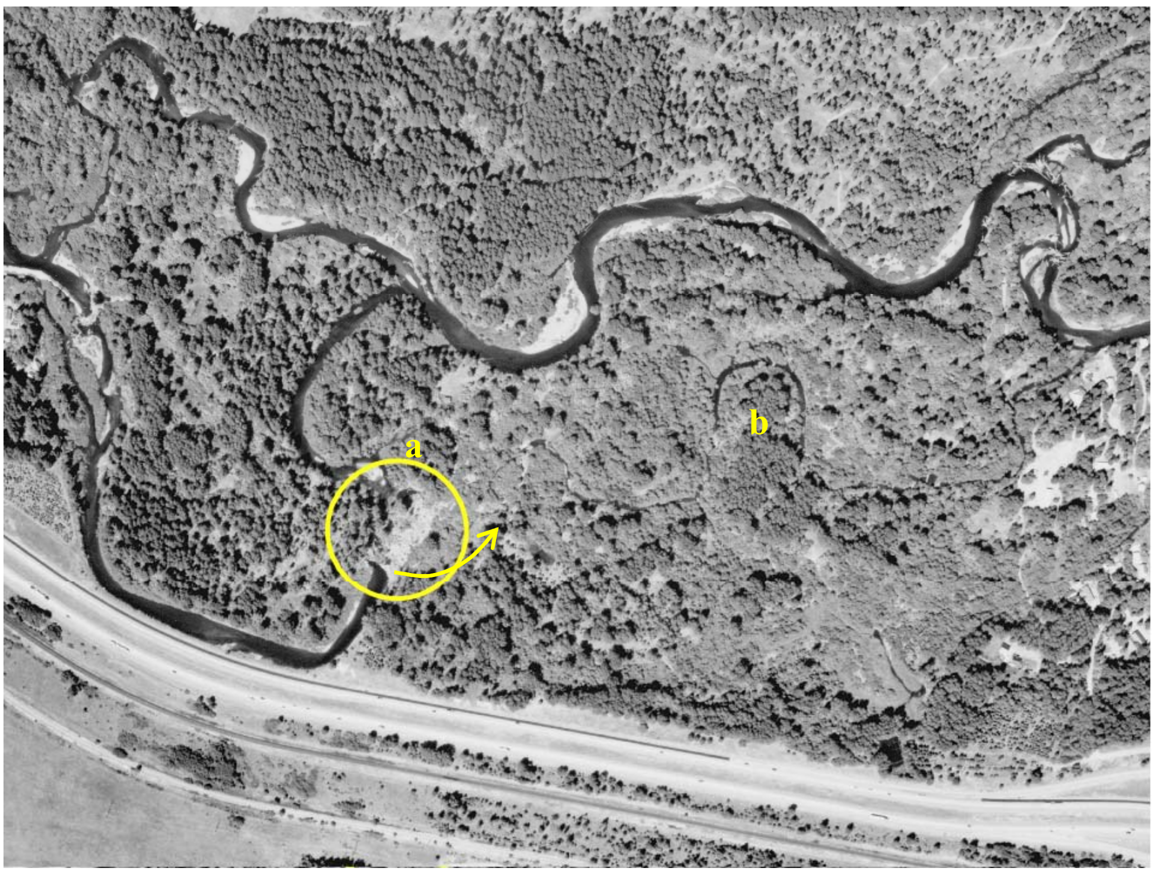


Figure 4.1-2. Upper Yakima River immediately north of I-5, August 1998. Flow is left to right.
Note that logjam completely fills the river (a), deflecting flow to both the left and right into a long secondary channel (b). Field of view is 1,600 x 1,200 m.

by instream manipulation and have undergone remarkable transformations in the past 40 years (chesney 2004 personal communication). None of the studies reviewed quantifies casual removal of wood from streams (firewood, salvage, etc.).

McIntosh et al. (1994) investigated the management history of eastside ecosystems from 1935 to 1992. They used Bureau of Fisheries surveys from 1934 to 1946 to compare past conditions with current conditions in the Columbia River basin. Unfortunately, the Bureau of Fisheries did not collect data on instream LWD. Therefore, McIntosh et al. (1994) collected data on current amounts of LWD (diameter >0.1 meter, length >2.0 meters) in managed and unmanaged basins in eastern Oregon and Washington (Grande Ronde, Yakima, Wenatchee, and Methow Basins) to quantify the effect of management activities on wood loading. They found that the frequency of LWD and debris complexes is about 50 percent greater in unmanaged streams than in managed streams (Table 4.1.2). McIntosh et al. attribute this difference to the extensive debris removal programs initiated in the 1950s through the 1980s and riparian timber harvest (Sedell et al. 1991).

Table 4.1-2. Current amounts of LWD in managed and unmanaged basins of eastern Oregon and Washington.
(Data from McIntosh et al. 1994).

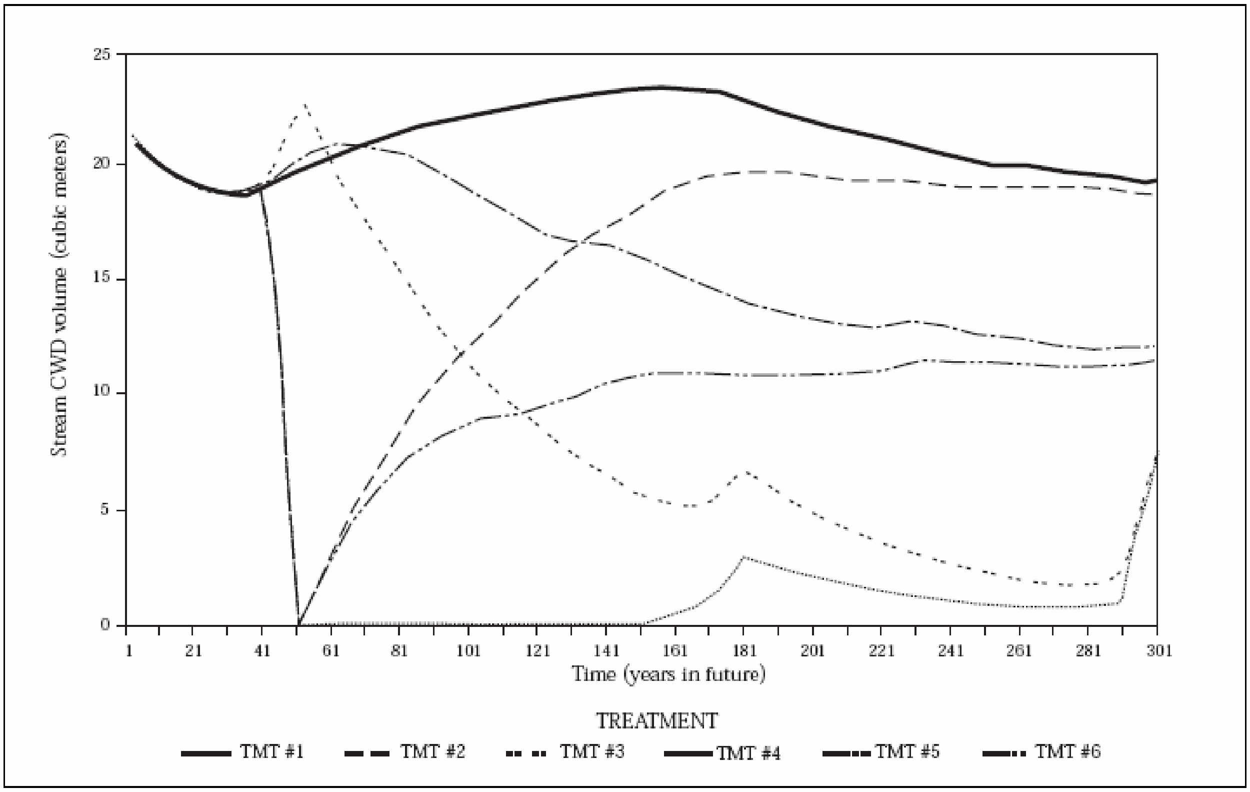
Basin Name	Length (km)	LWD (#/km)	LWD Complexes (#/km)
Managed Streams			
Grande Ronde River Basin	148.7	40.0	5.9
Jordan Creek	3.1	1.0	0.6
Rock Creek	2.2	6.0	1.3
McCoy Creek	4.7	6.2	1.4
Grande Ronde River	73.4	14.6	1.9
Five Points Creek	2.8	23.3	3.6
Catherine Creek	30.7	52.0	8.0
Beaver Creek	3.3	59.0	10.1
N Fork Catherine Creek	6.6	65.6	13.4
Meadow Creek	18.6	65.8	
S Fork Catherine Creek	3.3	66.0	12.5
Yakima River Basin	8.1	32.8	5.8
Wenatchee River Basin	33.6	26.7	3.5
Nason Creek	33.6	26.7	3.5
Methow River Basin	146.1	69.2	12.3
Chewack River	33.9	71.5	12.5
Methow River	69.6	50.6	7.8
Twisp River	42.5	85.6	16.7
Total	336.5	42.2	6.9
Unmanaged Streams			
Yakima River Basin	18.8	72.7	13.8
Wenatchee River Basin	80.0	72.5	11.9
Jack Creek	6.8	73.3	10.7
Icicle Creek	14.1	81.9	11.2
Chiwawa River	59.1	62.4	13.9
Methow River Basin	30.3	40.2	8.1
Chewack River	30.3	40.2	8.1
Total	129.1	61.8	11.3

According the 1941 Bureau of Fisheries survey, the Grande Ronde River was a major logdriving river between the late 1800s and 1919. Splash dams were built at Perry and Vey Meadows, on Dark Canyon, Meadow, and Fly creeks. After the Union Pacific Railroad was extended in 1919, the need for splash dams and log drives were less important.

The earliest timber harvesting in the Teanaway, Menastash, Taneum, and the upper Yakima basins occurred from 1890 to 1900 (Plummer 1902; McIntosh et al. 1994). The Wenatchee basin experienced selective harvesting up until 1955, since then partial cutting and clearcutting have been the predominant harvesting methods (McIntosh et al. 1994). The most intense harvesting in the Wenatchee basin occurred in the 1980s (Mullen et al. 1992; U.S. Department of Agriculture, Forest Service 1990). Harvesting activity was limited to the riparian zone and adjacent hillslopes in the Methow basin until about 1970, when more significant harvesting and road construction began (Spotts personal communication; as cited by McIntosh et al. 1994). It is unclear whether stream cleaning has taken place in these basins (Yakima, Wenatchee, Methow).

Along with logging (log drives/splash dams), there were several other activities impacting wood loading in many of the basins mentioned above, including mining, livestock grazing, road construction, stream channelization, and insects and disease (McIntosh et al., 1994). Therefore it is difficult to make assumptions about wood loading based solely on the effect of stream cleaning.

Bragg and Kershner (1997) developed a tool that uses a growth and yield model (Forest Vegetation Simulator, FVS) with a mechanistic recruitment model (CWD) to simulate long-term effects of woody debris removal from streams in northwestern Wyoming. Numerous riparian forest and stream woody debris characteristics were sampled in order to help parameterize the CWD model. The FVS model is used to simulate both forest growth patterns and the influence of management. Bragg and Kershner evaluated six different treatments on first, second and third order streams over a simulation period of 300 years. During the stream cleaning treatments, for modeling purposes, it was assumed that all woody debris was eliminated at the first treatment, but not during subsequent harvests. The simulations revealed that woody debris loads changed drastically with stream cleaning; under no-harvest, clear-cut, and selective harvest conditions (Figure 4.1-3). TMT #1 and #2 refers to no-harvest conditions with stream cleaning occurring in TMT #2; TMT #3 and #4 refers to clearcut conditions with stream cleaning occurring in TMT #4; and TMT #5 and #6 refers to selective harvest conditions with stream cleaning occurring in TMT #6. Stream cleaning in streams with no-harvest resulted in decade-long lags (80 to 110 years) in woody debris volume. “Even 250 years after stream cleaning, it is unlikely that a similar volume of very large trunks and rootwads could be replaced” (Bragg and Kershner 1997). Both clearcut and selective harvest conditions combined with stream cleaning, TMT #4 and #5, resulted in a long-term loss of woody debris which was less able to replenish depleted woody debris loads. Repeated clearcutting combined with stream cleaning (TMT #4) eliminated nearly all woody debris from the streams for almost a century after treatment. Bragg and Kershner acknowledge that the model involves many assumptions and oversimplifies the processes, but the results are suggestive of the potential trends. The authors also recognize that different ecosystems, and even portions of the same ecosystem, may respond differently to each treatment.



TMT#1	No harvest	No stream cleaning
TMT#2	No harvest	Stream cleaning
TMT#3	Clearcut	No stream cleaning
TMT#4	Clearcut	Stream cleaning
TMT#5	Selective harvest	No stream cleaning
TMT#6	Selective harvest	Stream cleaning

Figure 4.1-3. Simulated CWD loads (per 100m), Moose Gulch Creek, Wyoming. TMT #2,4,6 include stream cleaning at year 50 along with no harvest (#2), clear-cut (#4), and selective cut (#6). From Bragg and Kershner (1997).

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Existing studies establish that stream clearing was extensively practiced throughout eastern Washington and the Pacific Northwest; and has had long-term impacts on wood loading and in-stream flow conditions. Several studies clearly demonstrate that removal of large wood debris from channels and riparian areas results in severe long-term consequences to stream morphology and habitat.

Summary and Recommendations

Non-documented wood removal such as firewood collection or channel clearing for recreational boaters is completely unknown in forest streams and rivers. The relative magnitude of this type of wood removal could be evaluated by tagging and monitoring in-stream wood such as in the study conducted by Abbe and White (2000). A more thorough effort of researching municipal, county, state and federal records of stream cleaning or salvage operations could also provide information to address this question. Historical studies of wood loading in Puget Sound rivers (Collins et al. 2002) could be used as models for studies in eastern Washington. Collins et al. (2002) investigated changes in the distribution and function of wood in Puget Lowland rivers in the past ~150 years. The authors used field data from the Nisqually, Snohomish, and Stillaguamish rivers; and historical data from annual reports of the Corps of Engineers (U.S. War Department 1880 to 1910) to quantify changes in wood abundance and functions.

Aerial surveys of wood loading during the late fall or early spring prior to leaf out could be conducted to map the locations of channel congested with large wood accumulations such as observed in upper Yakima River. Once identified, channels with large wood debris accumulations could be surveyed to determine hydraulic and geomorphic influences such as backwatering, sedimentation and changes in channel profile.

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4.2 Question 12 Response

If possible, quantify the extent of stream cleaning and beaver dam removal in eastern Washington forested streams.

Summary of Literature Sources

Of the references reviewed, four were found that had quantitative and/or descriptive information relating to historical management activities in the Pacific Northwest; of these, three had information relevant to eastern Washington. Table 4.2-1 provides a summary of these references.

Summary of Quantitative Data

There is very little information available to quantify the extent of stream cleaning and beaver dam removal in eastern Washington.

For over 150 years, Pacific Northwest streams and rivers have been cleaned of woody debris and boulders. Sedell and Luchessa (1982) provide a timeline of stream disturbance in the Northwest (Table 4.2-2). They found most early descriptions of northwest rivers in United States and British Army journals.

As described in the Question 11 response, the first accounts of stream cleaning occurred during the process of log drives. In the late 1880s, mills in the Blue Mountains of Washington and Oregon were cutting up to 30 million feet of lumber per year (Beckham 1995). The Palouse River in the Blue Mountains was used to transport the logs downstream to Colfax and Palouse (Beckham 1995). It was estimated that 4 million feet of lumber was moved down the Palouse River each year (Cox 1974). In 1888, the Spokane Mill Company produced 15 million feet of lumber and in 1889 Spokane had nine mills which produced an estimated 30 million feet of lumber (Beckham 1995). Logs were transported to these mills by driving them down the St. Joe, St. Mories, and Coeur d'Alene rivers and were rafted across Lake Coeur d'Alene (Kensel 1968).

Information regarding removal of beaver dams was not found in the references reviewed. The only information found dealt with the removal of beavers from eastern Washington rivers and streams. Fur trappers arrived in eastern Washington and Oregon in the early 1800s (USFWS 2002). By the mid-1800s, beaver were practically eliminated from many rivers and streams across the inland west, including the Umatilla and Meacham watersheds (USFWS 2002).

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Table 4.2-1. Summary of literature sources containing data relevant to question 12.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	General Geology of Study Area	Is Riparian Area Managed or Unmanaged	Type of Data [b]	Peer-Reviewed?
Eastern Washington Studies									
Beckham, S.D. 1995	Columbia Basin	N/A	CB	N/A	N/A	N/A	M	Q	N
McIntosh et al. 1994	Grande Ronde, Methow, Wenatchee, and Yakima basins	3,000, 4,641, 3,437, 15,942	BM, NC, SC	ND [c]	ND	Medium rubble	Both	S,Q	No
Pacific Northwest Studies									
Sedell and Luchessa 1982	Pacific Northwest	N/A	N/A	N/A	N/A	N/A	Both	Q	No
Cox 1974	Pacific Northwest	N/A	N/A	N/A	N/A	N/A	Both	Q	No

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

Table 4.2-2. Timeline of stream disturbance in the Northwest.
From Sedell and Luchessa (1982).

Years	Activities
1848-1880	Early settlers in Willamette Valley and Puget Sound, small-scale localized clearing occurred on lower rivers and main rivers for transportation
1880-1920	Corps of Engineers and timber companies performed intensive boulder blasting, debris removal, and splash damming/sluicing for "river and stream improvement for navigation"
1870-1920	Ditching and draining
1920-1950s	Logging into streams and road building along streams
1930-1940s	WPA snag and brush removal; diking
1972 (OR), 1976 (WA)	Forest Practices Act
	Overzealous debris clean-up in 1st, 2nd order, and intermediate-sized streams
	Salvage downed wood from riparian buffer as soon as trees are undercut or blown down
	Debris-jam removal- primary fisheries habitat improvement procedure

Summary and Recommendations

Records of stream clean-up and "improvement" in the Northwest may be found in pioneer interviews, county court records, state court records, and U.S. Army Corps of Engineers reports (Sedell and Luchessa 1982). A more thorough research effort aimed at these and other municipal, county, state and federal records of stream cleaning or salvage operations could provide information to address this question.

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5.0 Decay Rates

5.1 Question 13 Response

What is the expected decay rate of wood in eastside streams? (Summarize available numeric information.)

Summary of Literature Sources

Of the references reviewed, there were no quantitative studies found pertaining to eastern Washington or analogous regions; four quantitative studies were found relevant to the subject of decay rates of wood in Pacific Northwest streams. Table 5.1-1 provides a summary of these references.

Summary of Quantitative Data

No research was found that assessed rates of wood decay in eastern Washington streams, however, limited research has been completed on decay rates in other regions.

The mass of a decaying log is commonly evaluated using the equation provided in Harmon et al. (1986):

$$M_t = M_0 e^{-kt}$$

where M_0 is the log's initial mass, M_t is the mass of the log at a given time, t, and k, is the decay rate.

In this single exponent model (Harmon et al. 1986), the mass of the decaying log is most sensitive to this decay rate value. While this single exponent model simplifies the decay process, Means et al. (1985) found that both single exponent models and summation-exponential models gave virtually identical, statistically significant fits to terrestrial decay data.

In-stream Decay Rates

Decay rates for logs in streams are not well documented, but are related to terrestrial decay rates, which are well documented. Terrestrial decay rates reported in multiple studies are summarized in Yin (1999) and Harmon et al. (1986). Wood decays more slowly in streams than it does on land due to water saturation that reduces oxygen availability below the wood surface and in turn prevents fungal growth (discussed in Bilby et al. 1999). As a result, decay occurs only on the surface of submerged wood, and there at a relatively slow rate. Because wood decays more slowly when submerged, terrestrial decay rates, which are well documented for most tree species, can be used to estimate maximum decay rates for wood in streams. Generally,

Table 5.1-1. Summary of literature sources containing data relevant to question 13.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach									
Murphy and Koski 1989	S.E. Alaska	ND [c]	Other	Spruce, hemlock, peat bog	0.4 – 2.9	ND	Unmanaged	S, Q	Yes
Hyatt and Naiman 2001	Queets River, WA	1,157	WW	Sitka spruce, Douglas-fir, western hemlock, and black cottonwood	ND	Alluvium	Unmanaged	S, Q	Yes
Bilby et al. 1999	3rd order stream - Tributary to Deschutes River, WA	ND	WW	Douglas-fir, western redcedar, western hemlock, red alder, bigleaf maple	ND	ND	ND	S, Q	Yes
Martin and Benda 2001	Game Creek basin, S.E. Alaska	132	Other	Western hemlock, Sitka spruce, Sitka alder	0.7 – 15.0	ND	Both	S, Q	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

coniferous species decay more slowly than hardwood species and large pieces decay more slowly than small pieces in terrestrial environments (Harmon et al. 1986); various studies of wood in streams show similar trends.

Wood that is constantly submerged can last for hundreds of years. Abbe et al. (2003) cites piles used in the foundation of St. Mark's in Venice, which have been constantly submerged and are over 1,000 years old, as evidence of wood resisting decay when submerged. Hyatt and Naiman (2001) found pieces of LWD in the Queets River, Washington, that were over 1,400 years old; it is assumed that this wood was buried for some of this time. Murphy and Koski (1989) found an average age of 122 years for large (>90 cm diameter), decay class 6 wood. Table 5.1-2 presents a qualitative classification system for categorizing LWD and associated root wads.

Table 5.1-2. Decomposition classes for categorizing LWD and associated root wads.

Decay Class [a]		Root Wad Class	
Number	**Description**	**Number**	**Description**
1	Bark intact, limbs and twigs present	1	Dirt or previous vegetation intact
2	Bark intact, limbs and twigs absent	2	Medium roots (<2.54 cm) intact
3	Bark loose or 5% absent	3	Major roots (>10.16 cm) remaining
4	Bark 95% absent, surface firm	4	No root wad, upper broken bole
5	Surface deteriorating, center solid	B	Buried, not determined
6	Surface deteriorating, center patchy		
7	Surface deteriorating, center rotten		

Source: Hyatt and Naiman (2001).
[a] Classes 5-7 require sampling with an increment borer to assess interior wood condition.

Bilby et al. (1999) found that decay rates for fresh cut, submerged pieces of wood are slower than expected terrestrial decay rates. Logs of standard dimensions from five species of trees (red alder, western redcedar, Douglas-fir, western hemlock, and bigleaf maple) were placed in a 3rd order stream for five years to evaluate changes in strength and decomposition. Wood was submerged for the duration of the study. Density of interior wood did not change measurably for any of the wood over the course of the study and exterior decay rates were lower than terrestrial rates. This later finding was even more pronounced in decay rates following the first year, when the decay-prone bark had decomposed (Table 5.1-3). Over 75 percent of the diameter decrease in the Douglas-fir and western redcedar was due to bark loss, while only 40 percent of the diameter decrease for the bigleaf maple was attributable to bark loss. Decay should slow over time and the wood from all five species should persist for several decades if it remains submerged (Bilby et al. 1999). Additionally, Bilby et al. (1999) found lower rates of decay for the coniferous species in his study, which conforms to terrestrial observations, although his study suggests that, at least initially, decay rates vary less between tree species in streams than in terrestrial environments.

Table 5.1-3. Decrease in diameter and decay rate constants (*k*) for wood from five species of trees submerged in water for 5 years.

Species	Diameter Loss after 5 Years (mm) +/- one standard error	Decay Rate Constant (*k*)
Douglas-fir	13.0 +/- 2.7	0.026
Western redcedar	13.2 +/- 4.2	0.026
Western hemlock	10.6 +/- 4.9	0.031
Red alder	14.3 +/- 4.0	0.033
Bigleaf maple	21.8 +/- 6.3	0.038

Source: Bilby et al. (1999).

Other researchers have also found that inter-species differences in terrestrial decay rates are exhibited in in-stream attrition rates. Hyatt and Naiman (2001) found a correlation between terrestrial coniferous and hardwood decay rates and in-stream attrition rates. Hyatt and Naiman surveyed and recorded the species of the wood in the channel and of the trees on the surrounding banks. The proportion of coniferous to hardwood LWD in the channel was greater than the proportion of coniferous to hardwood trees in the recruitable riparian community. Furthermore, the relative ratio of in-channel to recruitable LWD for each tree species was consistent with decay rates reported by Harmon et al. (1986); species that have relatively high terrestrial decay rates are less likely to be in the channel than species with relatively low terrestrial decay rates (Figure 5.1-1). This portion of Hyatt and Naiman's study may be influenced by their survey of only LWD pieces of 60 cm diameter and greater.

Local Variability

Assigning decay rates for all wood in a system may be problematic. A host of factors can affect decay rates within watersheds and within river reaches.

Bilby (2003) discusses various local factors that can affect decay rates, including turbulence, which affects oxygen levels and consequently microbial activity, temperature, which also affects both microbial and invertebrate activity (lower temperatures slow decay rates). Nitrogen and phosphorus availability are also positively related to wood decay rates. Additionally, the number of times submerged wood is dried each year and the length of each time can dramatically change the decay rate of a piece of wood. Harmon et al. (1986) note that moisture content above or below 30 percent reduces microbial activity. Bilby et al. (1999) found relatively little decay in red alder when it was constantly submerged for five years, but Cederholm et al. (1997) observed significant degradation of partially submerged red alder logs in a restoration project after only three years. The work of Hyatt and Naiman (2001) suggests that location may exert much greater influence on decay rates than age; they only found significant relationships between decay class and LWD age at the extremes of their study (Figure 5.1-2). Martin and Benda (2001) found four groupings of decay classes with significantly different mean ages, although the methods used in this study may not accurately determine age (Table 5.1-4). This potential failing, along with the inadequacy inherent to the methods used by both studies to separate decay rate from downstream transport rate are detailed in the following section.

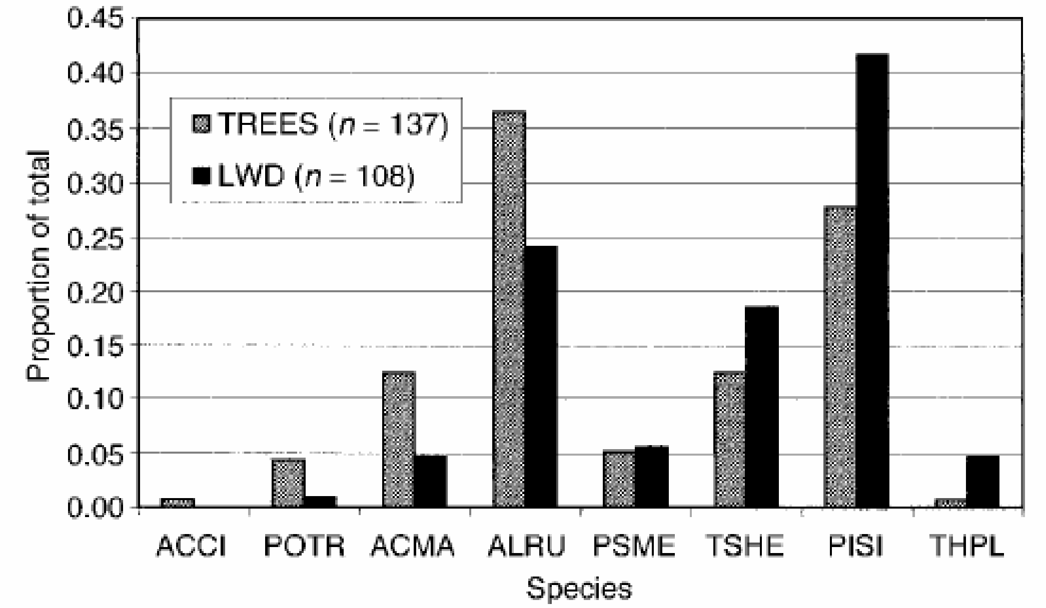

Figure 5.1-1. Relative abundance of LWD vs. riparian trees, by species (30 cm diameter and larger).
Species codes: ACCI, *Acer circinatum* (vine maple); ACMA, *Acer macrophyllum* (bigleaf maple); ALRU, *Alnus rubra* (red alder); PISI, *Picea sitchensis* (Sitka spruce); POTR, *Populus trichocarpa* (black cottonwood); PSME, *Pseudotsuga menziesii* (Douglas-fir); THPL, *Thuja plicata* (western redcedar); TSHE, *Tsuga heterophylla* (western hemlock). Source: Hyatt and Naiman (2001).

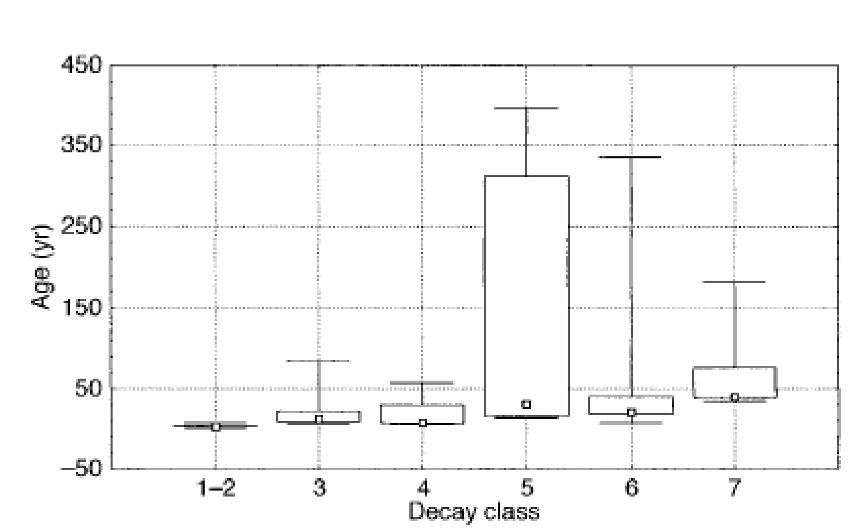

Figure 5.1-2. Box and whisker plot of LWD ages grouped by decay class, showing median values, 25th and 75th percentiles, and range.
Decay classes 1 and 2 were combined due to low sample size in class 2. Decay class is generally a poor predictor of wood age. The two oldest samples (age 1,340 years and 1,430 years, both in decay class 5) were removed from the data set to show greater resolution. Source: Hyatt and Naiman (2001).

Table 5.1-4. Age statistics for recruited large woody debris by unpooled and pooled decay classes.
Age of decay classes determined from dependent saplings (Martin and Benda 2001).

Decay Class	Mean	Median	SD	Maximum	Number Aged
Unpooled					
I	–	–	–	–	0
II	7.6	6.0	3.2	14	14
III	10.1	9.5	5.0	16	8
IV	18.7	17.0	9.4	42	5
V	30.3	29.0	11.9	65	47
VI	31.3	26.0	19.5	126	198
Pooled					
I	1.0 [a]	–	–	1 [a]	154 [b]
II, III	8.5	6.0	4.0	16	22
IV	18.7	17.0	9.4	42	53
V, VI	31.1	27.0	18.2	126	245

[a] Age of decay-class I is assumed to be 1 year.
[b] Number of recruits in decay-class I.

Techniques for Measuring Decay Rates

Multiple techniques have been used to assess in-stream decay rates. The first and most common in the Pacific Northwest is dating dependent saplings growing on LWD. This technique has been used to identify the amount of time it takes wood to reach specific decay classes. This technique cannot be used to identify specific decay constants, because the original density, mass, or volume of wood pieces is not known. This can be useful, however, for determining longevity of wood in the channel. Murphy and Koski (1989) dated LWD pieces in southeast Alaska from the age of the vegetation growing on them. A cross section of the trunk of one or two live hemlock trees growing on each piece of LWD or its rootwad was sampled. The annuli were counted under a microscope and the oldest sample from each piece was used for dating. Martin and Benda (2001) also used dependent saplings to estimate the age of LWD in southeast Alaska.

This technique is problematic because the rate of decay for a single piece out of many is not necessarily representative of normal decay rates. Pieces that have growth on them are likely to have moved less and experienced less inundation than an average piece. This means that the sample group is biased towards wood that have experienced conditions that slow decay. Additionally, the clock is reset every time a piece of wood moves, meaning that many pieces could be older than the piece with the oldest vegetation. Also, while Murphy and Koski (1989) report observing saplings growing on freshly fallen trees, Hyatt and Naiman (2001) found that many LWD pieces sit for periods of up to 20 years with no dependent growth and the oldest pieces in their study had no dependent growth whatsoever. Further, wood pieces that cultivate dependent saplings early on may be prone to rotting more quickly than average pieces. Hyatt and Naiman (2001) note that "dependent vegetation seems to be less an indicator of residence time than of relative stability."

Crossdating LWD cores with riparian tree cores is another method used to estimate decay rates. Hyatt and Naiman (2001) dated LWD in the Queets River by crossdating LWD cores with riparian conifers to determine the year of death. Decay class (1-7) was recorded for each sample. As with dependent sapling dating, the age data does not give true decay rates (instead, it gives the depletion rate, which includes loss of wood to downstream transport), but it is useful for determining longevity of wood in the channel. The average age of the LWD in each decay class can be used to estimate the longevity of wood in the channel.

The sporadic nature of LWD delivery to rivers makes this data less interpretable. For instance, Hyatt and Naiman (2001) found no significant relationship between LWD fall age and diameter, which counters the findings of terrestrial studies and other in-stream decay studies, but note that several of the larger logs in the data set were recruited in the most recent decade.

Unlike the methods described above, the methods used by Bilby et al. (1999) can be used to determine actual decay rates. Bilby et al. (1999) placed a total of 200 logs of standard dimensions from five species (red alder, western redcedar, Douglas-fir, western hemlock, and bigleaf maple) of trees in a 3rd order stream for five years to evaluate changes in strength and decomposition. Wood was submerged for the duration of the study. Diameter and density of interior and exterior wood was measured yearly.

The values calculated by this study can be used in eastern Washington. However, the short time-span of this study and the distorting effect of high bark decay rates relative to sapwood decay rates mean these rates have limited applications. Also, these rates represent constantly submerged wood in a 3rd order stream. As was discussed above, wood that is not constantly submerged is likely to decay at much higher rates.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

Methods for documenting terrestrial decay rates have been established and terrestrial decay rates may guide estimates of in-stream decay rates and indicate the relative in-stream persistence of various species. Overall, few studies have been conducted on in-stream decay rates and no studies have been conducted in eastern Washington. Further study is therefore needed to identify in-stream decay rates in eastern Washington.

Methods similar to those used to determine in-stream decay rates in western Washington and southeast Alaska could be improved upon and applied to wood in eastern Washington streams. The methods described in Bilby (1999), with modifications, could serve as a basis for future studies with trees native to eastern Washington in eastern Washington streams. The decay rates of each component of a tree (bark, sapwood, heartwood) should be measured separately by explicitly exposing different components prior to submerging the wood.

Another important aspect that should be researched is the decay rate of submerged wood that is intermittently exposed to air. This could also be accomplished by modifying the methods used by Bilby (1999). One population of LWD would be left entirely submerged for the period of study while another population would be pulled out of the water and exposed to the air intermittently. This would serve to identify decay rates over the range of conditions that LWD typically encounter.

Further, studies should also integrate the influence of basin area or effective stream size as the interaction between streamflow and LWD may differ significantly across this range and may dramatically influence decay rates and processes.

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5.2 Question 14 Response

How do decay rates vary with the size of a piece of wood? (Summarize available numeric information, and/or qualitative datasets [e.g., repeat imagery] in support of quantitative outcomes.)

Summary of Literature Sources

Of the references reviewed, there were no quantitative studies found pertaining to eastern Washington or analogous regions; five quantitative studies were found relevant to the subject of the effect of size on decay rates of wood in Pacific Northwest streams. Table 5.2-1 provides a summary of these references.

Summary of Quantitative Data

While no decay rate data is available for eastern Washington streams or analogous areas, data from western Washington streams, elsewhere, and terrestrial studies typically indicate that piece size influences decay rates. Large wood decays more slowly due to physical and chemical differences between small and large diameter wood. Some studies directly address these chemical and physical differences while others focus on real-world differences in large and small wood decay in streams.

Physical and Chemical Analysis

The makeup of wood pieces changes as trees grow larger. Relative to smaller wood, large wood contains proportionately more decay-resistant heartwood, proportionately less bark and sapwood, and has a higher ratio of volume to surface area (Figure 5.2-1).

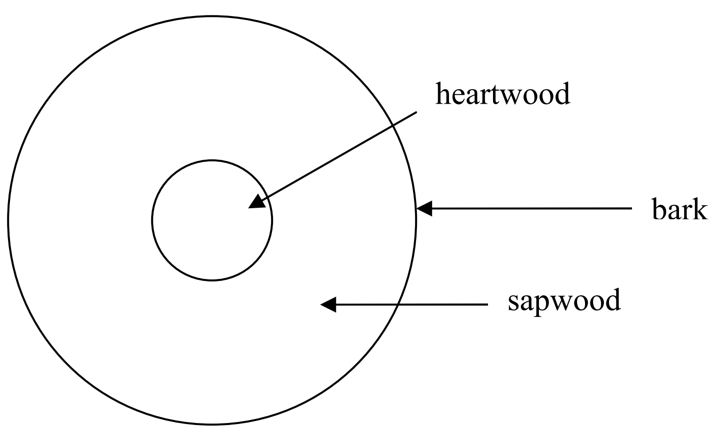

Figure 5.2-1. Structural division of wood types within a tree.

Table 5.2-1. Summary of literature sources containing data relevant to question 14.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach									
Abbe, T.B. 2000	Queets River, Olympic Peninsula, WA	1,164	WW	Sitka spruce, western redcedar, Douglas-fir, western hemlock, red alder, bigleaf maple, black cottonwood	0.01 – 0.25	Tertiary marine sandstones and shales	N/A	S, Q, O	Yes
Murphy and Koski 1989	S.E. Alaska	ND [c]	Other	Spruce, hemlock, peat bog	0.4 – 2.9	ND	Unmanaged	S, Q	Yes
Hyatt and Naiman	Queets River, WA	1,157	WW	Sitka spruce, Douglas-fir, western hemlock, and black cottonwood	ND	Alluvium	Unmanaged	S, Q	Yes
Mellen and Ager	W. Washington	ND	WW	Douglas-fir, western hemlock	ND	ND	ND	S	Yes?
Triska and Cromack 1979	H.J. Andrews Forest	ND	Other	ND	ND	ND	ND	Q	
Yin 1999	Multiple	Multiple	N Am.	ND	ND	ND	ND	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

Large wood, therefore, has proportionately less surface area than small wood where decay and abrasion can occur. Figure 5.2-2 shows the relationship between surface area and volume for a 10 meter long log with a diameter up to 2 meters and illustrates the decreasing ratio of surface area to volume with increasing diameter. Surface area, A_s, is calculated by the equation:

$$A_s=2\pi RL$$

Where R is the piece radius and L is the piece length. Piece volume, V, is calculated as:

$$V= \pi R^2 L$$

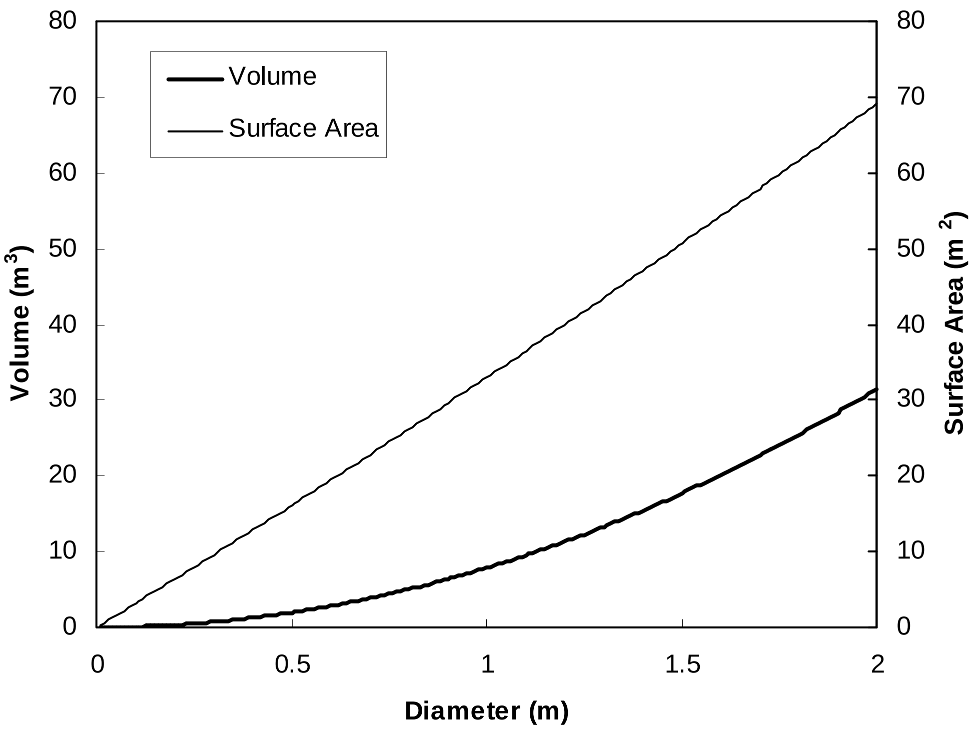

Figure 5.2-2. Relationship between surface area and volume for a 10 meter long log when diameter increases from 0 to 2 m.

In terrestrial studies, relatively smaller surface area limits oxygen penetration in the wood, which limits microbial and fungal growth. However, saturated wood already has low oxygen availability (Harmon et al. 1986) and saturated wood typically decays only on the outermost surface (Bilby et al. 1999), while terrestrial decay typically involves fungal decay throughout a log. As a result, in-stream decay rates may not be as affected by low surface area to volume ratios as terrestrial decay rates.

Large wood also has a larger proportion of decay-resistant heartwood (Hillis 1977, cited in Harmon et al. 1986). Heartwood contains more decay-inhibiting extractives and less decay-promoting sugars and proteins than other types of wood (Harmon et al. 1986). The decay resistance of heartwood and other wood components varies considerably between species, where extractive quantities and the effectiveness of extractives are not consistent. Extractive quantities also are not evenly distributed within the heartwood; they tend to be concentrated near the sapwood and near the base of the tree (Harmon et al. 1986). The decay-slowing effects of heartwood would probably not be immediately evident in in-stream decay rates because the heartwood would not begin to decay until the bark and sapwood was removed.

Empirical Data and Model Results

Empirical data on the relationship between size of wood and decay rates for in-stream wood is very limited. Murphy and Koski (1989) dated dependent saplings growing on LWD in southeast Alaskan streams. A cross section of the trunk of one or two live hemlock trees growing on each piece of LWD or its rootwad was taken. The annuli were counted under a microscope and the oldest sample from each piece was used for dating. Logs that had no saplings were not dateable, but it was assumed that these logs behaved similarly to logs with saplings on them. Longevity of wood in the channel was found to be directly proportional to bole diameter. This finding may reflect lower decay rates for large wood, but is confounded by the highly transportable nature of smaller pieces. It is difficult to determine from this study which of these two components exerts more influence on in-stream attrition.

Abbe (2000) developed empirical curves based on surveys of Douglas-fir species in the Queets River in western Washington. The curves indicate that the percent remaining LWD and the log diameter declines more rapidly in the first 20 to 40 years, then the decay rate slows asymptotically (Figure 5.2-3). The logs are projected to decay completely in up to 200 years.

Triska and Cromack (1979) report on an ongoing study with five types of fine wood substrates of Douglas-fir. Findings, however, are reported after only 220 days of study. Douglas-fir twigs, bark, chips, blocks, and sticks were placed in Mack Creek in the H.J. Andrews Forest, in western Washington, and on the forest floor nearby. At the time of publication, in-stream decay rates were faster than terrestrial rates for all groups; chips have the largest difference between in-stream and terrestrial decay rates and bark and heartwood sticks had the slowest rates of decay overall. The usefulness of this data is limited by the short duration of the study of this study and the limited methodology described.

Some studies show more mixed results. Hyatt and Naiman (2001) used increment cores of instream wood and riparian trees to identify the age of wood over 60 cm in diameter in the channel. They found that diameters of in-stream LWD were significantly larger than diameters of riparian trees as a whole for most tree species, indicating that smaller wood was disproportionately removed from the channel. However, their study did not identify the cause of wood disappearance in the channel and the results may be at least partially affected by the higher relative transport rates associated with smaller wood.

Other results reported by Hyatt and Naiman (2001) do not as strongly support the correlation between decay rates and wood size. They found no significant relationship between LWD fall age and diameter. This may indicate that factors other than decay affect in-stream wood accumulation and this may be influenced by the minimum 60cm diameter used in this study, a relatively small sample size, or varying wood input rates.

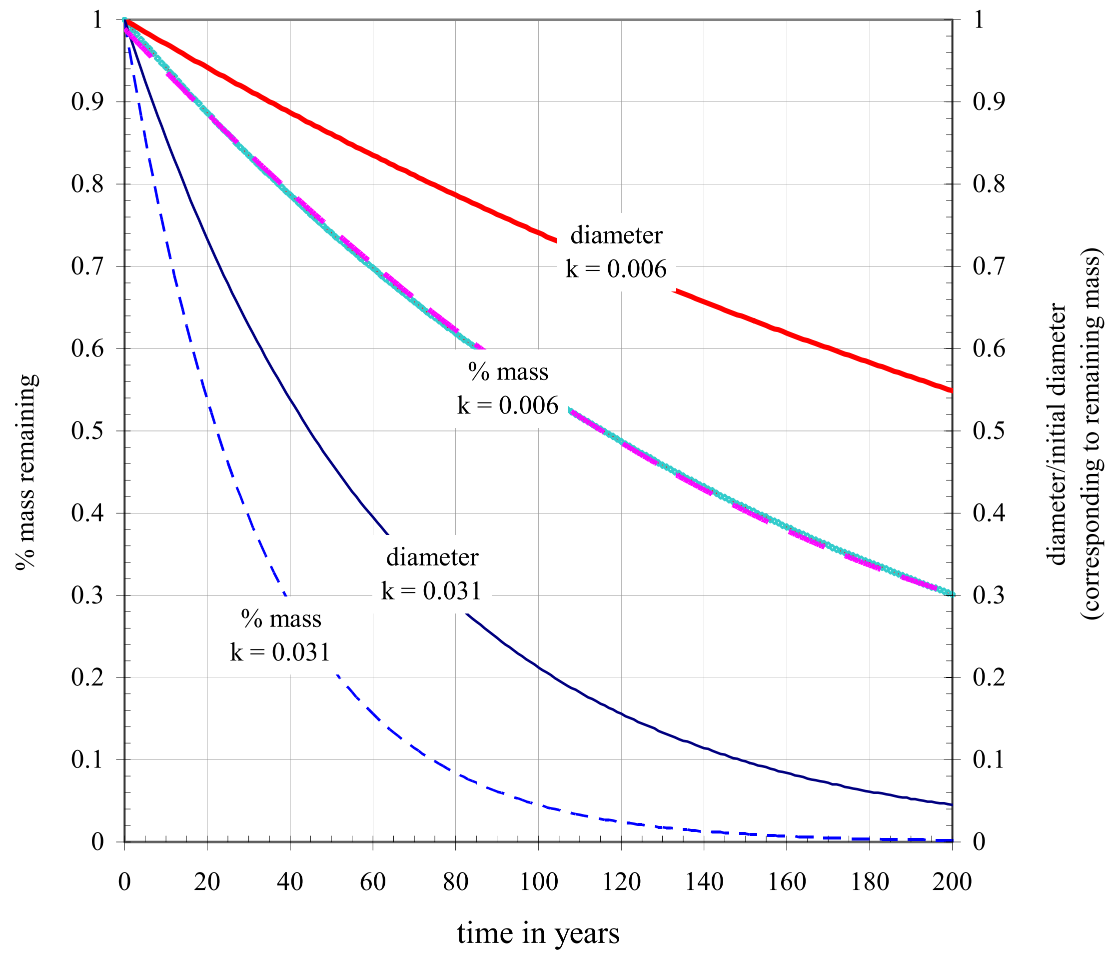

Figure 5.2-3. Empirical model of decay rates for Douglas-fir species submersed in the Queets River, Olympic Peninsula, Washington.
Source: Abbe (2000).

Harmon et al. (1986) summarizes studies that include wood piece size and terrestrial decay constants. Decay constants for tree species that are found in eastern Washington are listed in Table 5.2-2.

Table 5.2-2. Terrestrial decay rates from studies summarized by Harmon et al. (1986).

Common Name	Scientific Name	Study Type	Study Length (years)	Cause of Death	Diameter (cm)	Decay Constant (*k*)
Subalpine fir	*Abies lasiocarpa*	Snag-bole fragmentation	15	Fire	<7.5	0.317
Ponderosa pine	*Pinus ponderosa*	Snag-bole fragmentation	8	Bark beetles	<25	0.283
			8	Bark beetles	25-49	0.113
			8	Bark beetles	>50	0.161
			22	Fire	>20	0.073
			29	Bark beetles	>25	0.197
			29	Bark beetles	>25	0.112
			9	Bark beetles	<25	0.189
		Snag-bark fragmentation	8	Bark beetles	>1	0.005
Douglas-fir	*Pseudotsuga menziesii*	Snag-bole fragmentation	25	Unknown	10-18	0.354
			60	Unknown	29-31	0.109
			40	Unknown	32-46	0.033
			45	Unknown	47-71	0.055
			50	Unknown	<40	0.026
			30	Unknown	>65	0.014
		Log-bole fragmentation	250	Windthrow	>20	0.008
		Snag-bark fragmentation	50	Unknown	<40	0.11
			30	Unknown	>65	0.038
		Log-bark fragmentation	200	Windthrow	<40	0.039
			200	Windthrow	40-65	0.018
			250	Windthrow	>65	0.021
		Snag-bole mineralization	50	Unknown	<40	0.027
			30	Unknown	60-65	0.013
			30	Unknown	>65	0.003
		Log-bole mineralization	200	Windthrow	<40	0.004
			200	Windthrow	40-65	0.004
			250	Windthrow	>65	0.006
			320	Windthrow	>15	0.007

Yin (1999) analyzed 112 cases of terrestrial stem and branch LWD decay to create a model to calculate the decay rate of wood. This model was evaluated against 132 other reported decay rates. Yin's (1999) model incorporates species, air temperature and precipitation in January and July for forested sites, plus latitude and longitude for deforested sites to predict terrestrial decay rates. Yin's formula, however, does not include wood size. The significance of size is discussed by Yin as a possible control on wood decay, but wood size was not found to be a major factor in decay rates. Table 5.2-3 shows terrestrial decay constants associated with piece diameters summarized by Yin for species found in eastern Washington (although studies were not necessarily conducted there).

Table 5.2-3. Terrestrial decay rates from studies summarized by Yin (1999).

Common Name	Scientific Name	Location	Remnant WD	Study Length (years)	Type of Wood	Diameter (cm)	Decay Constant (*k*)
Subalpine fir	*Abies lasiocarpa*	Alberta	0.780	4	Branch	0.5	0.062
			0.868	4	Branch	2.25	0.035
			0.910	3	Root	0.05	0.031
			0.917	3	Root	1	0.029
Ponderosa pine	*Pinus ponderosa*	Kittitas, WA	0.889	7	Branch	1.5	0.017
			0.938	11	Branch	1.5	0.006
			0.865	15	Branch	1.5	0.010
			0.791	7	Branch	10	0.033
			0.830	11	Branch	10	0.017
			0.839	15	Branch	10	0.012
Douglas-fir	*Pseudotsuga menziesii*	W. WA	0.774	1	Branch	1.25	0.256
			0.734	2	Branch	1.25	0.155
			0.937	1	Branch	8	0.065
			0.887	2.1	Branch	8	0.057
			0.880	10	Stem	24	0.013
			0.776	10	Stem	37	0.025
		W. OR	0.850	2	Branch	1	0.081
			0.920	1	Branch	1	0.083
		W. OR	0.924	7	Stem	103	0.011
			0.704	17	Stem	113	0.021
			0.609	33	Stem	74	0.015
			0.498	82	Stem	57	0.009
			0.178	219	Stem	50	0.008
		W. OR	0.804	3	Stem	66	0.073
			0.715	11	Stem	52	0.030
			0.515	50	Stem	56	0.013
			0.315	87	Stem	36	0.013
		W. WA	0.909	2	Branch	1.5	0.048
			0.920	2	Branch	5	0.042
			0.956	2	Branch	10	0.022
			0.840	5	Branch	10	0.035
		W. WA	0.960	5	Branch	1.5	0.008
			0.937	8	Branch	1.5	0.008
			0.831	3	Branch	10	0.062
			0.865	5	Branch	10	0.029
			0.740	8	Branch	10	0.038

A model created by Mellen and Ager (2002) predicts the terrestrial decay constants for Douglas-fir and western hemlock logs and snags in western Washington. This model was created using data from six studies. Reported decay constants were related to log size (Table 5.2-4). Implicit to this model is diameter; the studies used to create this model indicated that slower decay constants are associated with larger diameters.

Table 5.2-4. Terrestrial log and fragmentation rates used in the Coarse Wood Dynamics Model.

Species [a]	Diameter Class (cm)	Decay Rate (*k*)	Fragmentation Rate [b] (kf)	Diameter Reduction Rate [b] (rd)	Length Reduction Rate [b] (rl)
DF	≤38.1	0.012	0.008	0.0031	0.0026
DF	15.2 – 38.1	0.015	0.010	0.0037	0.0030
DF	<15.2	0.026			
WH	≤38.1	0.019			
WH	15.2 – 38.1	0.023			
WH	<15.2	0.030			

Source: Mellen and Ager (2002).
[a] DF = Douglas-fir; WH = western hemlock.
[b] Fragmentation, diameter reduction, and length reduction rates apply to class 4 and 5 Douglas-fir logs only.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer the question.

Summary and Recommendations

Methods for documenting terrestrial decay rates are established. Terrestrial decay rates can be used to guide estimates of in-stream decay rates but cannot be used to determine actual in-stream decay constants. Few studies have been conducted on in-stream decay rates and no studies have explicitly tested decay rates of wood in streams in western or eastern Washington. Further study is needed to identify the affect of size on decay rates in eastern Washington.

For more precise information on the effect of size on decay rates, methods used to determine decay rates in western Washington and southeast Alaska could be improved upon and applied to studies of wood decay in eastern Washington streams. Studies using modifications to the methods described in Bilby et al. (1999) could best accomplish this task. To calculate decay rates within a reasonable timeframe, methods could be used with a variety of trees native to eastern Washington. Trees over a range of sizes, and, if possible, at a variety of initial decay conditions (pulled from local streams) could be subjected to typical river conditions for five years. Broken wood could also be used in this study, as many trees break when they fall. If possible, studies should also be conducted across a variety of stream sizes; the flow and stage differences between 1st and 5th order streams are likely to influence decay rates and processes.

References

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Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Hyatt, T.L. and R.J. Naiman. 2001. The residence time of large woody debris in the Queets river, Washington, USA. Ecological Applications 11(1):191-202.

Mellen, K. and A. Ager. 2002. A Coarse Wood Dynamics Model for the Western Cascades. Gen. Tech. Rep. USDA Forest Service.

Murphy, M.L. and K.V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North American Journal of Fisheries Management 9:427-436.

Triska, F.J. and K. Cromack, Jr. 1980. Role of wood debris in forests and streams. pp. 171-190 *in* Proceedings of the Annual Biology Colloquim (Oregon State University), No. 40. Forests: Presh Perspectives from Ecosystem Analysis. Edited by R.H. Waring. Oregon State University Press, Corvallis, Oregon.

Yin, X. 1999. The decay of forest woody debris: numerical modeling and implications based on some 300 data cases from North America. Oecologia 121:81-98.

5.3 Question 15 Response

Does decay rate vary with species of tree (e.g., cedar, pine, cottonwood)? (Summarize available numeric information.)

Summary of Literature Sources

Of the references reviewed, there were no quantitative studies found pertaining to eastern Washington or analogous regions; five quantitative studies were found relevant to the subject of the effect of species of trees on decay rates of wood in Pacific Northwest streams and in terrestrial areas. Table 5.3.1 provides a summary of these references.

Summary of Quantitative Data

No decay rate data is available for eastern Washington streams or analogous areas on decay rates of in-stream wood by species. Data from western Washington and other streams and terrestrial studies indicate that tree species is one of the greatest influences on decay rates. Nutrient availability varies between tree species as do decay-resistant chemical compositions and concentrations.

Terrestrial studies have shown marked differences between species-specific decay rates. Yin (1999) analyzed 112 cases of terrestrial stem and branch WD decay to create a model by which the decay rate of wood can be calculated. This model was evaluated against 132 other reported decay rates. Yin (1999) found that decay rate for terrestrial wood could be predicted by a maximum of five factors: species, air temperature and precipitation in January and July for forested sites, plus latitude and longitude for deforested sites. Species is such a dominant factor in decay that Yin's formula only requires species to estimate the decay rate when variables specific to location are accounted for. See Table 5.3-2 for terrestrial decay rates summarized by Yin (1999) for tree species that grow in eastern Washington (note that most decay rates reported by Yin were not measured in eastern Washington and that many studies used wood with diameters under 10 cm).

Harmon et al. (1986) also stresses the importance of species in predicting terrestrial decay rates. Typically, softwoods are more resistant to decay than hardwoods because softwoods have less nutrient rich living tissue and contain more potent decay-inhibiting extractives than hardwoods. The amount of living tissue, the type of tissue, and the quantity and potency of extractives also varies at the species level. For example, extractives specific to western redcedar (*Thuja plicata*) make it very decay resistant. Additionally, the proportion of bark, sapwood, and heartwood, which have different decay rates, varies with tree species. Heartwood contains more decay-inhibiting extractives and less decay-promoting sugars and proteins than other types of wood (Harmon et al. 1986). The decay resistance of heartwood and other wood components varies considerably between species, where extractive quantities and the effectiveness of extractives are not consistent.

Table 5.3-1. Summary of literature sources containing data relevant to question 15.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach									
Bilby et al. 1999	3rd order stream - Tributary to Deschutes River, WA	ND [c]	WW	Douglas-fir, western redcedar, western hemlock, red alder, bigleaf maple	ND	ND	ND	S, Q	Yes
Hyatt and Naiman 2001	Queets River, WA	1,157	WW	Sitka spruce, Douglas-fir, western hemlock, and black cottonwood	ND	Alluvium	Unmanaged	S, Q	Yes
Yin 1999	Multiple	Multiple	N Am.	ND	ND	ND	ND	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

Table 5.3-2. Terrestrial decay rates from studies summarized by Yin (1999).

Common Name	Scientific Name	Location	Remnant WD	Study Length (years)	Type of Wood	Diameter (cm)	Decay Constant (*k*)
Subalpine fir	*Abies lasiocarpa*	Alberta	0.780	4	Branch	0.5	0.062
			0.868	4	Branch	2.25	0.035
			0.910	3	Root	0.05	0.031
			0.917	3	Root	1	0.029
Ponderosa pine	*Pinus ponderosa*	Kittitas, WA	0.889	7	Branch	1.5	0.017
			0.938	11	Branch	1.5	0.006
			0.865	15	Branch	1.5	0.010
			0.791	7	Branch	10	0.033
			0.830	11	Branch	10	0.017
			0.839	15	Branch	10	0.012
Douglas-fir	*Pseudotsuga menziesii*	W. WA	0.774	1	Branch	1.25	0.256
			0.734	2	Branch	1.25	0.155
			0.937	1	Branch	8	0.065
			0.887	2.1	Branch	8	0.057
			0.880	10	Stem	24	0.013
			0.776	10	Stem	37	0.025
		W. OR	0.850	2	Branch	1	0.081
			0.920	1	Branch	1	0.083
		W. OR	0.924	7	Stem	103	0.011
			0.704	17	Stem	113	0.021
			0.609	33	Stem	74	0.015
			0.498	82	Stem	57	0.009
			0.178	219	Stem	50	0.008
		W. OR	0.804	3	Stem	66	0.073
			0.715	11	Stem	52	0.030
			0.515	50	Stem	56	0.013
			0.315	87	Stem	36	0.013
		W. WA	0.909	2	Branch	1.5	0.048
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			0.956	2	Branch	10	0.022
			0.840	5	Branch	10	0.035
		W. WA	0.960	5	Branch	1.5	0.008
			0.937	8	Branch	1.5	0.008
			0.831	3	Branch	10	0.062
			0.865	5	Branch	10	0.029
			0.740	8	Branch	10	0.038

Harmon et al. (1986) summarizes terrestrial decay rates reported by a number of studies. The studies are grouped by fragmentation, which is the rate at which snags and logs fall or fragment, and mineralization, which is the rate at which wood changes in density due to respiration and leaching. Table 5.3-3 summarizes terrestrial decay rates for species found in eastern Washington (note that many of these studies were not necessarily conducted in eastern Washington and that many studies used wood under 10 cm in diameter).

Table 5.3-3. Terrestrial decay rates from studies summarized by Harmon et al. (1986).

Common Name	Scientific Name	Study Type	Study Length (years)	Cause of Death	Diameter (cm)	Decay Constant (*k*)
Subalpine fir	*Abies lasiocarpa*	Snag-bole fragmentation	15	Fire	<7.5	0.317
Ponderosa pine	*Pinus ponderosa*	Snag-bole fragmentation	8	Bark beetles	<25	0.283
			8	Bark beetles	25-49	0.113
			8	Bark beetles	>50	0.161
			22	Fire	>20	0.073
			29	Bark beetles	>25	0.197
			29	Bark beetles	>25	0.112
			9	Bark beetles	<25	0.189
		Snag-bark fragmentation	8	Bark beetles	>1	0.005
Douglas-fir	*Pseudotsuga menziesii*	Snag-bole fragmentation	25	Unknown	10-18	0.354
			60	Unknown	29-31	0.109
			40	Unknown	32-46	0.033
			45	Unknown	47-71	0.055
			50	Unknown	<40	0.026
			30	Unknown	>65	0.014
		Log-bole fragmentation	250	Windthrow	>20	0.008
		Snag-bark fragmentation	50	Unknown	<40	0.11
			30	Unknown	>65	0.038
		Log-bark fragmentation	200	Windthrow	<40	0.039
			200	Windthrow	40-65	0.018
			250	Windthrow	>65	0.021
		Snag-bole mineralization	50	Unknown	<40	0.027
			30	Unknown	60-65	0.013
			30	Unknown	>65	0.003
		Log-bole mineralization	200	Windthrow	<40	0.004
			200	Windthrow	40-65	0.004
			250	Windthrow	>65	0.006
			320	Windthrow	>15	0.007

In-stream Findings

In-stream research also shows the relationship between species and decay rate.

Bilby et al. (1999) found that relative decay rates between species for fresh cut, submerged pieces of wood were consistent with decay rates for terrestrial wood. Logs of standard dimensions from five species of trees (red alder, western redcedar, Douglas-fir, western hemlock, and bigleaf maple) were placed in a 3rd order stream for five years to evaluate changes in strength and decomposition. Wood was submerged for the duration of the study. Density of interior wood did not change measurably for any of the wood over the course of the study. Exterior decay rates were lower than terrestrial rates, particularly after the first year when the bark, which is highly prone to decay, decayed (Table 5.3-4). Over 75 percent of the diameter decrease in the Douglas-fir and western redcedar was due to bark loss, while only 40 percent of the diameter decrease for the bigleaf maple was attributable to bark loss. Bilby et al. (1999) found lower rates of decay for the coniferous species in his study, which conforms to terrestrial observations, and found significantly faster decay rates for the maple logs. However, the variability between observed in-stream decay rates was less than the variability reported in terrestrial studies. This suggests that, at least initially, tree species may not influence in-stream decay rates as much as it influences terrestrial decay rates.

Table 5.3-4. Decrease in diameter and decay rate constants (*k*) for wood from five species of trees submerged in water for 5 years.

Species	Diameter Loss after 5 Years (mm) +/- one standard error	Decay Rate Constant (*k*)	Terrestrial Decay Constant
Douglas-fir	13.0 +/- 2.7	0.026	0.014 to 0.354 [a]
Western redcedar	13.2 +/- 4.2	0.026	
Western hemlock	10.6 +/- 4.9	0.031	0.0671
Red alder	14.3 +/- 4.0	0.033	0.49 to 0.520 [b]
Bigleaf maple	21.8 +/- 6.3	0.038	0.49 to 0.520 [b]

Source: Modified from Bilby (2003) and Bilby (1999).
[a] Smaller boles like those used in Bilby (1999) exhibit faster terrestrial decay rates.
[b] Range of values for other hardwood species.

Other research indicates that tree species does influence in-stream decay rates. Hyatt and Naiman (2001) found a correlation between terrestrial coniferous and hardwood decay rates reported by others and in-stream attrition rates. Hyatt and Naiman (2001) surveyed and recorded the species of the wood in the channel and of the trees on the surrounding banks. The proportion of coniferous to hardwood LWD in the channel was greater than the proportion of coniferous to hardwood trees in the recruitable riparian community. However, these results are confounded by the downstream transport of wood; hardwood LWD attrition may be a result of hardwoods propensity to break and consequently wash downstream. This study did not identify how wood was removed from the channel. However, other results support the case for varying attrition rates resulting from varying decay rates: The relative ratio of in-channel to recruitable LWD for each tree species was consistent with decay rates reported by Harmon et al. (1986); species that have relatively high terrestrial decay rates were less likely to be in the channel than species with relatively low terrestrial decay rates (Figure 5.3-1).

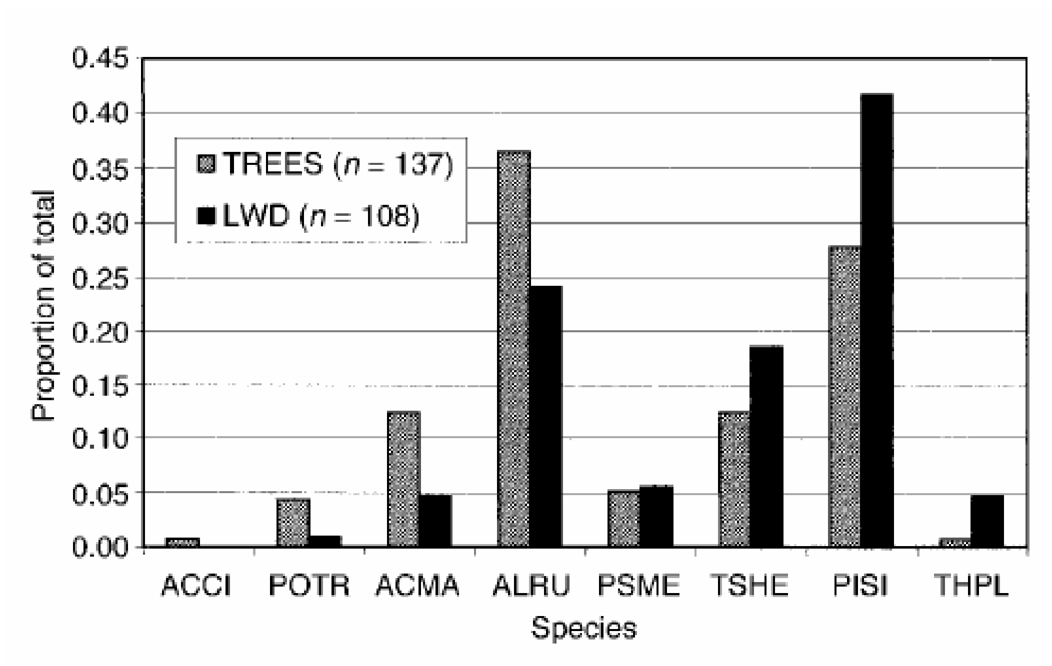

Figure 5.3-1. Relative abundance of LWD vs. riparian trees, by species (30 cm diameter and larger).
Species codes: ACCI, *Acer circinatum* (vine maple); ACMA, *Acer macrophyllum* (bigleaf maple); ALRU, *Alnus rubra* (red alder); PISI, *Picea sitchensis* (Sitka spruce); POTR, *Populus trichocarpa* (black cottonwood); PSME, *Pseudotsuga menziesii* (Douglas-fir); THPL, *Thuja plicata* (western redcedar); TSHE, *Tsuga heterophylla* (western hemlock). Figure from Hyatt and Naiman (2001), Figure 1.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer the question.

Summary and Recommendations

Methods for documenting terrestrial decay rates are established and terrestrial decay rates for specific species are reasonably well known. Terrestrial decay rates can be used as to guide estimates of in-stream decay rates and as a guide to determine what types of wood will last longer or shorter in streams. Few studies have identified species-specific, in-stream decay rates and no studies have been conducted in eastern Washington. Further study is needed to identify decay rates in eastern Washington.

The methods used to determine decay rates in western Washington could be improved upon and be applied to wood in eastern Washington streams to determine species-specific decay rates. A few studies using modifications to the methods described in Bilby (1999) could best identify decay rates. The decay rates of multiple species and each component of a tree (bark, sapwood, heartwood) should be measured by stripping the exterior and submerging the wood. Studies should use locally cut wood and, if possible, should also be conducted across a variety of stream sizes; the differences between 1st and 5th order streams is likely to dramatically influence decay rates.

Another aspect of decay that should be researched is the decay rate of wood that is intermittently exposed to air. This could also be accomplished by modifying the methods used by Bilby (1999). One population of LWD would be left submerged for the entire 5 year period. Another population could be pulled out of the water once or more per year for a set time-span. This could identify decay rates that more accurately reflect in-stream LWD.

References

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Bilby, R.E., J.T. Heffner, B.R. Fransen, J.W. Ward, and P.A. Bisson. 1999. Effects of immersion in water on deterioration of wood from five species of trees used for habitat enhancement projects. North American Journal of Fisheries Management 19:687-695.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

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Triska, F.J. and K. Cromack, Jr. 1980. Role of wood debris in forests and streams. pp. 171-190 *in* Proceedings of the Annual Biology Colloquim (Oregon State University), No. 40. Forests: Presh Perspectives from Ecosystem Analysis. Edited by R.H. Waring. Oregon State University Press, Corvallis, Oregon.

Yin, X. 1999. The decay of forest woody debris: numerical modeling and implications based on some 300 data cases from North America. Oecologia 121:81-98.

5.4 Question 16 Response

Does the cause of tree fall/mortality influence decay rate (fire-scarred wood vs. disease-killed trees)? (Summarize available numeric information, and/or qualitative datasets [e.g., repeat imagery] in support of quantitative outcomes.)

Summary of Literature Sources

Of the references reviewed, there were no quantitative studies found pertaining to eastern Washington or analogous regions; two quantitative studies were found relevant to the subject of the effect of tree fall/mortality on terrestrial decay rates of wood in the Pacific Northwest. Table 5.4-1 provides a summary of these references.

Summary of Quantitative Data

No decay rate data is available for eastern Washington streams or analogous areas on the effect of cause of mortality on decay rates of wood. Very limited datasets, which were not created to explicitly measure this, indicate that the cause of mortality does control decay rates to some extent.

Physical Analysis

Wood decays more slowly in streams than it does on land due to water saturation that reduces oxygen availability below the wood surface, which in turn prevents fungal growth (discussed in Bilby et al. 1999). As a result, decay occurs only on the surface of submerged wood, and therefore at a relatively slow rate. Any organism or event that creates more surface area on a submerged log will cause decay to accelerate. Disease and insect killed trees may have more surface area on which microbial decay can occur in-stream. Fires do not necessarily cause great harm to wood; Boyce (1961) states that the actual loss by direct burning is seldom more than three percent of gross volume (cited in Lyon 1977).

Harmon et al. (1986) reports decay constants from terrestrial studies on trees that were killed by bark beetles, cutting, defoliation, fire, fir-waves and windthrow. Where cause of mortality differed between trees of the same species (tree type is a major factor in decay rate; see Question 15 response for more information), decay rates appear to be affected. Of these studies, seven were conducted on *Pinus ponderosa* and the cause of mortality of six of these was bark beetles, the other was fire. The terrestrial decay constants reported for trees killed by bark beetles ranged from 0.112 to 0.283, while the decay constant was 0.073 for the tree killed by fire.

Harmon et al. (1986) summarizes terrestrial decay rates reported by a number of studies. Harmon groups studies by fragmentation, which is the rate at which snags and logs fall or fragment, and mineralization, which is the rate at which wood changes in density due to respiration and leaching. Table 5.3-3 summarizes terrestrial decay rates for species found in

Table 5.4-1. Summary of literature sources containing data relevant to question 16.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach									
Harmon et al. 1986	Various	ND [c]	ND	ND	ND	ND	ND	S	Y

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

eastern Washington (note that many of these studies were not necessarily conducted in eastern Washington and that many studies used wood under 10 cm in diameter).

Table 5.4-2. Terrestrial decay rates from studies summarized by Harmon et al. (1986).

Common Name	Scientific Name	Study Type	Study Length (years)	Cause of Death	Diameter (cm)	Decay Constant (*k*)
Subalpine fir	*Abies lasiocarpa*	Snag-bole fragmentation	15	Fire	<7.5	0.317
Ponderosa pine	*Pinus ponderosa*	Snag-bole fragmentation	8	Bark beetles	<25	0.283
			8	Bark beetles	25-49	0.113
			8	Bark beetles	>50	0.161
			22	Fire	>20	0.073
			29	Bark beetles	>25	0.197
			29	Bark beetles	>25	0.112
			9	Bark beetles	<25	0.189
		Snag-bark fragmentation	8	Bark beetles	>1	0.005
Douglas-fir	*Pseudotsuga menziesii*	Snag-bole fragmentation	25	Unknown	10-18	0.354
			60	Unknown	29-31	0.109
			40	Unknown	32-46	0.033
			45	Unknown	47-71	0.055
			50	Unknown	<40	0.026
			30	Unknown	>65	0.014
		Log-bole fragmentation	250	Windthrow	>20	0.008
		Snag-bark fragmentation	50	Unknown	<40	0.11
			30	Unknown	>65	0.038
		Log-bark fragmentation	200	Windthrow	<40	0.039
			200	Windthrow	40-65	0.018
			250	Windthrow	>65	0.021
		Snag-bole mineralization	50	Unknown	<40	0.027
			30	Unknown	60-65	0.013
			30	Unknown	>65	0.003
		Log-bole mineralization	200	Windthrow	<40	0.004
			200	Windthrow	40-65	0.004
			250	Windthrow	>65	0.006
			320	Windthrow	>15	0.007

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer the question.

Summary and Recommendations

The effects of fire on the decay rate of wood in eastern Washington streams should be relatively easy to document. Harmon et al. (1986) measured the decay rate of fire-killed wood because the date of death was consistent and known. Decay rates of fire-killed trees could be identified by visiting a basin soon after a fire, measuring wood volumes and diameters, tagging wood, and returning yearly. A control group could be wood placed in-stream in a nearby basin that was not burned. The methods described by Bilby et al. (1999) could be used to adequately describe the decay rate.

References

Bilby, R.E., J.T. Heffner, B.R. Fransen, J.W. Ward, and P.A. Bisson. 1999. Effects of immersion in water on deterioration of wood from five species of trees used for habitat enhancement projects. North American Journal of Fisheries Management 19:687-695.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

6.0 Wood Transport

6.1 Question 17 Response

What are the mechanisms for the transport of wood downstream? Provide any available quantitative (numeric) information regarding the rates of downstream transport. Document qualitative (imagery) information that supports these datasets.

Summary of Literature Sources

Of the references reviewed, a total of 14 were found that had quantitative and/or descriptive information relating to transport mechanisms; of these, one had information relevant to eastern Washington, two had information from analogous regions, and 11 were analogous process-based studies. Table 6.1-1 provides a summary of these references.

Summary of Quantitative Data

The mechanisms for transport of wood downstream can be summarized in two main categories: stream flow and debris flow. Transport of wood by stream flow occurs when there is sufficient flow depth (buoyancy) and velocity (drag) to overcome the resisting forces (channel slope, obstructions, substrate) acting on the wood. These conditions typically occur in higher order channels, where logs are unconstrained by channel banks. Thus stability is a function of buoyancy, friction, flow and a deformable bed (Abbe 2000). In some cases, larger, key pieces of wood may become the dominant resisting forces on smaller wood. Wood mobility tends to increase as channel depth and width increases relative to the diameter and length of wood (Abbe 2000, Abbe et al. 2003). The relationship between wood mobility, wood size, and channel size is discussed in more detail in the Question 18 response.

In steep, ephemeral, headwater channels, where log length usually exceeds channel width, resistance to movement will be provided by channel banks (Abbe 2000). A log spanning a low-order, headwater channel will, most likely, not move unless it is broken, thus it is the material strength of the log that controls its stability (Abbe 2000).

Looking at low-order confluences, Benda et al. (2003) found the majority of instream wood originated from debris flows. Debris flows occur at a frequency of approximately 500 years. Considering the vast quantity of wood accumulated within the 500-year cycle, Benda and Sias (1998) consider debris flows to yield the single largest point source of wood to high-order channels.

Braudrick, et al. (1997) described three regimes for the transport of wood in a flume experiment: uncongested, semi-congested, and congested. Specific patterns of transport are present within each regime. During congested transport there is pulsed movement, and during uncongested transport there is gradual accumulation on bars. Semi-congested transport included both pulsed movement and gradual accumulation on bars. The highest piece transport rates occurred during

Table 6.1-1. Summary of literature sources containing data relevant to question 17.

Reference	Location	Drainage Area (km^2)	Region[a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Studies in Eastern Washington									
Fox 2001	Tributaries to the Naches, Cle Elum, Wenatchee, Methow, and Stehekin River basins	0.9 – 186	SC, NC, CB	Subalpine fir, grand fir, Douglas-fir/ponderosa pine	0.2 – 47%	Alluvial and bedrock	Unmanaged	S	Yes
Studies in Analogous Regions									
Lienkaemper and Swanson 1987	H.J. Andrews Experimental Forest, Willamette NF, OR	0.1 – 60.5		Douglas-fir, western hemlock, western redcedar	3 – 37	Tertiary volcanic rock- boulders	Unmanaged	S,Q,O	YES
Young 1994	NW Wyoming- Crow Creek and Jones Creek	49.46, 64.23			4.1, 5.5	Absaroka Volcanic rock- cobble/rubble	Fire activity (one site)	Q, S	YES
Analogous Process-based Approach									
Benda et al. 2003	Olympic Mountains, WA	1 – 16	WW	Unknown	2.5 – 8	Marine sedimentary and basaltic rocks	Managed and Unmanaged	Q,S	YES
Berg, T. et al. 1998	Sierra Nevada, CA	8.3 – 25		Mixed conifer and red fir, east-side pine	Unknown	cobbles, boulders, bedrock	Managed	S,Q	YES
Grette 1985	Olympic Peninsula, WA	3.4 – 12.4		Western hemlock; Sitka spruce; western redcedar; Douglas-fir; red alder	0.5 – 2.0		Managed and Unmanaged	S,Q,O	YES
Murphy and Koski	SE Alaska	Low flow channel widths: 8.2 – 31.4m		Western hemlock, Sitka spruce	0.4 – 3	Alluvium and bedrock	Unmanaged	S,O	YES
Abbe 2000	Queets River, Olympic Peninsula, WA; quantitative models	1,164	WW	Sitka spruce, Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple, black cottonwood	0.01 – 0.25	Tertiary marine sandstones and shales	Unmanaged and Managed??	S,Q,O	YES
Abbe and Montgomery 1996	Queets River, Olympic Peninsula, WA	1,164	WW	Sitka spruce, Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple, black cottonwood	0.01 – 0.25	Tertiary marine sandstones and shales	Unmanaged and Managed??	S,Q,O	YES

Table 6.1-1. Summary of data available to answer question 17 (continued).

Reference	Location	Drainage Area (km^2)	Region[a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach (continued)									
Diehl 1997	Literature review of drift accumulations at bridges for various locations around the world			N/A	N/A	N/A	N/A	Q	NO
Braudrick, C.A. et al. 1997	Flume experiment	N/A	N/A	N/A	N/A	N/A	N/A	Q,S	YES
Benda and Sias 1998	Theoretical study	N/A	N/A	N/A	N/A	N/A	N/A	Q	NO
Gurnell, A.M. et al. 2002	Qualitative review								

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington

[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

pulsed movement. Individual logs moved by rolling, sliding, or when flow was deep enough, floating. Floating was the most common mode of transport observed (Braudrick, et al. 1997). Diehl (1997) found that most floating pieces move downstream in a zone of convergence at average water velocity; submerged pieces are carried to the banks and bars by slower, diverging near-bed flow.

Very little quantitative and empirical data exists regarding the rates of downstream transport of wood. One study was found for eastern Washington, and several studies were found for analogous regions.

Fox (2001) studied the effect of debris flows on the distribution of wood in eastern and western Washington streams. Although, transport rates were not explicitly collected, Fox does have data for the quantity and volume of wood per 100m for streams with debris flow disturbance and streams without disturbance. Channels were separated into gradient classes to distinguish between transport (>10 percent) and depositional (<6 percent) reaches. In channels with gradients greater than 10 percent, median quantities and volumes of wood per 100m were less in channels experiencing debris flows than channels with no recent disturbance. In channels with gradient < 6 percent median quantities and volumes of wood per 100m were roughly the same between channels that have experienced recent debris flows and those that had not. Although the results found are not statistically significantly, they illustrate a potential association that would require further research to be substantiated.

Lienkaemper and Swanson (1987) studied the dynamics of LWD in old-growth Douglas-fir forests. Their study sites were located in the Andrews Experimental Forest, Oregon. LWD was mapped in 1975, 1976, 1977, and 1984; changes in log position and rate of introduction of new logs were noted. Logs were not tagged; and recognition was based on shape, location, and distinctive characteristics. Woody debris in this study was defined as logs with diameter ≥ 10cm, and length ≥ 1.5m. Data from Lienkaemper and Swanson (Table 6.1-2) show transport rates of 0.78-9.32 percent of wood pieces moved per year. Using data from Lienkaemper and Swanson (1987), Figure 6.1-1 displays percentage of pieces moved per year relative to basin size. Pieces included in the original survey effort, "initial pieces" (closed squares), and pieces delivered to the reach during the study duration, "recruited pieces" (open squares) are included in the figure. As shown in Figure 6.1-1, more data are needed, specifically over a greater range of drainage basins sampled, to verify a significant relationship. Lienkaemper and Swanson collected data for distances wood pieces traveled, but the raw data were not included in the 1989 publication.

Young (1994) studied wood transport in burned and unburned watersheds in Wyoming. In-stream woody debris (length ≥ 2.0m, diameter ≥ 15cm) was measured and tagged in August, 1990. The distance and compass bearing to reference trees corresponding to tagged pieces were noted and each tagged piece and reference tree was photographed. In September, 1991, each reference tree and the original location of each tagged piece was relocated. In-stream wood was inspected for tags and, when found, the distance to the original reference tree was measured. Relocated pieces were considered mobile if the orientation had changed or the distance to reference tree had changed by at least 0.5m.

Table 6.1-2. Summary of woody debris redistribution by study site.
Data from Lienkaemper and Swanson (1987).

Study Site	Duration of Sampling Interval (years)	Drainage Area (km2)	Stream Gradient (percent)	Reach Length (m)	Mean Bankfull Width (m)	Φ (reach length / bfw width)	Number of Pieces Mapped / Φ	Number of Pieces Moved / Φ	Percent of Pieces Moved/Year	Number of Pieces Recruited / Φ	Number of Recruited Pieces Moved / Φ	Percent of Recruited Pieces Moved/Year
Watershed 9	8	**0.1**	37	170	3.5	49	1.7	0.10	**0.78**	0.25	0	**0**
Watershed 2	8	**0.8**	26	146	5.2	28	3.1	0.25	**1.0**	0.53	0	**0**
Mack Creek [a]	9	**6**	13	332	11.9	28	3.8	1.9	**5.6***	1.5	0.65	**4.7***
Upper Lookout Creek	9	**11.7**	8	483	15.5	31	9.8	1.3	**1.5**	0.7	0.16	**2.7**
Lower Lookout Creek	7	**60.5**	3	350	24	15	3.2	2.1	**9.3**	0.8	0.41	**7.1**

[a] Mack Creek experienced a 10-year flow event during the sampling period.

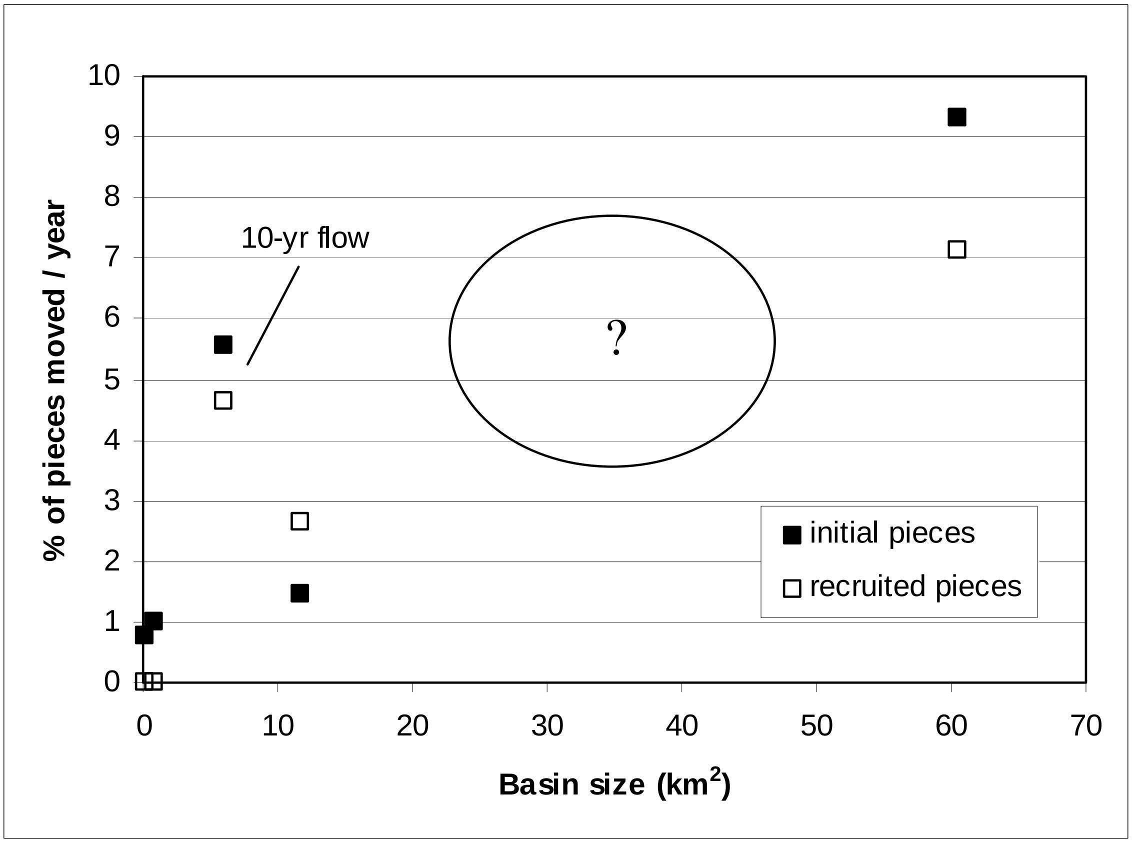

Figure 6.1-1. Percentage of wood pieces moved per year for old-growth streams in western Cascades of Oregon.
Closed squares represent data from initial mapped wood; open squares represent wood that was recruited to the site through various mechanisms. Mack Creek (drainage area = 6 km^2) experienced a 10-year flow event during the sampling period; the flow in all other sites was less than a 10-year flow event. The question mark in the middle represents the need for additional wood transport data for a greater range of basin sizes. Data from Lienkaemper and Swanson, 1987.

Transport rates for the two sites, in Young (1994), varied significantly. In the burned site, 58 percent of tagged pieces moved in one year and the mean distance traveled was 95.3m. In the unburned site, 18 percent of tagged pieces moved in one year and the mean distance traveled was 21.9m. Note that, in order to make comparisons between different sites, reach length and bankfull width are needed to normalize the transport rates.

Several additional studies have data on transport rates in the form of percent of pieces moved/year and distance moved/year, but are not in analogous regions and would need further analysis to evaluate the significance of relationships (Grette 1985; Murphy and Koski 1989; Berg et al. 1998)

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. The development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

There are two main mechanisms for the transport of wood downstream: streamflow, effective mainly in higher-order streams; and debris flows, effective mainly in lower-order streams. Transport rates of woody debris have not been quantified for eastern Washington, but several studies in analogous regions address transport rates. Young (1994) found transport rates of 58 percent and 18 percent of wood pieces moved per year for burned and unburned locations, respectively. Lienkaemper and Swanson (1987) show transport rates between 0.78 percent and 9.3 percent of wood pieces moved per year (Table 6.1-2), for an old-growth Douglas-fir forest in Oregon. There are specific uncertainties regarding the methodology used in this study, and these should be addressed when performing further research. The first is whether the authors counted missing pieces as pieces that have moved. Another question is the origin of the added pieces and whether they came from upstream of reach or from the banks within the reach.

The transport rate of woody debris is highly dependent on several variables, including: the characteristics of the wood piece (length, diameter, shape, and buoyancy), and channel characteristics (width, depth, sinuosity, stream order, velocity/discharge, flow regime, grain size of substrate, and depth of substrate). Several of these variables have been addressed by the studies mentioned above and are examined in more detail in Question 18. Another important factor that can change wood transport rates dramatically and should be quantified in wood transport studies are features that catch and accumulate wood in a reach (key log, boulder, bar, bank) (Abbe 1996). The importance of key wood (functional wood) is discussed in detail in Question 19. Another important factor for consideration is the flood history experienced by the study reach during the period of observation. The impacts of peak flow events on instream wood loading include local recruitment due to bank erosion and downstream flushing. Observations of Washington rivers indicate that the number of pieces in a reach can increase dramatically following a high flow event showing that local inputs have exceeded downstream transport (Abbe, unpublished).

Further analysis will need to be performed on the studies mentioned above (analogous regions) and on-going wood budget studies (e.g., Stillaguamish and Elwha River studies). Based on these and recent theoretical studies, there exists a good foundation for development of field protocols to assess wood transport in eastern Washington.

References

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Berg, N., A. Carlson, and D. Azuma. 1998. Function and dynamics of woody debris in stream reaches in the central Sierra Nevada, California. Canadian Journal of Fisheries and Aquatic Sciences 55:1807-1820.

Braudrick, C.A., G.E. Grant, Y. Ishikawa, and H. Ikeda. 1997. Dynamics of wood transport in streams; a flume experiment. Earth Surface Processes and Landforms 22(7): 669-683.

Diehl, T.H. 1997. Potential drift accumulation at bridges. Report No. FHWA-RD-97-028. U.S. Geological Survey, Water Resources Division, Nashville, Tennessee.

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

Young, M.K. 1994. Movement and characteristics of stream-borne coarse woody debris in adjacent burned and undisturbed watersheds in Wyoming. Canadian Journal of Forest Resources 24:1933-1938.

6.2 Question 18 Response

Does the rate of transport vary with wood size, stream size, or channel morphology? If so, how? Quantify.

Summary of Literature Sources

Of the references reviewed, a total of 16 studies were found that had quantitative and/or descriptive information relating to controlling factors on the rate of transport of wood. Of these, none had information relevant to eastern Washington, three contained data from analogous regions, and 13 were analogous process-based studies. Table 6.2-1 provides a summary of these references.

Summary of Quantitative Data

Effect of Wood Size and Stream Size on Wood Transport

There were no studies found relating wood size and stream size to wood transport for eastern Washington streams.

Studies in Analogous Regions

Lienkaemper and Swanson (1987), as discussed in Question 17, studied the dynamics of LWD in old-growth Douglas-fir forests. They found that piece length relative to bankfull width is an important factor in its mobility. Figure 6.2-1, from Lienkaemper and Swanson (1987), shows that during an estimated 10-year flow event, pieces with lengths less than bankfull width moved farther than pieces with lengths greater than or equal to bankfull width. They also found that higher transport rates occurred in larger streams (Table 6.1-2). In larger streams, 10 to18 percent of pieces were longer than bankfull width, in contrast with smaller streams, where 23 to 29 percent of pieces exceeded bankfull width.

Young (1994), as mentioned in Question 17, studied wood transport in burned and unburned watersheds in Wyoming. He found characteristic differences between mobile and stable pieces for both burned and unburned sites. Debris length was significantly different between mobile and stable debris in Crow Creek, and debris volume was significantly different between mobile and stable debris in both Jones and Crow Creek (Figure 6.2-2).

Analogous Process-based Approaches

Bilby (1984) studied effects of woody debris removal on stream channel stability in the Coast Range of Washington. In a 600m-study reach, seventy-four pieces of wood were tagged and monitored throughout one winter season. Diameter, length, degree of anchoring/burial, and distance to reference bank marker for each tagged piece of debris was measured. After each high flow event during the 1980-1981 winter season, tagged pieces were relocated and positions

Table 6.2-1. Summary of literature sources containing data relevant to question 18.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Studies in Analogous Regions									
Lienkaemper and Swanson 1987	H.J. Andrews Experimental Forest, Willamette NF, OR	0.1 – 60.5		Douglas-fir, western hemlock, western redcedar	3 – 37	Tertiary volcanic rock-boulders	Unmanaged	S,Q,O	Yes
Young, M.K. 1994	NW Wyoming- Crow Creek and Jones Creek	49.46, 64.23			4.1, 5.5	Absaroka Volcanic rock-cobble/rubble	Fire activity (one site)	Q, S	Yes
Marcus, W.A. et al. 2002	Yellowstone Ecosystem	14.1 – 242.7		Blue spruce, cottonwood, lodgepole pine	0.088 – 2.9	Gravel to cobble	Fire activity		Yes
Analogous Process-based Approach									
Murphy and Koski 1989	SE Alaska	Low flow channel widths: 8.2 – 31.4m		Western hemlock, Sitka spruce	0.4 – 3	Alluvium and bedrock	Unmanaged	S,O	Yes
Grette, G.B. 1985	Olympic Peninsula, WA	3.4 – 12.4		Western hemlock; Sitka spruce; western redcedar; Douglas-fir; red alder	0.5 – 2.0		Managed and Unmanaged	S,Q,O	Yes
Berg, T. et al. 1998	Sierra Nevada, CA	8.3 – 25		Mixed conifer and red fir, east-side pine	Unknown	Cobbles, boulders, bedrock	Managed	S,Q	Yes
Bilby, R.E. 1984	Coast Range, WA	9	WW	Unknown	1.5	Unknown	Managed	S	Yes
Abbe, T.B. 2000	Queets River, Olympic Peninsula WA; quantitative models	1,164	WW	Sitka spruce, Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple, black cottonwood		Tertiary marine sandstones and shales	Unmanaged and Managed??	S,Q,O	Yes

Table 6.2-1. Summary of literature sources containing data relevant to question 18 (continued).

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach (continued)									
Abbe and Montgomery 2003	Queets River, Olympic Peninsula WA; quantitative models	724	WW	Sitka spruce, Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple, black cottonwood	1.3 – 69	Tertiary marine sandstones and shales	Unmanaged and Managed??	S,Q	Yes
Millard, T. 2001	Anderson River watershed, Cascades								
Diehl 1997	Literature review of drift accumulations at bridges for various locations around the world	N/A	N/A	N/A	N/A	N/A	N/A	Q	No
Benda and Sias 1998	Theoretical study	N/A	N/A	N/A	N/A	N/A	N/A	Q	No
Benda and Sias 2003	Theoretical equations for wood transport	N/A	N/A	N/A	N/A	N/A	N/A	Q	Yes
Braudrick, C.A. and G.E. Grant 2000	Theoretical model and flume study	N/A	N/A	N/A	N/A	N/A	N/A	Q,S	Yes
Braudrick, C.A. and G.E. Grant 2001	Flume experiment	N/A	N/A	N/A	N/A	N/A	N/A	Q,S	Yes
Gurnell, A.M. et al. 2002	Qualitative review	N/A	N/A	N/A	N/A	N/A	N/A	Q	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington

[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

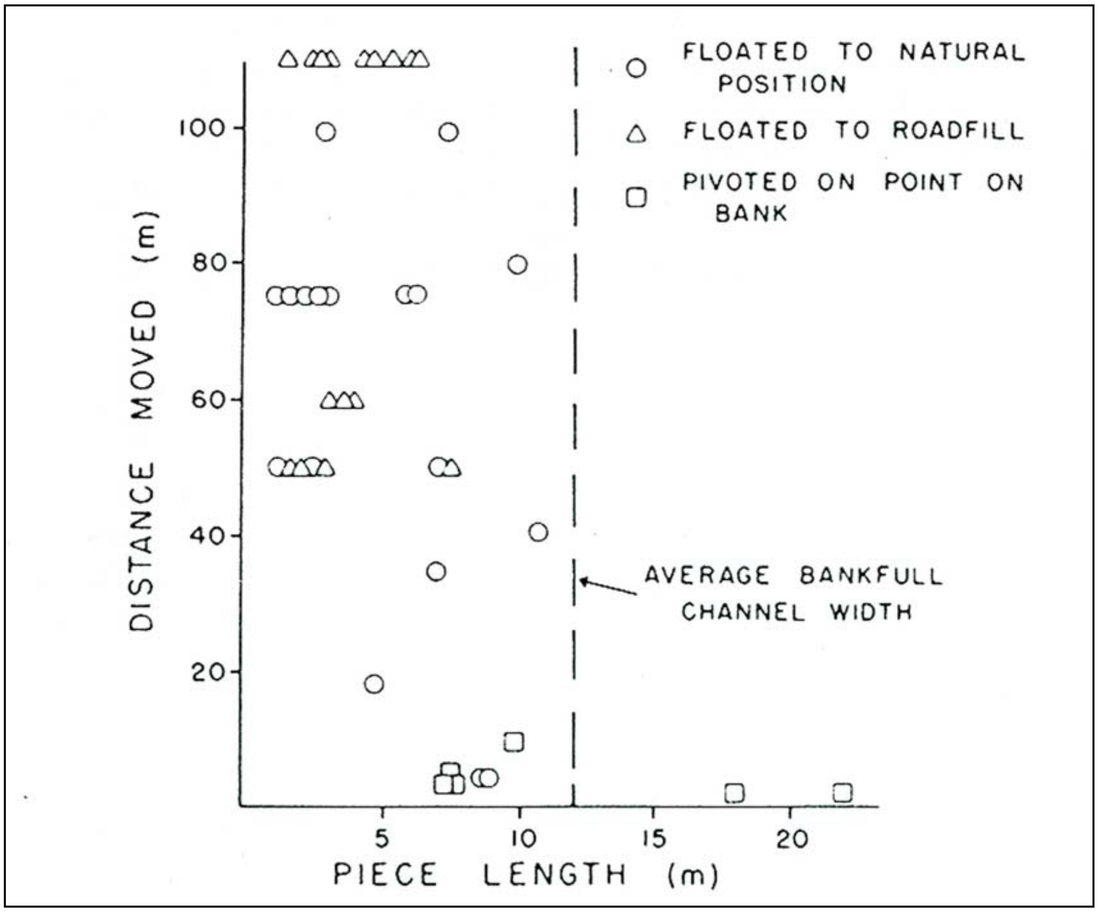

Figure 6.2-1. Redistribution of logs in November 1977 high flow (10-year flow event) at Mack Creek, pieces with lengths less than bankfull width moved farther than pieces with lengths greater than or equal to bankfull width.
From Lienkaemper and Swanson (1987).

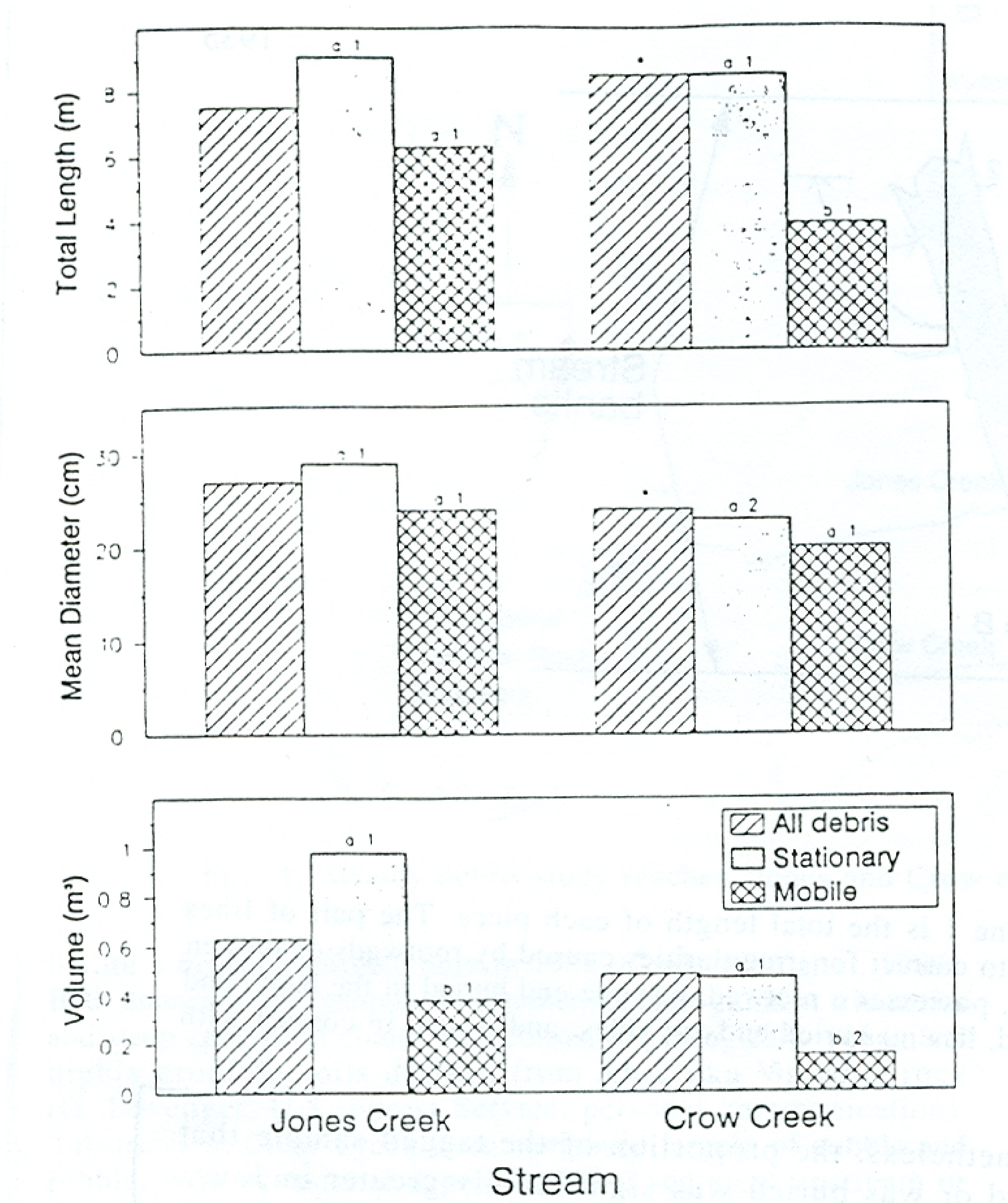

Figure 6.2-2. Comparison of length, diameter and volume of all measured woody debris and tagged mobile and stable debris in a burned (Jones Creek; D_A=64km^2) and unburned (Crow Creek; D_A=50km^2) site.
Debris length is significantly different between mobile and stable debris in Crow Creek, and debris volume is significantly different between mobile and stable debris in both Jones and Crow Creek. From Young (1994).

remeasured. Percent of pieces moved was calculated for each high flow event, length class, diameter class, and anchoring class. Bilby found that piece length, diameter, and anchorage structure are all correlated to the percent of pieces moved in one year.

Grette (1985) studied debris stability in nine streams on the western Olympic Peninsula of Washington. Four hundred and thirty pieces of woody debris (diameter ≥ 10cm and length ≥ 3m) were tagged with aluminum tags and mapped in the summer of 1982. The position and distance moved were determined the following summer. Tagged debris was classified according to length, diameter, and anchoring. The percentage of pieces that moved tended to decrease as piece length and diameter increased.

Millard (2001) studied transport of logging slash in S5 and S6 streams in Chilliwack Forest District, B.C. Data collection included predictor variables (channel characteristics) and response variables (largest size of woody debris moved). A multivariate analysis was performed to characterize the movement of logging slash in streams. A Kruskal-Wallis test showed channel width as a significant predicting variable of the size of woody debris moved. Channel width was positively correlated with the size of woody debris transported.

Murphy and Koski (1989) studied input and depletion of woody debris in Alaskan streams, using LWD age. LWD pieces were dated using dendrochronology methods. Depletion rates were calculated from the inverse of the weighted mean age of LWD in each channel type. Results include depletion rates for different types of channels and size of LWD. For Alaskan streams, Murphy and Koski found that depletion rates varied inversely with LWD diameter.

Berg, et al. (1998) studied dynamics of woody debris in disturbed and undisturbed channels in the central Sierra Nevada, California. Field measurements included hydrologic variables for each 100-m reach and for woody debris characteristics. Wood debris size, location, and abundance were measured in the summers of 1993, 1994, and 1995 in six different streams, each with an upper and lower reach. In-stream woody debris with diameter ≥ 0.08m and length ≥ 1m were tagged in three places. Each consecutive year, new debris was tagged and downstream movement of existing wood was quantified. Pieces with diameter ≥ 0.08m and length ≥ 1m were considered medium (MW); and pieces with diameter ≥ 0.3m and length ≥ 3m were considered large (LW). Berg et al. found an increase in stream flow to be the primary cause of movement; during a low-flow season, 0.8 percent of the MW moved and none of the LW moved; during a high-flow season, 31 percent of the pieces had either moved or were not found.

Abbe and Montgomery (2003) studied debris stability on the Queets River in western Washington. They found that stable woody debris depended on piece diameter in large channels where bankfull widths are greater than the maximum length of instream wood (Figure 6.2-3).

There have been several theoretical/conceptual models and flume studies that have evaluated stream transport of wood (Bend and Sias, 1998; Braudrick and Grant, 2000; Braudrick and Grant, 2001; Marcus et al., 2002; Bend and Sias, 2003). Braudrick and Grant (2000) developed a theoretical model of wood entrainment and performed flume experiments to investigate thresholds for wood movement. They found that piece diameter and the presence of rootwads

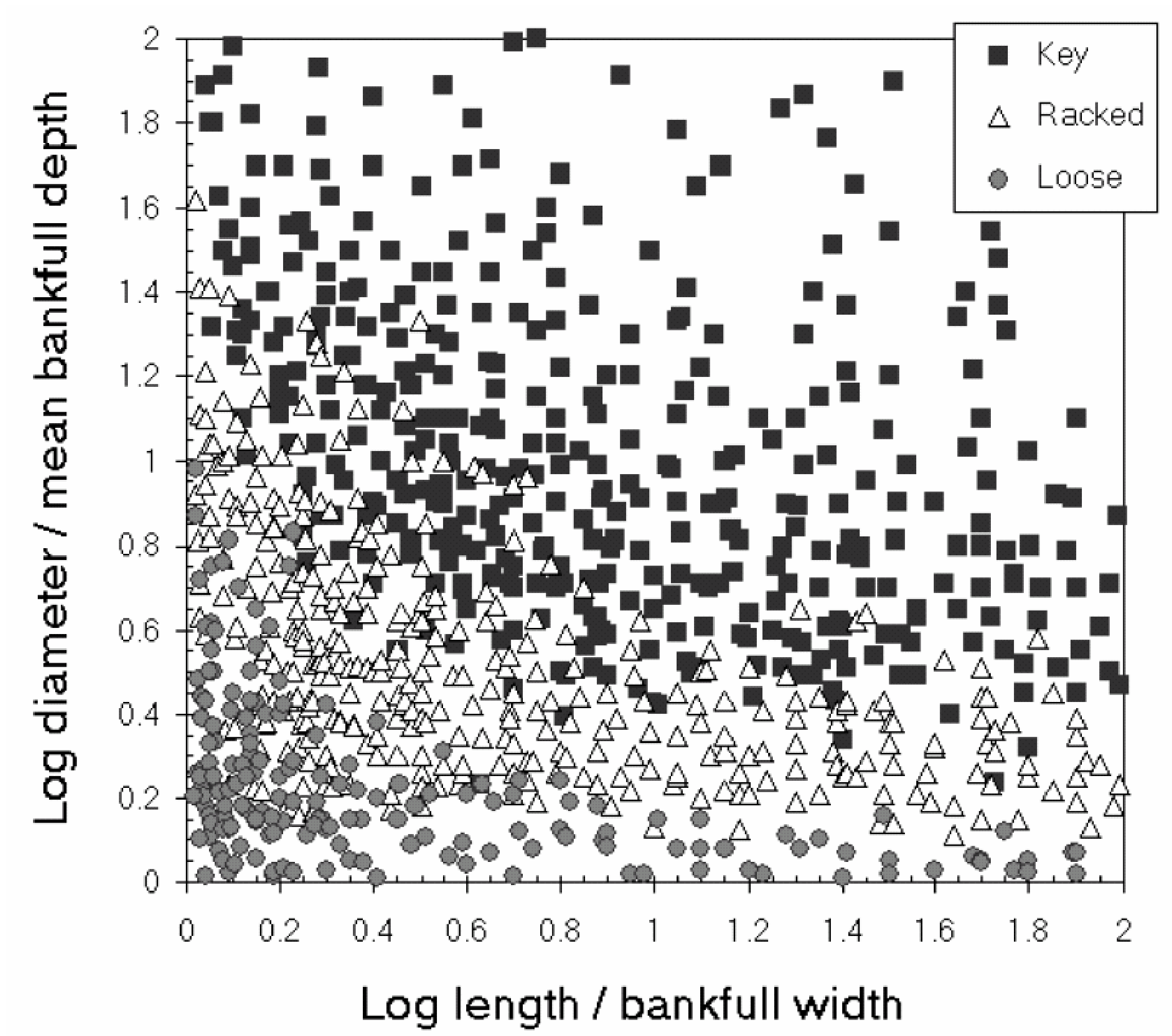

Figure 6.2-3. Dimensionless plot of log diameter per bankfull depth versus log length per bankfull width.
Data display distinct fields of woody debris in log jams from the Queets River system, Washington. From Abbe and Montgomery (2003); Montgomery et al. (2003).

are the most important factors in determining piece stability. Marcus, et al. (2002) studied the spatial and temporal distribution of woody debris in the greater Yellowstone ecosystem. They suggest that LWD transport thresholds exist between stream sizes, where LWD is transport-limited in headwaters and supply-limited in downstream reaches."

Effect of Channel Morphology on Wood Transport

There were no studies found relating channel morphology to wood transport for eastern Washington or analogous regions.

Analogous Process-based Approaches

Murphy and Koski (1989) studied the effect of channel types on wood debris in southest Alaska watersheds. Each stream reach in their study was classified under a certain channel type (Table 6.2-2), using the Channel Type Classification System, CTCS (Paustian et al., 1984). They found that woody debris depletion rates, described above, depend on channel type. In the C2 channel, depletion rates of large size woody debris were similar to the other channel types, but for small and medium size woody debris, the depletion rates were 20-85 percent greater. Depletion rates were lowest in the B6 channels.

Table 6.2-2. Characteristics of six channel types measured in 32 stream reaches in old-growth forest, southeast Alaska.
From Murphy and Koski (1989).

Channel Type	B1	B3	B6	C1	C2	C3
Stream order	2^{nd}-3^{rd}	2^{nd}-3^{rd}	2^{nd}-3^{rd}	3^{rd}-5^{th}	3^{rd}-5^{th}	3^{rd}-5^{th}
Valley segment type	Valley bottoms and dissected upper valleys	Valley bottoms and dissected upper valleys	Valley bottoms and dissected upper valleys	Valley bottoms and lowlands	Valley bottoms and lowlands	Valley bottoms and lowlands
Gradient (%)	1.0	2.0	2.9	0.8	1.0	0.4
Channel width (m)	8.2	11.0	9.5	20.3	14.6	31.4
Hydraulic control	Alluvium	Alluvium/ bedrock	Bedrock	Alluvium	Bedrock	Alluvium

Qualification of Literature Sources

Part of this question (effects of wood size and stream size on wood transport) can be answered based on studies in analogous regions but there is not sufficient data from a region within eastern Washington to sufficiently answer the question (#3). The next step is collection of an eastern Washington data set identical to existing data sets from analogous regions and then comparison of these data sets. If correlation is sufficiently close, numerical analysis of existing information can provide the basis for future resource management guidelines.

The other part of this question (effect of channel morphology on wood transport) cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

Several studies have found that wood piece length relative to bankfull width, piece volume, and stream size are significant factors for wood mobility. Several characteristics not addressed by this question also play important roles in the mobility of wood (see Question 17). Wood stability has been shown to be dependant on the size and shape of the wood and the substrate characteristics and these parameters influence how the wood interacts with the channel bed (Abbe 2000). The presence of rootwads has been found to stabilize wood pieces in many different sized channels (Lienkaemper and Swanson 1987; Young 1994; Braudrick and Grant 2000; Abbe 2000).

Debris anchoring has also been found to affect debris stability (Bilby 1984; Grette 1985; Lienkaemper and Swanson 1987; Young 1994; Abbe 2000; Abbe et al. 2003). Resisting forces increase exponentially with burial of the wood due to skin friction, passive earth pressures, and surcharge (Abbe et al. 2003). Braudrick and Grant (2000) also found that the interaction between wood pieces and grain roughness was a significant factor in piece stability.

To empirically evaluate the affect of wood size, stream size and channel morphology on wood transport rates a protocol needs to be developed that explicitly address each of these interests. Including measurements of bankfull width and depth in a monitoring protocol provides a means to assess the importance of piece size relative to channel size within the fluvial system as well as a means for comparative analyses between basins of similar and dissimilar scales. Wood measurements should include piece shape, size (length and diameter), and density. Further, characterization of streambed sediment can provide a valuable means to appraise anchorage stability. Lastly, evaluations of the influence of channel morphology on wood transport must define the type and scale of morphological characteristics being evaluated and provide clear justification for the use of these features.

Suggestions to fully answer this question might involve development of a theoretical framework to predict mobility or modifications to existing theoretical models (Wallerstein 1995). These efforts should be based on and calibrated with empirical data.

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Bilby, R.E. 1984. Removal of woody debris may effect stream channel stability. Journal of Forestry 82(10):609-613.

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6.3 Question 19 Response

What portion of the wood that is transported out of a stream reach becomes functional wood downstream? Does this vary with the size of the pieces of wood? Provide summaries of available numeric information. Document qualitative (imagery) information that supports these datasets.

Summary of Literature Sources

Of the references reviewed, a total of five were found that had quantitative and/or descriptive information relating to downstream functional wood. Of these, one had information relevant to eastern Washington, two contained data from an analogous region, and two were analogous process-based studies. Table 6.3-1 provides a summary of this reference.

Summary of Quantitative Data

The term 'functional wood' is assumed to have two main definitions: a physical function and an ecological function. The physical attribute of functional wood involves the production of hydraulic complexity and bed deformation. The ecological attribute of functional wood involves the creation of habitat, which includes: additional cover, substrate, and accumulation of organic debris.

Abbe and Montgomery (2003) studied debris stability on the Queets River in western Washington. Figure 6.2-3 displays the log stability thresholds for key, racked, and loose pieces in 32 jams in the Queets channel network. This data illustrates the significance of piece size relative to bankfull channel dimensions in determining piece functionality.

There was very little quantitative data found pertaining to the function of wood following mobilization and downstream transport. Lienkaemper and Swanson (1987), as mentioned in the previous two question responses, studied wood transport in old-growth Douglas-fir forests. During a high flow (10-year recurrence interval) on Mack Creek, they collected data on the characteristics of wood redistribution (Figure 6.2-1). They recorded the piece length, distance moved, and resting location for 42 mobile pieces. During the high flow, water became ponded behind a roadfill at the downstream end of the study reach, and most of the debris that was transported out of the reach became trapped in the ponded area. Other transported debris accumulated at several points along the study reach. Figure 6.2-1 displays the results, although it is unclear whether there is a relationship between piece size and downstream functional wood. Expanding on a study of this type could prove useful in answering Question 19.

Fox (2001) studied the distribution of "key" wood pieces (independently stable and serving to collect other pieces of wood) in eastern and western Washington streams. Fox (2003 and unpublished) also studied the proportion of wood in channels that can be attributed to an adjacent source or can be attributed to wood that moved into the reach from upstream. This data would need further analysis to relate results to this question.

Table 6.3-1. Summary of literature sources containing data relevant to question 19.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Studies in Eastern Washington									
Fox 2001, 2003	Tributaries to the Naches, Cle Elum, Wenatchee, Methow, and Stehekin River basins	0.9 – 186	SC, NC, CB	Subalpine fir, grand fir, Douglas-fir/ponderosa pine	0.2 – 47	Alluvial and bedrock	Unmanaged	S	Yes
Studies in Analogous Regions									
Lienkaemper and Swanson 1987	H.J. Andrews Experimental Forest, Willamette NF, OR	0.1 – 60.5		Douglas-fir, western hemlock, western redcedar	3 – 37	Tertiary volcanic rock- boulders	Unmanaged	S,Q,O	Yes
Young, M.K. 1994	NW Wyoming- Crow Creek and Jones Creek	49.46, 64.23			4.1, 5.5	Absaroka Volcanic rock- cobble/rubble	Fire activity (one site)	Q, S	Yes
Analogous Process-based Approach									
Abbe and Montgomery 2003	Queets River, Olympic Peninsula WA; quantitative models	724	WW	Sitka spruce, Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple, black cottonwood	1.3 – 69	Tertiary marine sandstones and shales	Unmanaged and Managed??	S,Q	Yes
Berg, T. et al. 1998	Sierra Nevada, CA	8.3 – 25		Mixed conifer and red fir, east-side pine	Unknown	cobbles, boulders, bedrock	Managed	S,Q	Yes
Bilby, R.E. 1984	Coast Range, WA	9	WW	Unknown	1.5	unknown	Managed	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington
[b] Q - qualitative descriptions, S - summarized numeric values, O - original data provided.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

Although there was very little quantitative data found describing downstream functional wood, Lienkaemper and Swanson (1987) have a good start at quantifying this relationship. There are several other studies addressing wood transport that could be expanded to include characteristics of downstream functional wood. The methods of most of these studies involve long-term monitoring of tagged wood. Lienkaemper and Swanson (1987), Bilby (1984), Young (1994), Berg et al. (1998) and Stillaguamish and Elwha wood budget studies (unpublished) are just a few example studies that could prove useful when designing a study specific to eastern Washington.

References

Abbe, T.B. and D.R. Montgomery. 2003. Patterns and processes of wood debris accumulation in the Queets River basin, Washington. Geomorphology 51(1-3):81-107.

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Young, M.K. 1994. Movement and characteristics of stream-borne coarse woody debris in adjacent burned and undisturbed watersheds in Wyoming. Canadian Journal of Forest Resources 24:1933-1938.

7.0 Pool Formation

7.1 Question 20 Response

What is the distribution of sizes and characteristics of pools in eastside streams? Is it significantly different than Westside streams? Provide summaries of numeric information.

Summary of Literature Sources

Of the references reviewed, a total of 27 were found that had quantitative and/or descriptive information relating to pool characteristics. Of these, 18 had information relevant to eastern Washington, one contained data from analogous regions, and eight were found related to the topic in western Washington and Oregon. Table 7.1-1 provides a summary of these references.

Summary of Quantitative Data

Distribution of Sizes and Characteristics of Pools in Eastside Streams

Pool Sizes

Data to describe average length, width and depth of pools in eastern Washington streams are rare. Curran (unpublished data; Curran and Wohl 2003) provided pool dimensions, reporting on 10 streams in the eastern central Cascades and 10 in the western central Cascades. Average pool volumes were 0.40 m^3 (±0.29 m^3, standard deviation) for eastern, and 0.39 m^3 (±0.40 m^3) for western streams (Table 7.1-2). On the east side, average pool volume ranged from 0.10 to 1.14 m^3. In the western Washington streams they studied, pool volumes ranged from 0.08 to 1.41 m^3.

Curran (unpublished data; Curran and Wohl 2003) also collected data and reported summary information for several aspects of stream morphology and hydrology, including drainage area, elevation, slope, average velocity, hydraulic radius, bankfull width and depth, sediment size, counts of large woody debris, and number of steps and pools in the study reach. Baldwin (unpublished) has raw numbers for pool widths and depths associated with instream wood, but this data needs to be further analyzed before its value can be determined.

Watershed analyses provided minimal data about pool sizes as most used a qualitative system of ranking habitats. Four watershed analyses ranked pool volumes relative to criteria for evaluating habitat quality for fish (DNR 1997). Three out of four of these watersheds received an overall rating of “poor” with respect to pool size, indicating that the average size of pools was smaller than those considered high quality fish habitat (Table 7.1-2).

Pool Area and Frequencies

Pool area, expressed as the percent of stream area taken up by pools, and pool frequency, expressed as the number of pools relative to a stream unit (e.g., bankfull width or channel

Table 7.1-1. Summary of literature sources containing data relevant to question 20.

Reference	Location	Basin Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Study Area Geology	Drainage Management?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Curran unpublished data	E. and W. central Cascades	<10km²/stream studied	NC	Conifer/deciduous mix	0.06 to 0.18 m/m	Volcanic, metamorphic, and glacial till	ND [c]	O	No
Raines et al. 1999	Upper Little Klickitat Watershed; Klickitat County	243	CB	Grassland, ponderosa pine/Douglas-fir	<1 – >20%; 50% are 4 – 12%	Volcanic, sedimentary	M,U	O,S	No
Raines et al. 1997	Onion Creek Watershed; Stevens County	192	NE	Western hemlock (low); fir/pine/spruce (high)	Mostly 2 – 4%	50% glacial sediments; granitic; sedimentary	M,U	O,S	No
R2 Resource Consultants 2002	Sinlahekin Watershed; Okanogan County	188	NC	Ponderosa pine/Apache pine/Douglas-fir; alpine	<1 – >20%	Volcanic, sedimentary, glacial drift	M,U	O,S	No
	Toats Coulee Watershed; Okanogan County	181	NC	Ponderosa pine/Apache pine/Douglas-fir; Alpine	<1 – >20%	Igneous/metamorphic; glacial deposits	M,U	O,S	No
Dunton et al. 1997	Thompson Creek Watershed; Spokane County	101 – 121	NE	Cedar-hemlock	Mostly <8%	Volcanic; metamorphic	M,U	O,S,Q	No
Doughty et al. 1996	Teanaway Watershed; Kittitas County	120	NC	Ponderosa pine, grand fir, Douglas-fir; grasslands	Mainstem 1 – 2%; main tributaries <4%	Glacial deposits; erodable soils	M,U	O,S,Q	No
McKinney et al. 1996	South Fork Touchet Watershed; Columbia County	207	BM	Ponderosa pine/Quaking aspen (low); ponderosa pine, grand fir, Douglas-fir, western larch (mid); grand fir, Douglas-fir (high)	<1 – >8%	Volcanic; loess	M,U	O,S,Q	No
Lee et al. 1997	Interior Columbia Basin	Study reaches are 0.2 – 45.6 km length	NC, SC, CB, BM, WW	Wide range	Wide range	Wide range	M,U	S	No
Raines et al. 1995	Big Sheep Creek Watershed; Stevens County	193	NE	Ponderosa pine, Douglas-fir (low); grand fir/western redcedar (high)	<1 – >8%	Glacial out-wash, volcanic metamorphic marine/granitic	M,U	S,Q	No

Table 7.1-1. Summary of literature sources containing data relevant to question 20 (continued).

Reference	Location	Basin Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Study Area Geology	Drainage Management?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies (continued)									
Smith 1993	E. central Cascades	214 – 398	NC	Ponderosa pine; western hemlock/deciduous	1.6%	Basalt/sandstone	M	S,Q	No
Carlson et al. 1996	West branch of Little Spokane Watershed ; Spokane County	260	NE	Douglas-fir , grand fir , western hemlock	<1 – >20%	Granitic/Meta-sedimentary	M,U	S,Q	No
Curran and Wohl 2003	E. and W. central Cascades	<10 km^2/stream studied	NC	Conifer/deciduous mix	0.06 – 0.18 m/m	Volcanic, metamorphic, glacial till	ND	S,Q	Yes
McIntosh et al. 1994	Interior Columbia River Basin	828 – 15,900	NC, CB, BM	ND	ND	ND	M,U	S,Q	Yes
McIntosh et al. 2000	Interior Columbia River Basin	<50 – >4700	NC, SC, CB, BM, WW	ND	ND	ND	ND	S,Q	Yes
Ralph et al. 1993	W. and Central Washington	ND	NC, WW	ND	ND	ND	ND	S,Q	No
McKinney et al. 1997	Ahtanum Watershed: Yakima County	281	CB	Pine/fir(high); ponderosa pine/fir/deciduous (low)	66% of streams are >20%	Columbia river basalts	M,U	Q	No
Dunton et al. 1995	Huckleberry Watershed; Stevens County	Approx. 200	NE	Mixed wood/pasture	<1 – >20%	Metamorphic marine/granitic; sedimentary; glacial till, loess	M,U	Q	No
Baldwin unpublished	LeClerc, Priest River, and Lost Creek basins		NE	Riparian species: western redcedar, Englemann spruce, subalpine fir, Douglas-fir, western hemlock	1.97 – 6.59		U	S	No
Studies in Analogous Regions									
Beak Consultants 1996	Grossman Creek; NE Oregon	113	BM	Conifer-dominated: grand fir, Douglas-fir, ponderosa pine, western larch (low); lodgepole pine, Apache pine (high)	<3 – >20%	Basalt	M,U	Q	No

Table 7.1-1. Summary of literature sources containing data relevant to question 20 (continued).

Reference	Location	Basin Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Study Area Geology	Drainage Management?	Type of Data [b]	Peer Reviewed?
Western Washington/Oregon Studies									
Beechie and Sibley 1997	Stilliguamish, Skykomish, and Snoqualmie Rivers	2.6 – 118.3	WW	Western hemlock (low); Pacific silver fir (high)	<0.04 m/m	Glacial/alluvial	M,U	S	Yes
Bilby 1984	Salmon Creek; southwestern Cascades	9	WW	ND	1.5%	ND	M,U	S	Yes
	Fall River: southwestern Cascades	14	WW	ND	1.6%	ND	M,U	S	Yes
Kiem et al. 2002	Central coastal Oregon	7.0 – 15.5	WO	TSHE	0.0004 – 0.011 m/m	Alluvial sand/gravel	M	S	Yes
MacFarlane and Wohl 2003	Central and southwestern Cascades	0.62 – 5.9	WW	ND	4 – 18%	ND	M	S	Yes
Montgomery et al. 1995	Tolt River; western Cascades	ND	WW	ND	0.002 – 0.085 m/m	Pleistocene limestone, granite; tertiary igneous, sedimentary	M,U	S	Yes
Moore and Gregory 1988	Western Cascades of Oregon	5.4 – 9.7	WO	Coniferous; red alder; shrub	5.3 – 10.0%	ND	M,U	S	Yes
Ralph et al. 1994	Western Washington	<16	WW	Red alder/bigleaf maple (low); western hemlock/ Douglas-fir/western redcedar (mid); Pacific silver fir (high)	<12%	Volcanic, glacial, sedimentary	M, U	S,Q	Yes
Rot et al. 2000	Western Cascades	4.4 – 62.3	WW	Western hemlock, Pacific silver fir	<4%	Igneous	M, U	S,Q	Yes

[a] Region is the major basin in which the study was performed: BM: Blue Mountains; CB: Columbia Basin; NC: Northeast Cascades; NE: Northeast Corner; OH: Okanogan Highlands; SC: Southeast Cascades; WO: western Oregon; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

length), were often used as metrics of habitat quality in watershed analyses. In the peer-reviewed and gray-literature for eastern Washington, pool area and pool frequency are reported more often than pool volume. Values reported in the grey and peer reviewed literature for pool area ranged from 0 to 100 percent (Table 7.1-2). Due to differences in methods, differences in the geographic extent of surveys, and differences in presentation, it is not possible to combine data to derive a reliable probability distribution of values for pool area. Any pattern in the frequency distribution of pool areas of eastern Washington streams remains obscure.

Some studies in eastern Washington and the interior Columbia River basin used pool frequencies to compare historic and current pool abundances, evaluating changes in stream morphology and fish habitat over time. In the eastern Cascades, Smith (1993) conducted a study comparing historic pool surveys from 1935 with 1990 stream surveys on the Little Naches River, using the USDA Region 6 protocol, and on Taneum Creek, using the Timber Fish and Wildlife Ambient Monitoring survey methodology. Parameters reported include: large pools ($\geq$20m^2 area, $\geq$1m depth), total pools, pool frequency, substrate composition, total channel length, wetted channel width, active channel width, channel surface area, stream canopy opening widths, composition of riparian vegetation, and summaries (qualitative and as a percent of total watershed area) of major land uses for the two study streams. Thirty-two percent of the Little Naches River stream area, and 38 percent of Taneum Creek, were reported as occupied by pools in 1990 surveys. Pool frequencies were 3.8 and 3.4 pools/km for Taneum Creek and Little Naches River, respectively (Table 7.1-2). Smith compared these values to historical data from the same watersheds[11] and concluded that pool abundance is improving in these areas relative to the 1930s, and suggests that this trend may be a result of lower levels of timber harvest and diminished agricultural activities. Smith states that pool abundances for eastern Washington documented in her study are still below standards set by the US Forest Service Region 6.

McIntosh et al. (1994) provide data for large (>20m^2 area, $\geq$0.9m depth) pool frequencies within individual streams for several ecoregions of eastern Washington and northeastern Oregon. This paper also provides data on land use history, including timber harvest levels and livestock densities, as a context for examining changes in stream pool habitat over time. Average pool frequencies reported by McIntosh et al (1994) ranged from 2.1 pools/km for Asotin Creek in the Blue Mountains of southeastern Washington, to 7.7 pools/km in some parts of the Wenatchee River basin (Table 7.1-2). McIntosh et al. (2000) used the same criteria as McIntosh (1994) for large pools, and also included deep pools ($\geq$20m^2 area and $\geq$1.8 m depth). This study provides data on historical trends in pool frequency based on streams classified as "commodity" (in roaded areas managed primarily for resource extraction), or "natural" (largely unmanaged). Pool frequency data for the study on which McIntosh et al. (2000) based their paper is also reported in Lee et al. (1997) (Table 7.1-2).

Consistent with Smith's (1993) finding, McIntosh et al. (1994 and 2000) concluded that there was an increase in pool frequencies in several streams of the north and eastern-central Cascades

[11] Historic data are not included in this summary or tables.

Table 7.1-2. Summary of data describing characteristics of pools in eastern Washington. In some cases, additional data may be available in the reference for smaller scales of the study, including individual stream or stream segment data.

Reference	Watershed/ Stream	Pools as % of Stream Area [Rating [a]]	Mean (± SD) Pool Frequency [b] [Rating]	Mean (± SD) Pool Size [c] [Rating]
Eastern Washington Studies				
Curran, unpublished data (methods in Curran & Wohl 2003)	10 Streams in western central Cascades	ND [d]	1.64 (± 0.64) bfw/p	0.39 m^3 (± 0.40) (V)
R2 Resource Consultants 2002	Loomis Watershed	21 – 84% [most are fair-good]	4 – 23/1,000 ft [fair-good]	ND
Raines et al. 1997	Onion Creek Watershed	11 – 68%	ND	>15 cm (D)
Raines et al. 1999	Upper Little Klickitat Watershed	0 – 65% [1/3 poor, 2/3 good]	ND	[poor]
Dunton et al. 1997	Thompson Creek Watershed	[poor]	4.8 – 7.0 bfw/p [poor-fair]	8.25 in. (D) 5.3 – 1 ft (L)
Doughty et al. 1996	Teanaway Watershed	0 – 92% [poor-good]	[poor-fair]	ND
Dunton et al. 1995	Huckleberry Watershed	ND	ND	ND
Lee et al. 1997	Northern Cascades: Managed	ND	3.8/km (large) 0.6/km (deep)	ND
	Unmanaged	ND	4.6/km (large) 0.7/km (deep)	ND
	Blue Mountains: Managed	ND	2.5/km (large) 0.1/km (deep)	ND
	Unmanaged	ND	1.3/km (large 0/km (deep)	ND
McIntosh et al. 1994	Wenatchee River: Managed	ND	7.7/km	ND
	Unmanaged[e]	ND	7.5/km	ND
	Methow River: Managed	ND	3.4/km	ND
	Unmanaged	ND	3.4/km	ND
	Yakima River: Managed	ND	3.8/km	ND
	Unmanaged	ND	3.9/km	ND
	Tucannon River	ND	6.5/km	ND
	Asotin Creek	ND	2.1/km	ND
Smith 1993	Little Naches River	32%	3.8/km	ND
	Taneum Creek	38%	3.4/km	ND
Raines et al. 1995	Big Sheep Creek	ND	[poor]	[poor]
	American Fork	ND	[fair-good]	[fair-good]
Carlson et al. 1996	West branch of Little Spokane Watershed	10 – 70% [good]	ND	[poor-fair]

Table 7.1-2. Summary of data describing characteristics of pools in eastern Washington (continued).

Reference	Watershed/ Stream	Pools as % of Stream Area [Rating [a]]	Mean (± SD) Pool Frequency [b] [Rating]	Mean (± SD) Pool Size [c] [Rating]
Eastern Washington Studies (continued)				
McKinney et al. 1996	South Fork Touchet	9.7% [poor]	8.3 bfw/p [poor]	ND
	Wolf Fork	8.4% [poor]	6.3 bfw/p [poor]	ND
	Robinson Creek	mean: 0.1% [poor]	10.2 bfw/p [poor]	ND
Ralph et al. 1994	Six streams in E and W Cascades	0.0 – 7.5 P/R [f]	ND	ND
McKinney et al. 1997	Ahtanum Creek Watershed	ND	ND	ND
Studies in Analogous Regions				
Beak Consultants 1996	Grossman Creek Watershed	ND	[poor]	<1m (D)
McIntosh et al. 1994	Grande Ronde River, (Oregon)	ND	6.5/km	ND
Western Washington Studies				
Beechie and Sibley 1997	Stilliguamish, Skykomish, and Snoqualmie Rivers	13 – 79%	1.7 – 5.9 bfw/p	ND
Bilby 1984	Salmon Creek , Fall River	32 – 74%	ND	ND
Curran, unpublished data (methods in Curran and Wohl 2003)	10 streams in eastern central Cascades	ND	2.54 (±1.52) bfw/p 0.88 – 6.38bfw/p	$0.4m^3$ (± 0.29) (V) $0.096 – 1.14m^3$
Lee et al. 1997	Coast Range: Managed [e]	ND	0.7/km (deep) [g]	ND
	Unmanaged	ND	ND	
	Western Cascades: Managed	ND	6.9/km (large) [g] 1.6/km (deep)	ND
	Unmanaged	ND	12.5/km (large)	ND
Kiem et al. 2002		$0.15 – 0.4\ m^3/m$ [h]	ND	ND
Montgomery et al. 1995	Tolt River; western Cascades	ND	0.21 – >13.20 bfw/p	ND
Moore and Gregory 1988	Western Cascades of Oregon	21 – 34%	ND	ND
Rot et al. 2000	Western Cascades	34 – 39%	2.1 – 4.9	ND

[a] In several of the watershed analyses, no quantitative data is given for pool characteristics, but a rating is given (Poor, Fair, or Good). This rating refers to the value of the pool relative to benchmark values for fish habitat quality as established in the Department of Natural Resources Watershed Analysis Manual (DNR 1997), p. F-24.
[b] Pool frequency is a summary of the number of pools per a given stream dimension, e.g., bfw/p = number of bankfull channel widths per pool, or #/km = number of pools/kilometer.
[c] Pool sizes are given in length (L), depth (D), or Volume (V).
[d] ND = No Data given in the reference for this characteristic.
[e] McIntosh et al. (1994) and Lee et al. (1997) differentiate in some river basins between managed (area heavily influenced by human activities) versus unmanaged (area minimally impacted by human activities).
[f] Ralph et al. provide pool abundance as pool/riffle ratio; pool/riffle/cascade ratio is also given, including raw data.
[g] Lee et al. (1997) provide pool frequency data for large (>$20m^2$ and 0.8m depth) and deep (>$20m^2$ and 1.6m depth) pools.
[h] Kiem et al. (2002) report area of pools as residual pool volume over channel length.

region between the 1930s and the 1990s. In contrast, pool frequency declined significantly in the Blue Mountains and the western Cascades over this time period (McIntosh et al. 1994; McIntosh et al. 2000). Overall, large pool frequencies increased by 77 percent between the 1930s and 1990s in unmanaged basins, while declining 28 percent over the same time period in managed basins.

To explain ecoregional differences in the changes in pool frequency over time, McIntosh et al. (2000) cite differences in the degree of recent and historical human activity. The large extent of wilderness area in the north Cascades is given as the reason for higher pool frequencies relative to the Blue Mountains region. In the Blue Mountains, high levels and long duration of human activity have lead to simplification of stream channels, which McIntosh et al. (2000) attributes to be the cause of decreases in quantity and quality of stream pool habitat.

Pool Formation Factors

Information to describe mechanisms of pool formation is extremely limited. Neither Smith (1993), McIntosh (1994 and 2000), nor Ralph (1993) provide any quantitative data regarding pool formation factors. Some watershed analyses list factors in pool formation on a reach-by-reach basis; however, these factors are described in most analyses in narrative form and are usually not quantified or assigned frequencies. Carlson et al.'s (1996) watershed analysis provides the percent of pools for which LWD is a primary causal factor. For 16 selected study reaches in the west branch of the Little Spokane River watershed, the percent of pools formed by wood ranged from 0 to 75 percent. Carlson et al. (1996) presented the proportion of pools formed by large woody debris in conifer-dominated study reaches (mean ± SD: 55.0 ± 38.0; N = 6 transects); and the percent of pools formed by large woody debris in alder-dominated stream reaches (39.0 ±25.0, N=7).

Raines et al.'s (1999) Upper Little Klickitat Watershed Analysis provided percent of pools formed by large woody debris per study transect: of 27 transects for which data was reported, 17 transects contained zero percent LWD-formed pools, nine transects had up to 50 percent of pools formed by LWD, and two transects had >50 percent of pools formed by LWD.

Curran and Wohl (2003) provide the percent of steps in eastern Cascades streams that contain large (>10cm diameter, >1m length) woody debris, small (smaller than large debris) woody debris, and clasts. Average percent of steps that included large woody debris ranged from 5 to 60 percent for eastern Cascades streams. From 5 to 40 percent of steps in these streams included fine woody debris, while clasts were associated with 35 to 90 percent of steps in the streams.

Comparison Between Eastern and Western Washington Streams

Although numerous studies describe pool characteristics in the mountain ranges of western Washington (e.g., Bilby 1984; Ralph et al. 1993; Ralph et al. 1994; Montgomery et al. 1995; Beechie and Sibley 1997; Rot et al. 2000; Kiem et al. 2002) and western Oregon (Moore and Gregory 1988; MacFarlane and Wohl 2003), few investigate pools in both eastern and western Washington streams. Ralph et al. (1993) provide ratios of pool/riffle and pool/riffle/cascade for several streams in eastern Washington (Table 7.1-2) as well as for the Puget Sound lowlands, the Olympic Peninsula, and the Northern Rockies. However, the authors did not provide a comparative analysis by region. As a result, it is difficult to make direct comparisons between western and eastern Washington streams.

Methods of Curran (unpublished) and Curran and Wohl (2003) were consistent for eastern and western Cascades streams, allowing direct comparison of pool volumes and frequencies between regions. The authors found similar ranges and averages of pool volumes and frequencies for streams in the eastern and western Cascades (Figure 7.1-1; Table 7.1-2). The range, distributions and standard deviations of average pool volumes suggest that average pool volumes in eastern Washington streams were not different than average pool volumes in western Washington streams. Further statistics are needed to test significance between east and west streams.

McIntosh et al. (2000) include 15 coastal (Oregon and Washington) and 33 western Cascades streams in their analyses of historical changes in pool frequencies in the Columbia Basin. They found that the magnitude of declines in frequencies of large pools in the western Cascades was similar to that in the Blue Mountains, while coastal streams did not show significant declines over time in large pool frequency. Declines in frequencies of deep (>1.8m depth) pools, however, were greater in the western Cascades and Coast Range than in the eastern Washington ecoregions studied. The authors suggest that widespread removal of LWD from western Washington and Oregon streams from the 1950s to the 1980s, as well as timber harvest practices influencing LWD recruitment, were likely causative factors in the lower frequency of deeper pools in the western Cascades and Coast Range.

It has been suggested that more frequent flooding in the western Cascades and Olympic Mountains results in scour which maintains pools, and therefore western Washington streams have an inherently higher pool frequency (lower pool spacing) than do eastern Washington streams (Smith 1993). Curran's (unpublished) data for small streams does show a wider distribution of pool spacing and pool volume for eastern Cascades streams, however the distinct range of basin areas sampled east and west of the Cascades makes direct comparison difficult. Additional statistical analysis is necessary to determine whether pool spacing in eastern Washington streams is significantly greater than in western Washington streams. Additional data from larger basins west of the Cascades and smaller basins east of the Cascades would facilitate a more robust comparison. Data for larger westside basins exists and could be incorporated into this analysis (Abbe unpublished).

Although direct comparisons between regions are not generally available, it may be possible to use watershed analyses to compare pool frequencies and areas between streams in western and eastern Washington. The feasibility of this approach is discussed below.

Qualification of Literature Sources

This question can be answered now for the Northeast Cascades, Southeast Cascades, Columbia Basin, and Northeast Corner regions, based on existing information (#1). The geographic scope of the data found, however, is not representative of all ecoregions and channel size/drainage

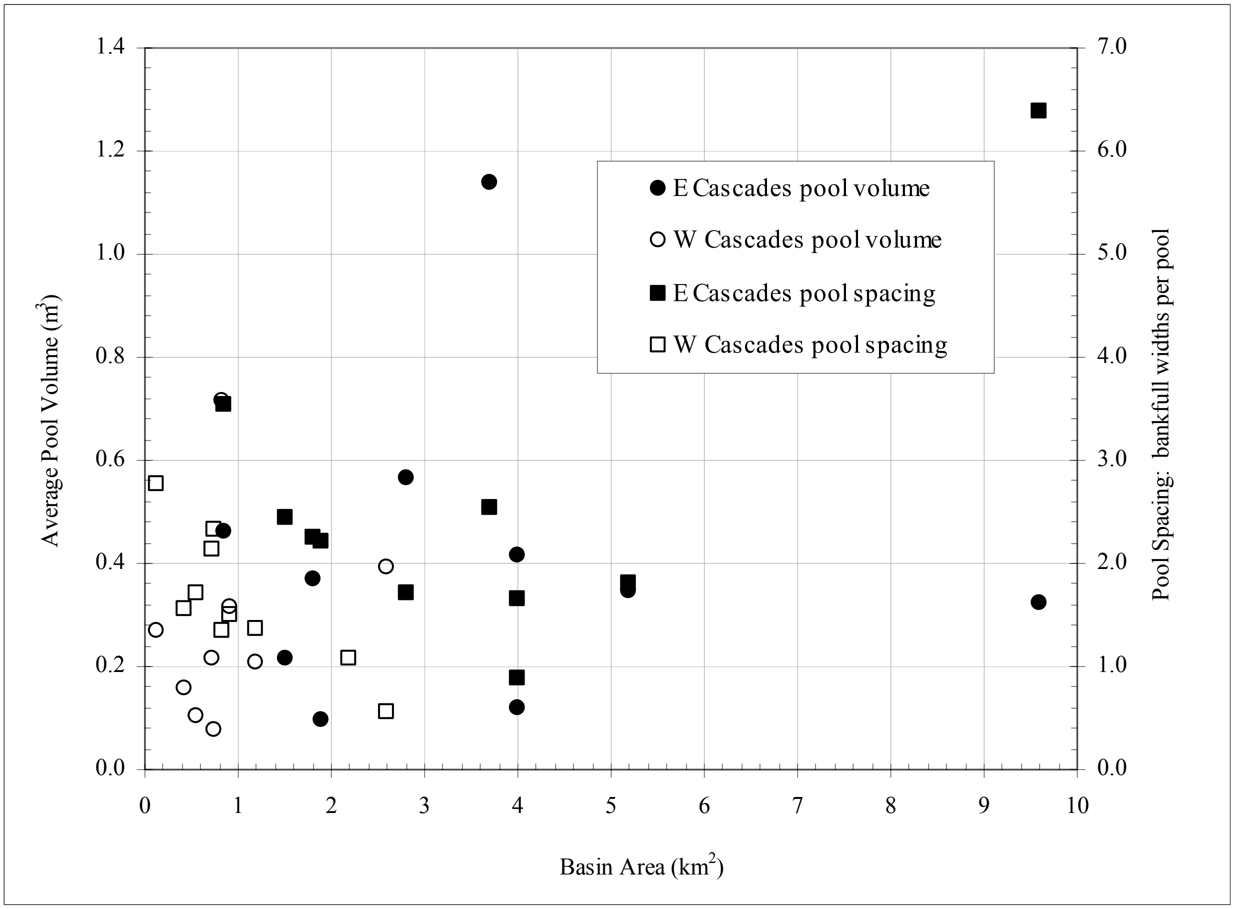

Figure 7.1-1. Average drainage areas of east Cascades streams = 3.5 +/- 2.5 km^2 (mean +/- s.d.) and west Cascades streams = 1.0 +/- 0.8 km^2.
Summary of unpublished data provided by Curran. The distribution of pool volumes and spacing is greater for eastern Washington streams. The range of basin areas sampled east and west of the Cascades, however, makes direct comparison difficult.

areas. It is possible that further review of watershed analyses may provide additional data (Table C1).

Summary and Recommendations

Synthesizing the available data is difficult due to the variation in methods and the temporal and spatial extents of the studies involved. The scale of research varies widely, ranging from just meters of stream length to watershed-wide assessments. Standardized parameters were focused on for this summary, but in many cases values cannot be extrapolated to a common metric to allow comparison among studies.

Watershed analyses provide a substantial amount of data, but the usefulness of this data is limited by variation in data quality and in the reporting of methods. Several watershed analyses do not provide enough information on methods for the reader to judge the data quality. Although the DNR Watershed Analysis Manual Version 4.0 (WDNR 1997) was reviewed, several of the Watershed Analyses are based on earlier versions of this manual, and the consistency of those versions with version 4.0 could not be verified.

The level of detail and the format of data provided in the watershed analyses is also highly variable (Table 7.1-2). To use these data to address questions about pools in eastern Washington streams would require that the original data be obtained and analyzed specifically with respect to these questions. The original data for these watershed analyses does not currently exist in a centralized location, so the sponsoring institutions and/or analysts would have to be contacted. This would likely be labor-intensive (Sturham 2003 personal communication). Additional time would also be necessary for reviewing the methods with respect to earlier versions of the Watershed Analysis Manual and gathering additional information from study authors about their methods.

The studies obtained for this summary are not sufficient to provide comprehensive information about the distribution and characteristics of pools of eastern Washington and do not provide direct comparisons between regions. The wide range of scales at which these studies were performed cautions against direct comparisons of pool characteristics among studies. There is substantially more peer-reviewed information available to describe the distribution of pools and the relationships of pools to large wood for western Washington and the Oregon Coast Range than there is for eastern Washington. Because many references obtained for both regions provided only summary or qualitative information, it may be possible that Question 20 and others in the pool formation topic could be more thoroughly addressed if authors of these papers are contacted, original data procured, methods reviewed, disparate metrics reconciled and original analyses performed. However, without clearer information on the condition and type of original data, the specific level of effort that would be required cannot be determined. This would likely be a labor-intensive process.

The design and execution of a focused, field-based research project in a limited geographic area could provide a more cost-effective approach to address the specific interests of SAGE regarding the distribution of pools in western versus eastern Washington. If the SAGE requires that all information cover as much of the region as possible, then continued and intensive mining of the gray literature, including an effort to compile, standardize and analyze original data files for the reports summarized above and possibly other watershed analyses is recommended. A field program to address Question 20 for several different regions would be very costly. If the SAGE focused their interest on a specific region of importance, for example, a region for which there is currently no information, than a focused field study may provide a more direct and less costly approach to the desired information.

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7.2 Question 21 Response

What is the relationship between stream flow, wood, and the pools formed? Provide summaries of numeric information.

Summary of Literature Sources

Of the references searched, two studies were found directly related to eastern Washington, none were found relating to analogous regions and two were found that related to the topic, but not the region. References used in response to Question 21 are listed in detail on Table 7.2-1

Summary of Quantitative Data

Little research has been published to describe the relationships between flow, woody debris, and pool characteristics specifically for eastern Washington streams. No peer-reviewed publications were found that explicitly explored these relationships for any eastern Washington ecoregions. Existing watershed analyses contain little information linking variables related to pool formation. Neither discharge nor velocity was taken as a measurement in any of the analyses reviewed. Channel width was the only variable consistently measured that might suggest the size of the stream, but this variable does not necessarily directly translate to discharge. Only a few analyses (Carlson et al. 1996; Raines et al. 1997) simultaneously present data for channel width, pool frequency, and large woody debris. Relationships between these variables were not analyzed by the authors.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer the question. We found no quantitative data or analyses to describe relationships between stream flow, wood, and pool characteristics in eastern Washington. A few watershed analyses provide data for these variables, but the usefulness of this data is limited by variation in data quality and in the reporting of methods (see discussion in Question 20). The level of detail and the format of data provided in the watershed analyses are also highly variable. None of the watershed analyses conducted statistical tests or provided a discussion of these relationships based on quantitative information.

Summary and Recommendations

It may be possible that Question 20 and others in the pool formation topic could be more thoroughly addressed if authors of these papers are contacted, original data procured, methods reviewed, disparate metrics reconciled and original analyses performed. The original data for these watershed analyses does not currently exist in a centralized location, so the sponsoring

Table 7.2-1. Summary of literature sources containing data relevant to question 21.

Reference	Location	Basin Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Study Area Geology	Drainage Management?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Carlson et al. 1996	West branch of Little Spokane Watershed ; Spokane County	260	NE	Douglas-fir, grand fir, western hemlock	<1 – >20%	Granitic/Meta-sedimentary	M,U	S,Q	No
Raines et al. 1997	Onion Creek Watershed; Stevens County	192	NE	Western hemlock (low); Fir/pine/spruce (high)	Mostly 2 – 4%	50% glacial sediments; granitic; sedimentary	M,U	O,S	No
Analogous Process-based Approach									
Bilby and Ward 1989	Willapa Hills and SW Cascades	0.4 – 68	WW	Western redcedar, Douglas-fir, western hemlock, red alder	1 – 18	Gravel/cobble; volcanic rock	U	S	Yes
Montgomery et al. 1995	Corner and Trap Bay, AK; Tolt River watershed, WA	Width: 2.7 – 38.1m	WW and Alaska	Unknown	0.2 – 8.5	AK: limestone, granite and metasediments; WA: tertiary igneous and sedimentary rocks and pre-Tertiary mélange	M,U	S,O	Yes

[a] Region is the major basin in which the study was performed: BM: Blue Mountains; CB: Columbia Basin; NC: Northeast Cascades; NE: Northeast Corner; OH: Okanogan Highlands; SC: Southeast Cascades; WO: western Oregon; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

institutions and/or analysts would have to be contacted (Sturham 2003 personal communication). Additional time would also be necessary for reviewing the methods with respect to earlier versions of the DNR Watershed Analysis Manual and gaining additional information from study authors about their methods. Without more specific information on the condition and type of original data, the level of effort that would be required cannot be estimated however, it would likely be a labor-intensive process.

There is some peer-reviewed information available to describe these relationships for western Washington and other regions (e.g., Bilby and Ward 1989; Montgomery et al. 1995). Bilby and Ward (1989) studied the relationships between LWD characteristics and pool characteristics, and how these relationships changed with stream size. They collected data for wood characteristics (diameter, length, and orientation; length, height, width of accumulations) and pool characteristics (type and surface area) for a range of stream sizes and examined percent and size of pools for given wood characteristics (orientation, size, volume). Montgomery et al. (1995) examined the effects of LWD on pool spacing in southeast Alaska and Washington.

One approach to answering this question may be to build from the design and methods used in the western Washington studies to create a study specific to one or more ecoregions of eastern Washington. The design and execution of a focused, field-based research project in a limited geographic area could provide a more cost-effective approach to address the specific interests of SAGE regarding the relationships between stream flow, wood, and pools in eastern Washington. A field program to address Question 21 for several different regions would be costly. If the SAGE focused their interest on a specific region of importance, or on specific characteristics of drainage basins that are representative of basins of interest to the SAGE, choosing sites from stratified sample, then a focused field study may provide a more direct and less costly approach to the desired information.

References

Bilby, R.E. and Ward, J.W. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Transactions of the American Fisheries Society. 118:368-378.

Carlson, T., B. Collins, D. Glass, J. Greenberg, B. Higgins, J. Kirtland, D. Martin, M. McGreevy, B. Bidstrup, D. Parent, J. Stofel, L. Torgerson, D. Whitwill, and W. Wold. 1996. West Branch of the Little Spokane River Watershed Administrative Unit 550101 Watershed Analysis: Resource Assessment Report and Prescriptions Draft Report. Prepared for Boise Cascade Corporation.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Keller, E.A. and F.J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4:361-380.

Montgomery, D.R., J.M. Buffington, R.D. Smith, K.M. Schmidt, and G. Pess. 1995. Pool spacing in forest channels. Water Resources Research 31(4):1097-1105.

Raines, M., C. Cooper, K. Doughty, K. Vanderwal Dube, C. Fairbanks, D. Glass, J. Greenberg, G. Konkel, and K. Kuzis. 1997. Onion Creek Watershed Analysis. Prepared for Boise Cascade Corporation.

Sturham, N. 2003. Personal communication (telephone conversation with 10,000 Years Institute regarding state watershed assessments). Washington Department of Natural Resources. October 24, 2003.

7.3 Question 22 Response

What is the distribution of residual pool volumes? Is it significantly different than Westside streams? Provide summaries of numeric information.

Summary of Literature Sources

Of the references searched, three studies were found directly related to eastern Washington and two were related to western Washington. References used in response to Question 22 are listed in detail on Table 7.3-1.

Summary of Quantitative Data

The available literature for eastern Washington contains few data on residual pool volumes. Only two of the 12 watershed analyses we reviewed reported residual pool volumes. The west branch of the Little Spokane River Watershed Analysis (Carlson et al. 1996) reported percentages of pools that fall into a series of residual depth categories (e.g., 8.3 percent of pools in one study reach of a tributary of the Little Spokane River range from 0 to15 cm residual depth) (Table 7.3-2). The Thompson Creek Watershed Analysis (Dunton et al. 1997) reported residual pool depths for 9 of 31 reaches surveyed; values reported ranged from 12 to 19 inches (30 to 48 cm) (Table 7.3-3). The proportions of residual pool depths reported from the Little Spokane watershed were highly variable, though for nearly all reaches studied, the majority of the residual depths recorded were greater than 30cm.

In the eastern Cascades, Smith (1993) conducted a study comparing historic pool surveys from 1935 to 1990 stream surveys on the Little Naches River and Taneum Creek. She stated in her methods that she recorded residual pool depth, "measured at the pool tail crest in all pool units" (p. 30), in two streams in eastern Washington. However, we could not find any presented data describing residual pool characteristics in Smith's (1993) thesis.

There were two references for westside streams reporting data for residual pool characteristics. Nelson (1998) evaluated LWD and sediment effects on pool characteristics in western Washington. He found that residual pool depth is predominantly a function of basin area ($p<0.001$). Keim et al. (2002) reported residual pool volumes (residual depth x residual width x residual length) for the Oregon Coast Range in an experiment adding LWD to streams and measuring resultant changes in pool characteristics. The authors reported mean residual pool volume per channel length (m^3/m) ranging from 0.15 to 0.5 for three streams studied.

No studies were found that provide a comparison of residual pool volumes between eastside and westside streams.

Table 7.3-1. Summary of literature sources containing data relevant to question 23.

Reference	Location	Basin Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Raches (%)	Study Area Geology	Drainage Management?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Carlson et al. 1996	West branch of Little Spokane Watershed ; Spokane County	260	NE	Douglas-fir, grand fir, western hemlock	<1 – >20%	Granitic/Meta-sedimentary	M,U	S,Q	No
Dunton et al. 1995	Huckleberry Watershed; Stevens County	Approx. 200	NE	Mixed wood/pasture	<1 – >20%	Metamorphic marine/granitic; sedimentary; glacial till, loess	M,U	Q	No
Smith 1993	E. central Cascades	214 – 398	NC	Ponderosa pine; western hemlock/ deciduous	1.6%	Basalt/sandstone	M	S,Q	No
Westside Streams									
Nelson 1998	Skagit and Stillaguamish watersheds, WA	8.6 – 33.8	WW		0.5 – 3.1				Yes
Kiem et al. 2002	Central Coastal Oregon	7.0 – 15.5	WO	TSHE	0.0004 – 0.011 m/m	Alluvial sand/gravel	M	S	Yes

[a] Region is the major basin in which the study was performed: BM: Blue Mountains; CB: Columbia Basin; NC: Northeast Cascades; NE: Northeast Corner; OH: Okanogan Highlands; SC: Southeast Cascades; WO: western Oregon; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. The only data found pertinent to this question was from two watershed analyses, representing only the east Okanogan ecoregion of eastern Washington (Table 7.1-1).

It is possible that other watershed analyses that were not reviewed for this study provide additional information for residual pools. However, the low proportion of watershed analyses that did contain residual pools data (2 of 12) suggests that residual pool data may not be included in other watershed analyses. It will be necessary to collect new field information to acquire data for residual pool characteristics.

Summary and Recommendations

All of the qualifications of data listed in Question 20 regarding spatial and temporal variation in studies and inconsistency in methods also apply to this question. Moreover, data were not presented consistently between the studies that did provide residual pool depths and volumes. While some documents present pool depths, others present pool depth categories, and the rest present pool volumes. As a result, direct comparisons cannot be made even if other differences between the studies, such as drainage area or sample size, are ignored.

A successful methodology to assess the distribution of residual pool volumes in eastside streams will include residual pool measurements in three dimensions such as in Keim et al. (2002). Further, measurements of bankfull width should be included in surveys so that residual pool volume distribution can be expressed in terms of normalized reach length, where normalized reach length is a function of bankfull width. Data in this form can be used for comparative analyses between basins in different ecoregions or of different sizes and also to investigate the influence of other parameters, such as channel morphology or presence of woody debris.

References

Carlson, T., B. Collins, D. Glass, J. Greenberg, B. Higgins, J. Kirtland, D. Martin, M. McGreevy, B. Bidstrup, D. Parent, J. Stofel, L. Torgerson, D. Whitwill, and W. Wold. 1996. West Branch of the Little Spokane River Watershed Administrative Unit 550101 Watershed Analysis: Resource Assessment Report and Prescriptions Draft Report. Prepared for Boise Cascade Corporation.

Dunton, D., W. Bidstrup, J. Powell, D. Beich, c. chesney, J. Parodi, M. Raines, R. LeCaire, and J. Fenner. 1995. Huckleberry Watershed Analysis. Prepared for Boise Cascade Corporation and Washington DNR.

Dunton, D., L. McDougall, J. Powell, L. Vauegeois, K. Lautz, J. Parodi, M. Hunter, and S. Shaw. 1997. Thompson Creek Watershed Analysis. Prepared for Washington Department of Natural Resources. August 1997.

Table 7.3-2. Residual pool data from the West Branch of the Little Spokane River Watershed Analysis.
All quantitative data provided in the assessment are shown here as presented in the report. The data provided is a subset of the data collected by the researchers (Carlson et al. 1996).

Stream Name	Reach Number	Portion of Pools with a Residual Depth of				
		0-15cm	15-30cm	30-60cm	60-100cm	>100cm
Buck Creek	1	8.33	66.67	16.67	8.33	0.00
Buck Creek	2	23.08	50.00	19.23	7.69	0.00
Buck Creek	5	7.41	70.37	22.22	0.00	0.00
Buck Creek	6	37.50	59.38	3.13	0.00	0.00
Buck Creek	7	0.00	47.62	28.57	19.05	4.76
Heel Creek	3	0.00	56.00	20.00	24.00	0.00
Heel Creek	4	25.00	64.29	10.71	0.00	0.00
Heel Creek	11	13.46	84.62	1.92	0.00	0.00
Heel Creek	12	17.31	67.31	15.38	0.00	0.00
Sec 5 Creek West Branch	8	0.00	70.59	23.53	5.88	0.00
Hwy 211 West Branch	9	12.5	62.5	12.5	12.5	0.00
Hwy 211	9	0.00	100.00	0.00	0.00	0.00
Beaver Creek	10	25.00	56.25	9.38	9.38	0.00
Beaver Creek	14	9.62	59.62	26.92	1.92	1.92
Fan Lake Outlet	13	62.50	37.50	0.00	0.00	0.00

Table 7.3-3. Residual pool data from the Thompson Creek Watershed Analysis.
All quantitative data provided in the assessment are shown here. The data provided is a subset of the data collected by the researchers (Dunton et al. 1997).

Unit Number	Unit Length (feet)	Unit Length (m)	Residual pool depth (inches)	Residual pool depth (cm)
Thompson Creek downstream transect				
2	8	2.4	8	20
4	15	4.6	6	15
6	6	1.8	11	28
8	15	4.6	8	20
Thompson Creek upstream transect				
5	4	1.2	8	20
7A	4	1.2	6	15
9	11	3.4	12	30
11	3	0.9	7	18
14A	4	1.2	7	18
17A	10	3.0	9	23
22	4	1.2	10	25
24	4	1.2	7	18
27	4	1.2	8	20

Keim, R., A.E. Skaugset, and D.S. Bateman. 2002. Physical aquatic habitat II. Pools and cover affected by large woody debris in three western Oregon streams. North American Journal of Fisheries Management 22(1):151-164.

Nelson, K. 1998. The Influence of Sediment Supply and Large Woody Debris on Pool Characteristics and Habitat Diversity. M.S. Thesis. University of Washington, Seattle, Washington.

Smith, J.E. 1993. Retrospective analysis of changes in stream and riparian habitat characteristics between 1935 and 1990 in two eastern Cascade streams. M.S. Thesis. University of Washington, Seattle, Washington.

7.4 Question 23 Response

Do pool sizes vary by ecoregion, stream size, and/or channel morphology, if so in what way? Provide summaries of numeric information.

Summary of Literature Sources

Of the references searched, three studies were found directly related to eastern Washington and one was related to the topic but not directly to eastern Washington. References used in response to Question 23 are listed in detail on Table 7.4-1.

Summary of Quantitative Data

Variation of Pool Sizes and Volumes with Ecoregion

Reports of direct measures of "pool size" were not found in the literature search. Instead, authors report the frequency of pools of a certain size class.

McIntosh et al. (1994) provide frequencies of large (>20m^2 area, $\geq$0.9m depth) pools within individual streams for several ecoregions of eastern Washington and northeastern Oregon (Table 7.1-2). McIntosh et al. (2000) used the same criteria as McIntosh (1994) for large pools and also include deep pools ($\geq$20m^2 area and $\geq$1.8 m depth; Table 7.1-2). Both studies concluded that there was an increase in pool frequencies in several streams of the north and eastern-central Cascades region between the 1930s and the 1990s. In contrast, pool frequency declined significantly in both the Blue Mountains and the western Cascades over this time period (McIntosh et al. 1994; McIntosh et al. 2000).

To explain ecoregional differences in the frequency of large pools over time, McIntosh et al. (2000) cite differences in the degree of recent and historical human activity. The large extent of wilderness area in the north Cascades is given as the reason for higher pool frequencies relative to the Blue Mountains region. In the Blue Mountains, high levels and long duration of human activity have lead to simplification of stream channels, which McIntosh et al. (2000) believe drove the decrease in quantity and quality of stream pool habitat.

Curran (unpublished) conducted one of the few studies that directly compared pool characteristics between regions, but does not analyze differences in pool frequencies between the eastern and western Cascades streams she studied. A brief examination of Curran's data shows a wider distribution of pool spacing and pool volume for streams in the eastern Cascades, as discussed in Question 20 (see Figure 7.1-1). The eastern Cascades data, however, is not qualified by ecoregion and so there is no opportunity to evaluate the effect of this variable. Further, trends in the data for pool volume based on basin size are not readily apparent.

Pool Characteristics and Stream Size, Channel Morphology

Several of the watershed analyses reviewed make distinctions between geomorphic types of streams, classifying them by channel and valley form, slope, and stream morphology. Some of

Table 7.4-1. Summary of literature sources containing data relevant to question 23.

Reference	Location	Basin Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches	Study Area Geology	Drainage Management?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Curran unpublished data	E. and W. central Cascades	<10km^2 /stream studied	NC	Conifer/deciduous mix	0.06 – 0.18 m/m	Volcanic, metamorphic, and glacial till	ND [c]	O	No
McIntosh et al. 1994	Interior Columbia River Basin	828 – 15,900	NC, CB, BM	ND	ND	ND	M,U	S,Q	Yes
McIntosh et al. 2000	Interior Columbia River Basin	<50– >4,700	NC, SC, CB, BM, WW	ND	ND	ND	ND	S,Q	Yes
Analogous Process-based Approach									
Ralph et al. 1993	W. and Central Washington	ND	NC, WW	ND	ND	ND	ND	S,Q	No

[a] Region is the major basin in which the study was performed: BM: Blue Mountains; CB: Columbia Basin; NC: Northeast Cascades; NE: Northeast Corner; OH: Okanogan Highlands; SC: Southeast Cascades; WO: western Oregon; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

these watershed analyses break down pool characteristics by geomorphic channel type, or classify the stream (according to gradient, or as “pool-riffle” vs. “step-pool” channel type). However, no watershed analyses were identified that had analyzed relationships between channel type, stream size, and pool characteristics. Instead, watershed analyses used classification by geomorphic channel type as a way to gather more specific information about the watershed at finer scales, rather than to conduct comparisons among these channel types. In most cases, it cannot be determined whether size of the study reach or sample number were measured consistently between geomorphic channel types to enable independent comparisons.

McIntosh et al. (2000) stated, in their study of changes in pool characteristics across ecoregions of eastern and western Washington, that they “found no significant relationships between pool frequency and any measures of stream size for the historical or current data set” (p. 1483). However, there were problems with the completeness of their historical data and inconsistencies in the ways stream sizes were measured. Channel gradient and bankfull width measurements were, the authors stated, unavailable or beyond the scope of their study.

Ralph et al. (1993) explored relationships between pool characteristics and channel morphology in a Washington statewide stream monitoring study. Unfortunately, the authors do not stratify their analyses by ecoregion; all surveyed streams across the state are included in the analysis, so conclusions cannot be drawn about eastern Washington streams specifically. Ralph et al (1993) reported decreasing scour-pool frequency with increases in gradient and confinement, and an inverse relationship between the fraction of stream area taken up by pools and increasing gradient and confinement. Pools were uncommon in high-gradient streams relative to lower-gradient channels.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. The studies obtained for this summary do not provide direct comparisons of pool sizes between regions, stream sizes, or channel types. It is possible that further qualification and evaluation of watershed analyses data may provide further meaningful quantitative information but this is not highly probable.

Summary and Recommendations

Watershed analyses provide substantial data about pool characteristics, and some analyses categorize this data by channel type. However, the usefulness of this data is limited by differences in methods used, data quality and in the reporting of methods. Several watershed analyses do not provide enough information on methods to judge data quality or to conduct comparisons with confidence among watersheds, or within watersheds among channel types. To use these data to address questions about pools in eastern Washington streams would require that the methods be verified for consistency between different reports, and that the original data be obtained and analyzed specifically with respect to these questions. The original data for these watershed analyses does not currently exist in a centralized location, so the sponsoring institutions and/or analysts would have to be contacted, which would be labor intensive (N. Sturham 2003 personal communication). Additional time would also be necessary for reviewing the methods with respect to earlier versions of the DNR Watershed Analysis Manual and gaining additional information from study authors about their methods.

The wide range of scales at which these studies were performed suggests that direct comparisons among studies from different ecoregions should be made only following careful review of the data and methods to be sure such comparisons are statistically valid. Because many references provided only summary or qualitative information, it may be possible that Question 23 and others in the pool formation topic could be more thoroughly addressed if authors of these papers are contacted, original data procured, methods reviewed, disparate metrics reconciled and original analyses performed. However, without more detailed information on the condition and type of original data, the specific level of effort that would be required cannot be determined. Since procuring new field data for pool characteristics for multiple ecoregions would be costly, it may be more cost-effective to continue intensive mining of the gray literature, including an effort to compile, standardize and analyze original data files for the reports summarized above and possibly other watershed analyses.

The design and execution of a focused, field-based research project in a limited geographic area could provide a more direct approach to address the specific interests of SAGE regarding comparisons of pool characteristics among ecoregions and channel types. It is feasible to design a new study to address relationships between pool characteristics and stream size or channel type, since this type of study could be conducted at the scale of a single or few watersheds. A successful methodology to assess the effect of ecoregion, stream size, and/or channel morphology on pool characteristics in eastside streams should include measurements of residual pool characteristics. Measurements of bankfull width should also be included in surveys so that pool size can be expressed in terms of normalized reach length, where normalized reach length is a function of bankfull width. Data in this form could be used for comparative analyses between basins in different ecoregions, different sizes, and varying channel morphologies. Evaluations of the influence of channel morphology on pool size must define the type and scale of morphological characteristics being evaluated and provide clear justification for the use of these features.

References

Curran, J.H. Unpublished. U.S. Geological Survey: Unpublished data used with permission from the author, October 14, 2003.

McIntosh, B.A., J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke, G.H. Reeves, and L.A. Brown. 1994. Historical Changes in Fish Habitat for Select River Basins of Eastern Oregon and Washington. Northwest Science 68(Special Issue):36-53.

McIntosh, B.A., J.R. Sedell, R.F. Thurow, S.E. Clarke, and G.L. Chandler. 2000. Historical changes in pool habitats in the Columbia river basin. Ecological Application 10(5):1478-1496.

Ralph, S., T. Cardoso, G.C. Poole, L.L. Conquest, and R.J. Naiman. 1994. Ambient Monitoring Project Biennial Progress Report, 1989-1991 Biennial Period. Center for Streamside Studies, University of Washington, Seattle, Washington.

Sturham, N. 2003. Personal communication (telephone conversation with 10,000 Years Institute regarding state watershed assessments). Washington Department of Natural Resources. October 24, 2003.

7.5 Question 24 Response

Is there a correlation between wood volume and/or number of pieces of wood in the stream segment and the number and/or volume of pools in that stream segment? If so, what is the relationship? Provide summaries of numeric information.

Summary of Literature Sources

Of the references searched, nine studies were related to eastern Washington and four studies were related to western Washington and/or Oregon. References used in response to Question 24 are listed in detail on Table 7.5-1.

Summary of Quantitative Data

Many researchers have described a positive relationship between LWD abundance and pool frequencies (Keller and Swanson 1979; Harmon et al. 1986; Nakamura and Swanson 1993; Abbe and Montgomery 1996; Nelson, 1998). Manuals that standardize methodology for research on large woody debris in Washington (Department of Natural Resources 1997; Shuett-Hames et al. 1999) specifically discuss the key role LWD can play in forming and maintaining pools. Reviewing the Washington literature, studies that confirm a positive relationship between LWD and pool abundance were found. However, many of the studies reviewed favored narrative descriptions of these relationships or simple presentations of numeric data, rather than rigorous statistical analyses of the relationships between specific stream and wood attributes.

Relationships Between Large Woody Debris Abundance and Pool Frequency Volume

Watershed analyses reviewed for the pool formation topic provided limited quantitative information describing LWD and pool relationships. Several of the watershed analyses reviewed provide narrative descriptions of LWD abundance in relation to pool abundance. Some analyses provide a ranking system of “poor” to “excellent” for both pool frequency and LWD abundance to describe habitat conditions relative to criteria for fish habitat quality set forth by the WDNR (DNR 1997). Some provide pool frequency and volume concurrent with LWD abundances, but few analyzed correlations among these variables.

Narrative descriptions in the watershed analyses suggest positive relationships between LWD and pool frequencies, or state that lack of LWD limits pool formation. For example, the Big Sheep Creek watershed analysis, Stevens County states that: for several areas of the main stem of Big Sheep Creek, “lack of wood limits pool formation” (Raines et al. 1995). In the Ahtanum watershed (McKinney et al. 1997), several survey transects are described with the comment that what little LWD exists functions to create pool habitat. In steep portions of the watershed, the analyst states that an increase in LWD “could increase pool habitat and stability” (p F-29).

The watershed analysis for the west branch of the Little Spokane River, Spokane County (Carlson et al. 1996) directly addresses correlations between LWD abundance and pool frequency by plotting these large wood pieces per channel width against pool spacing (Figure

Table 7.5-1. Summary of literature sources containing data relevant to question 24.

Reference	Location	Basin Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Study Area Geology	Drainage Management?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Carlson et al. 1996	West branch of Little Spokane Watershed ; Spokane County	260	NE	Douglas-fir , grand fir , western hemlock	<1 – >20%	Granitic/ Meta-sedimentary	M,U	S,Q	No
McIntosh et al. 1994	Interior Columbia River Basin	828 – 15,900	NC, CB, BM	ND [c]	ND	ND	M,U	S,Q	Yes
McKinney et al. 1996	South Fork Touchet Watershed; Columbia County	207	BM	Ponderosa pine/quaking aspen (low); ponderosa pine, grand fir, Douglas-fir, western larch (mid); grand fir, Douglas-fir (high)	<1 – >8%	Volcanic; loess	M,U	O,S,Q	No
Raines et al. 1999	Upper Little Klickitat Watershed; Klickitat County	243	CB	Grassland, ponderosa pine/Douglas-fir	<1 – >20%; 50% are 4 – 12%	Volcanic, sedimentary	M,U	O,S	No
Raines et al. 1997	Onion Creek Watershed; Stevens County	192	NE	Western hemlock (low); Fir/pine/spruce (high)	Mostly 2 – 4%	50% glacial sediments; granitic; sedimentary	M,U	O,S	No
R2 Resource Consultants 2002	Sinlahekin Watershed; Okanogan County	188	NC	Ponderosa pine/Apache pine/Douglas-fir; alpine	<1 – >20%	Volcanic, sedimentary, glacial drift	M,U	O,S	No
	Toats Coulee Watershed; Okanogan County	181	NC	Ponderosa pine/Apache pine/Douglas-fir; alpine	<1 – >20%	Igneous/metamorphic; glacial deposits	M,U	O,S	No
Western Washington									
Bilby and Ward 1989	Willapa Hills and SW Cascades	0.4 – 68	WW	Western redcedar, Douglas-fir, western hemlock, red alder	1 – 18	Gravel/cobble; volcanic rock	U	S	Yes
Nelson 1998	Skagit and Stillaguamish watersheds, WA	8.6 – 33.8	WW		0.5 – 3.1				Yes
Kiem et al. 2002	Central Coastal Oregon	7.0 – 15.5	WO	TSHE	0.0004 – 0.011 m/m	Alluvial sand/gravel	M	S	Yes
Montgomery et al. 1995	Tolt River; western Cascades	ND	WW	ND	0.002 – 0.085 m/m	Pleistocene limestone, granite; tertiary igneous, sedimentary	M,U	S	Yes

[a] Region is the major basin in which the study was performed: BM: Blue Mountains; CB: Columbia Basin; NC: Northeast Cascades; NE: Northeast Corner; OH: Okanogan Highlands; SC: Southeast Cascades; WO: western Oregon; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

7.5-1). The authors state that their analysis indicates an inverse relationship between large woody debris abundance and pool spacing (i.e., at higher LWD abundances, pools become more frequent), but they do not provide statistical analysis to indicate the strength or significance of the relationship. Original data are not given in the report.

A few studies noted differences in the importance of wood as a pool-forming or pool-maintaining factor based on the channel type and gradient. Raines et al. (1999), in their analysis of the upper Little Klickitat watershed, Klickitat County, stated that the role of woody debris in pool formation was most important in non-ephemeral channels with gradients of 2 to 8 percent, whereas LWD was less important in higher-gradient streams, where other effective step-forming agents such as boulders and bedrock were common. In the Loomis watershed, Okanogan County (R2 Resource Consultants 2002), moderate gradient channels (2 to 6 percent) were described qualitatively as being particularly responsive to LWD. They state that LWD was tightly associated with pools (42 percent of pools in these channel types were associated with LWD) in moderate gradient channels relative to other channel types, even though LWD abundance was lower in this channel type relative to other channel types.

McIntosh et al. (1994) found significantly lower numbers of large woody debris (defined by the authors as pieces ≥ 0.1m diameter and ≥2.0m length) in managed (heavy anthropogenic land use, including grazing and timber harvest) relative to unmanaged (low human impact) watersheds in the Northeast Cascades, Columbia Basin, and Blue Mountains regions (mean, managed: 41.8 pieces LWD/km; mean unmanaged: 66.1 pieces LWD/km, $p < 0.05$). The authors simultaneously found a 28 percent decrease in the frequency of large pools in managed basins over the period between the 1934 to 1942 surveys and the 1990 to 1992 surveys, while pool frequency in unmanaged basins over this same time period increased by 77 percent. It is not clear whether the same streams were used for these two analyses, and therefore the trends in pools may not be directly comparable to the trend in wood abundance. The authors maintain that "significantly lower amounts of CWD [coarse woody debris] in managed watersheds, coupled with the history of CWD removal…reduces habitat complexity, channel roughness, and sediment storage" (p. 49). In their discussion, they draw parallels between the decline of woody debris in managed basins and the decline of pool frequencies and other measures of morphological complexity in these streams.

Large Woody Debris as Cover

Several of the watershed analyses reviewed in this study provide the percentage of pools that were associated with wood that provided cover for fish (Table 7.5-2). This is not a direct assessment of the role of wood in forming or maintaining pools, but indicates when (for these sites) pools are closely associated with wood. Most often these data were recorded as a measure of quality of fish habitat, assuming that LWD provided shading and refuge for fish. In most analyses, the percentage of pools associated with wood as cover was provided with a ranking, from "poor" to "good," that referred to quality of fish habitat set by the DNR (1997) or the Forest Practices Resource Board. It is unclear in most of these analyses whether researchers used criteria for the size of wood considered to provide cover.

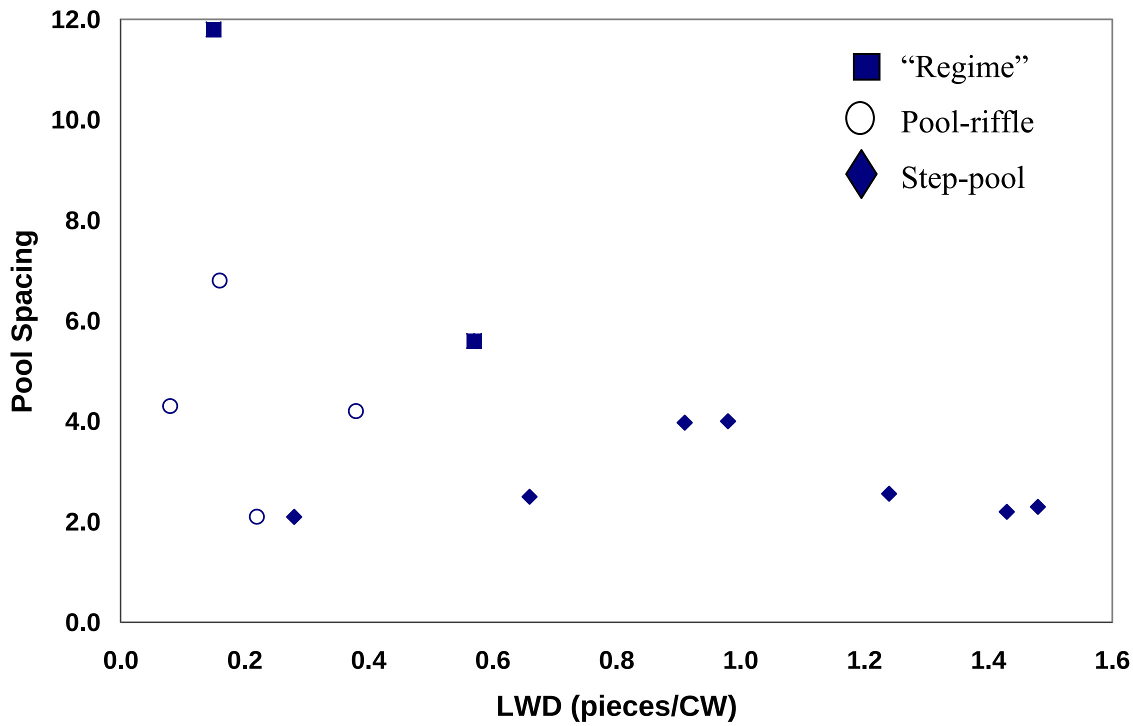

Figure 7.5-1. Relationships between pool spacing and large woody debris, by channel type, based on data from 13 stream reaches in the west branch of the Little Spokane Watershed Analysis.
Channel type is defined by the authors as based on D. Montgomery and J. Buffington's 1993 report: Channel classification, prediction of channel response, and assessment of channel condition, report TFW-SH10-93-002, Washington State Department of Natural Resources. The graph is recreated from figure F-2 in Carlson et al. 1996.

Table 7.5-2. Eastern Washington studies providing information about percentage of pools in study streams associated with wood cover.
See Table 7.1-1 for additional information about the location and basin characteristics of these studies.

Reference	Watershed/ Stream	Percentage of Pools Where Wood Provides Cover [Rating [a]]
R2 Resource Consultants 2002	Loomis Watershed	[poor-good; most are poor-fair]
Dunton et al. 1997	Thompson Creek Watershed	[good]
Doughty et al. 1996	Teanaway Watershed	[Poor-Good; 18 of 35 study reaches received a "poor" rating]
Raines et al. 1995	Big Sheep Creek	[Poor-Good]
Carlson et al. 1996	West Branch of the little Spokane River	0 to 97; for 55 percent of surveyed reaches, less than 50 percent of pools are associated with wood
McKinney et al. 1996	South Fork Touchet	15 – 30 [fair-good]
	Wolf Fork	16-34 [fair-good]
	Robinson Creek	10-29 [fair-good]
McKinney et al. 1997	Ahtanum Creek Watershed	All surveyed reaches <20 percent wood cover [poor-fair]
Kiem et al. 2002	Oregon Coast Range	$0.03 – 0.45\ m^2/m$[b]

[a] In several of the watershed analyses, no quantitative data is given for pool characteristics, but a rating is given (poor, fair, or good). This rating refers to the value of the pool relative to benchmark values for fish habitat quality as established in the DNR Watershed Analysis Manual (DNR 1997), p. F-24.
[b] Kiem et al. (2002) values are residual pool area covered by LWD per channel length (m^2/m).

Western Washington and Pacific Northwest Data

In the course of reviewing eastern Washington data for pools and LWD data, a few studies from other areas of the Pacific Northwest that provided information on relationships between LWD and pools were encountered. Montgomery et al. (1995) examined quantitative relationships between LWD loading and pool spacing in watersheds of southeast Alaska and the western Cascades of Washington. They found an inverse relationship between LWD loading and mean pool spacing in pool-riffle, plane-bed, and forced pool-riffle channels, while pool spacing in steeper step-pool channels was found to be independent of LWD loading.

In examining 2nd to 5th order streams in western Washington, Bilby and Ward (1989) found that pool area was positively correlated with the volume of the piece of wood forming the pool. The authors also found that the proportion of scour pools associated with large woody debris was positively related to width of the stream. The opposite trend was true for plunge pools, which, in the largest streams studied (>10m channel width), had the fewest pools associated with LWD.

Keim et al. (2002) measured changes in the percentage of residual pool area covered by LWD as a result of adding LWD to three streams in the Oregon Coast Range. LWD cover increased by 60 percent to 308 percent in the treated portions of these three streams within the first year after additions. Cover remained at least 60 percent higher than pretreatment values in the three subsequent years. The authors also illustrate that cover increased with residual pool volume and suggest that this positive relationship indicates a positive relationship between LWD and pool formation.

Nelson (1998) evaluated LWD and sediment affects on pool characteristics in western Washington. He found that LWD was associated with 58 percent of the pools measured. He also found that residual pool depth is predominantly a function of basin area ($p<0.001$) and that LWD was positively correlated with pool area and the frequency of pools ($p<0.002$, $p<0.001$, respectively).

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer the question. Only a few studies, representing the Northeast Cascades, Columbia Basin, East Okanogan, and Blue Mountains regions, were found to contain information to describe relationships between pool frequency or volume and LWD abundance. Even fewer of these contained quantitative data, and no eastern Washington studies were found that provided statistical analyses to examine these relationships.

Summary and Recommendations

Although there are some studies based in eastern Washington that address relationships between pool frequency or volume and LWD, the majority do not provide quantitative information or conduct analysis to rigorously explore these relationships. Several of the studies reviewed started from the premise that LWD was positively related to pool formation and maintenance, rather than attempting to test this relationship. As discussed in Question 20, additional effort could be expended to track down watershed analyses not reviewed here, and review these to identify appropriate data. Tracking down the original data for watershed analyses might yield additional quantitative information about LWD and pools. Several studies reviewed ranked the abundance of LWD in pool cover in terms of its ability to provide fish habitat. For these studies, it may be that original field data give the numeric values used for this ranking system. However, as discussed in Question 20, the original data for these watershed analyses does not currently exist in a centralized location, so the sponsoring institutions and/or analysts would have to be contacted to obtain the original files and field forms (Sturham 2003 personal communication). Additional time would also be necessary for reviewing field methods with respect to earlier versions of the DNR Watershed Analysis Manual and gathering additional information from study authors about their methods to determine if they are consistent and comparable.

However, it may be more appropriate to design a study that specifically sets out to explore relationships between large woody debris and pool characteristics, rather than to mine data from studies that were not designed to ask these questions. Comments on specific design methodology were presented in the previous pool formation question responses.

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7.6 Question 25 Response

Is there a correlation between wood volume and/or number of pieces of wood in the stream segment and residual pool volume in that stream segment? If so, how are they correlated? Provide summaries of numeric information.

Summary of Literature Sources

Of the references reviewed, four studies were found to provide data specifically about residual pool volumes that simultaneously described large woody debris frequency, volume, and/or cover. Two of these studies were from eastern Washington and two were from western Washington (Table 7.6-1). All four sources have limited information, either because analysis of the relationships between residual pool characteristics and LWD was not conducted, or because of inconsistencies between studies.

Summary of Quantitative Data

A review of the available literature for eastern Washington produced almost no data on residual pool characteristics and their relationship to LWD. Only two of the 12 Department of Natural Resources Watershed Analyses reviewed reported on residual pool volumes in addition to LWD data. The Thompson Creek Watershed Analysis (Dunton et al. 1997) reported residual pool depths for 9 of 31 reaches surveyed, and simultaneously reported the percent of pools that were covered by wood. While average residual pool depths per reach ranged between 12 and 19 inches (30 to 48 cm), the percent of pools within each reach that were associated with LWD as cover was consistently 2 to 3 percent.

The West Branch of the Little Spokane River Watershed Analysis (Carlson et al. 1996) reported percentages of pools that fall into a series of residual depth categories, and simultaneously reported ratios of abundance of large woody debris and channel width. Carlson et al. (1996) did not analyze relationships between these two parameters. A regression analysis of their data does not reveal any pattern in the relationship between these two parameters (Figure 7.6-1).

Two studies for streams in the western Cascades also reported relationships between residual pool characteristics and LWD. Keim et al. (2002) reported residual pool volumes (residual depth x residual width x residual length) for the Oregon Coast Range in a study examining changes in pool characteristics across a range of treatments in which LWD was added to the stream. The authors reported that in all treatments where LWD was added, residual pool volume increased in the first year after treatment and pool depths increased during the study. However , because LWD moved out of their treatment and sometimes into and through the control sections during high water events, there was no true control that would allow for proper inference that the effects observed were the result of LWD additions. While the authors maintained that their observations support other literature that shows positive correlation between LWD loading and pool volumes and frequency, they could not provide statistical evidence to support this relationship in their study.

Table 7.6-1. Summary of literature sources containing data relevant to question 25.

Reference	Location	Basin Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Study Area Geology	Drainage Management?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Dunton et al. 1995	Huckleberry Watershed; Stevens County	Approx. 200	NE	Mixed wood/pasture	<1 – >20%	Metamorphic marine/granitic; sedimentary; glacial till, loess	M,U	Q	No
Carlson et al. 1996	West branch of Little Spokane Watershed ; Spokane County	260	NE	Douglas-fir , grand fir, western hemlock	<1 – >20%	Granitic/Meta-sedimentary	M,U	S,Q	No
Western Washington									
Kiem et al. 2002	Central Coastal Oregon	7.0 – 15.5	WO	TSHE	0.0004 – 0.011 m/m	Alluvial sand/gravel	M	S	Yes
Nelson 1998	Skagit and Stillaguamish watersheds, WA	8.6 – 33.8	WW		0.5 – 3.1				Yes

[a] Region is the major basin in which the study was performed: BM: Blue Mountains; CB: Columbia Basin; NC: Northeast Cascades; NE: Northeast Corner; OH: Okanogan Highlands; SC: Southeast Cascades; WO: western Oregon; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

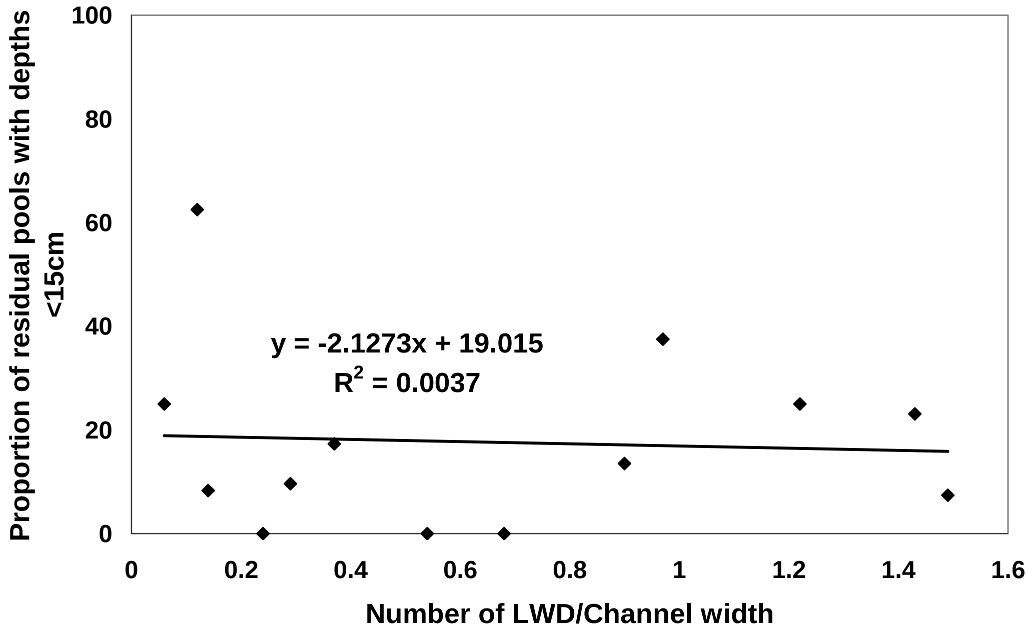

Figure 7.6-1. Correlation between the proportion of residual pools with depths <15cm and the number of large woody debris (defined as wood in the channel >10cm diameter, >2m length) per channel width in the Little Spokane River watershed, Spokane County, Washington.
(Carlson et al. 1996, Table F-4).

Nelson (1998) evaluated LWD and sediment affects on pool characteristics in western Washington. He found that residual pool depth is predominantly a function of basin area ($p<0.001$) and LWD was positively correlated with pool area and the frequency of pools ($p<0.002$, $p<0.001$, respectively). Further, LWD was associated with 58 percent of the pools measured.

Little information is available describing relationships between residual pool depths and LWD for either eastern or western Washington residual pools. No direct comparisons, either quantitative or qualitative, between these two regions were identified in this information search.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

The list of qualifications provided in Question 20, regarding spatial and temporal variation in studies, and inconsistency in methods, also apply to information available to address this question. Of the few studies that provided data for residual pool characteristics and LWD, the data was not presented consistently, and was either not analyzed for these relationships or not suitable for quantitative analysis. Therefore, direct comparisons cannot be made even if other differences among the studies, such as drainage area or sample size, are not considered. It is possible that watershed analyses not reviewed (Table C1) provide additional information that could be used to analyze relationships between residual pools and LWD. However, the low proportion of watershed analyses reviewed that did contain such information (2 of 12) suggests that residual pool data were not considered important in these studies, and therefore are unlikely to be reported in many other watershed analyses.

It will be necessary to collect new field information to evaluate relationships between residual pool characteristics and LWD specifically for eastern Washington. Comments on specific design methodology of residual pool characteristics were made in the Question 22 response.

References

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8.0 Bedload Transport and Sediment

8.1 Question 26 Response

What role does wood play in storage and sorting of sediment in eastern Washington streams? Quantify the relationship, if possible.

Summary of Literature Sources

Of the references searched, one study was found directly related to eastern Washington, two were found relating to analogous regions and 79 were found related to the topic, but not region. References used in response to Question 26 are listed in detail on Table 8.1-1.

Summary of Quantitative Data

Sediment Storage

Eastern Washington

chesney (2000) performed a study on the functions of wood in small, high-elevation streams in eastern Washington. Woody debris, sediment obstructions, and riparian conditions were measured at 16 sites. Woody debris volume was sampled using Ambient Monitoring Program Manual (Schuett-Hames et al. 1994). Sediment obstructions were approximated as wedges; their volume was estimated as half of the measured step height multiplied by the average width and length. The obstructions included in the data set had step heights greater than 20 cm, average width greater than 30cm, and length greater than 60 cm.

chesney (2000) evaluated several relationships between wood characteristics and quantity of steps and stored sediment. He found weak correlation between in-channel wood and number of steps, but fair correlation (r^2=61.2%) between in-channel and near-channel wood with number of steps for managed sites (n=10). He found good correlation between in-channel wood and total obstructed sediment volume for the managed sites: adjusted r^2=69.2 percent (in-channel wood) and adjusted r^2=72 percent (in- and near-channel wood). chesney (2000) found that the unmanaged sites (n=5) displayed poor correlation between in- and near-channel wood and sediment volume. Figure 8.1-1 shows that, using chesney's data, managed sites display fair correlation between total wedge volume per bankfull width and total wood volume per bank full width, but unmanaged sites did not. Given the small sample size of unmanaged sites, however, it is difficult to draw robust conclusions from the observed lack of correlation. Mean sediment wedge volume was 1.13 times greater in unmanaged sites than managed sites.

Table 8.1-1. Summary of literature sources containing data relevant to question 26.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
chesney 2000	Ahtanum, Cowiche American, and Tieton basins	0.6 – 4.0	CB	Pacific silver fir (13 sites), Alaska yellow cedar (1 site), ponderosa pine and Doulgas-fir (2sites)	5 – 30	Cobble/boulder	5 Unmanaged 11 Managed	S,O	NO
Studies in Analogous Regions									
Megahan 1982	Idaho batholith - Silver Creek study area – MF of Payette River basin	0.26 – 2.02	NC, NE	Douglas-fir, ponderosa pine, grand fir, subalpine fir	14.9 – 31.5	Coarse-textured granitics	2 Managed 5 Unmanaged	S	Yes
Potts, F.D.; Anderson, M.K.B., 1990	NE Montana - Johnson Gulch	23	NC, SC, NE, OH, BM	Douglas-fir, ponderosa pine, western larch	10 – 31	Precambrian metasediments	Unmanaged	S,O	Yes
Analogous Process-based Approach									
Buffington, J.M. and Montgomery, D.R. 1999	Olympic Peninsula, WA	w: 5.12 – 13.39m, h: 0.34 – 0.86m [c]	Sediment sorting	Sitka spruce, western hemlock, western redcedar, Douglas-fir	0.4 – 2.65	Eocene to Miocene marine basalts and sediments	Managed	S,O	Yes
	Southeastern AK	w: 4.6 – 29.12m, h: 0.32 – 1.17m [c]	Sediment sorting	Sitka spruce, western hemlock	0.17 – 2.67	Major rock types ranging from Proterozoic to Quaternary	Managed and Unmanaged	S,O	Yes
Curran, J.H. and Wohl, E.E. 2003	Cascades Range, WA	0.13 – 9.6	Sediment sorting	Coniferous and deciduous species	7.1 – 18	Volcanic, metamorphic, and sedimentary rocks and glacial till	Managed	S,O	Yes

Table 8.1-1. Summary of literature sources containing data relevant to question 26 (continued).

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach									
MacFarlane, W.A. and Wohl, E.E. 2003	Western slope of Cascades Range, WA – Green River, Nisqually, Puyallup and Cowlitz watersheds	0.45 – 5.9	Sediment sorting		4 – 18	Boulder, cobble step-pool	Unmanaged	S, O	Yes
House, R.A. and Boehne, P.L. 1986	OR – Tobe Creek	9.27	Sediment sorting	Young alder (red alder) and mature mixed-conifer and bigleaf maple	3	Cobble/rubble	Managed	S,O	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] w – bankfull width, h – cross-sectionally averaged bankfull depth.

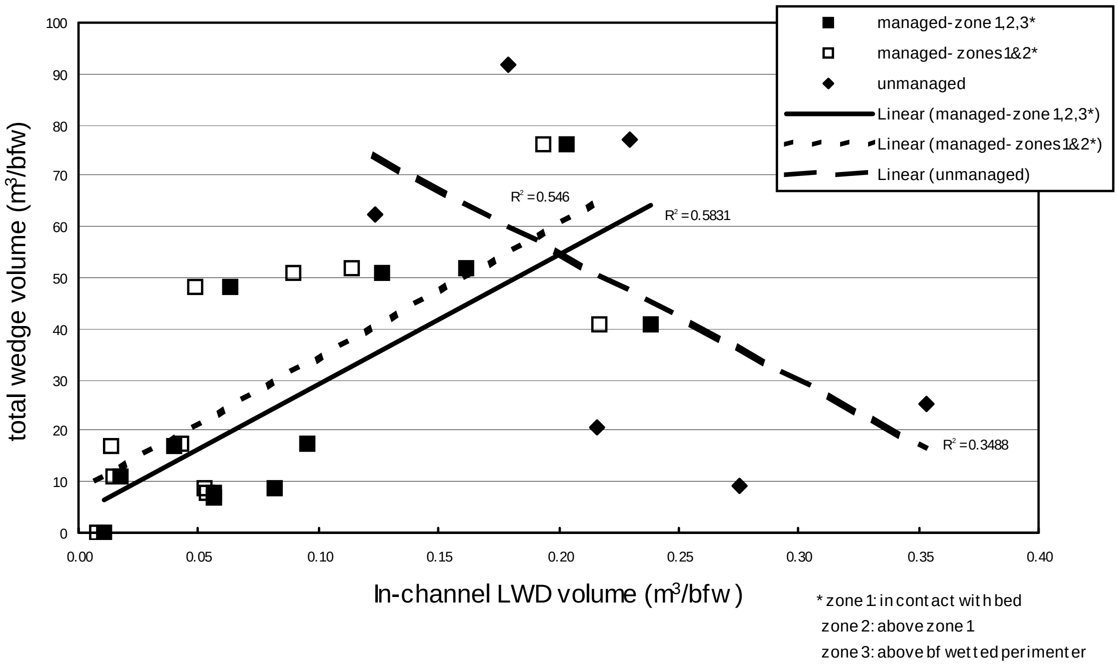

Figure 8.1-1. Relationship between LWD volume and total wedge sediment volume by managed and unmanaged riparian conditions.
From chesney (2000).

Analogous Regions

Megahan (1982) evaluated sediment storage behind obstructions. He looked at obstructions composed of logs (woody material over 10cm in diameter), rocks, roots, stumps, and debris (branches, twigs, leaves). Height, average width, and length of obstruction were measured. Sediment accumulation was determined by height, average width, and slope of deposition. This study illustrates the importance of log obstructions in sediment storage. Megahan found that, even though logs formed only 34 percent of obstructions (debris formed 42 percent), they were responsible for 49 percent of the total stored sediment (debris stored 29 percent). Figure 8.1-2 displays the frequency of occurrence of stored sediment behind logs and debris obstructions for 1^{st}–3^{rd} order streams with reach lengths between 1.0 and 9.5 km. Log steps retain fewer small sediment accumulations, but retain a higher number of large sediment accumulations. Unfortunately, a direct comparison of sediment retention by steps of varying composition between Megahan (1982) and chesney (2000) is not possible as chesney's data does not describe step composition when presenting sediment accumulation results. The range of sediment wedge volumes presented by Megahan (Figure 8.1-2), however, is narrower than that presented by chesney. chesney found maximum wedge volume to be 10.47 m^3 and the average volume to be between 0.18-1.8 m^3. It is also significant that Megahan's data does not reflect large logjams found in many moderate to large channels (Abbe and Montgomery 1996; O'Connor et al. 2003).

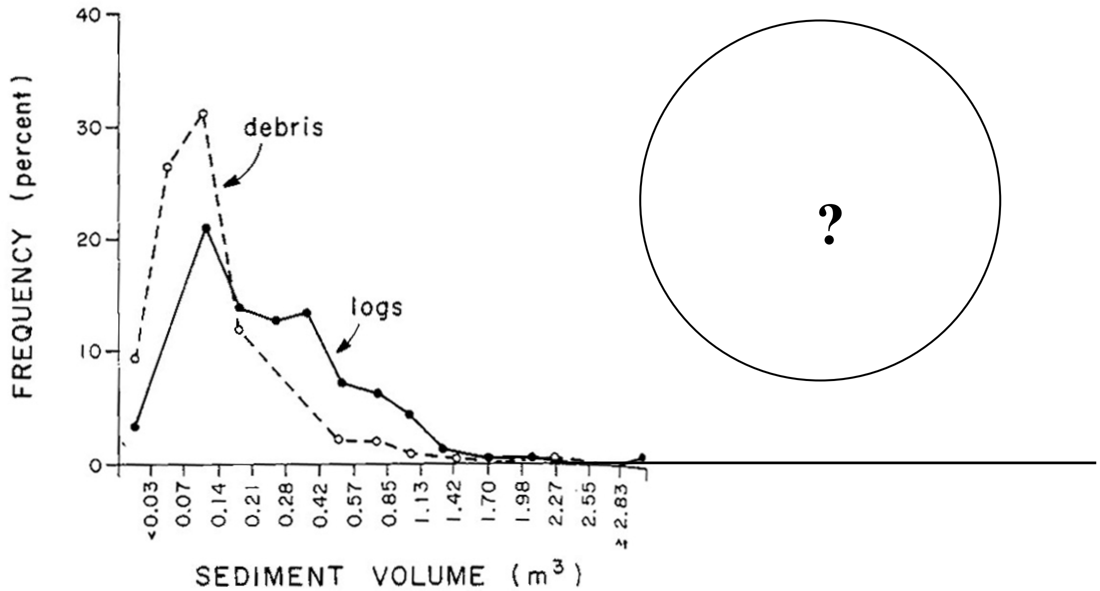

Figure 8.1-2. Frequency of occurrence for different volumes of sediment accumulation stored behind small woody debris steps and log steps, for 1st–3rd order streams with reach lengths between 1.0 and 9.5 km.
The majority of channel obstructions formed by small woody debris and logs store relatively little sediment by volume; and the majority of sediment storage occurs as relatively small wedges. Logs tend to store larger volumes of sediment than small debris and have a greater distribution with respect to sediment volume (Megahan 1982).

Potts and Anderson (1990) studied organic debris in western Montana streams that have greater drainage areas than the streams in previously mentioned studies. Organic material with diameter greater than 10 cm was considered LWD and material with a diameter less than 10 cm was considered small debris. The volume of sediment was determined geometrically. Potts and Anderson found that obstructions (log and small debris) in second order streams store the largest amount of sediment per unit area compared to first and third order channels. Log obstructions become more important as stream order increases: in first-order channels logjams retained 29 percent of total sediment, while small debris retained 33 percent; in second-order channels logs retained 56 percent and small debris retained 26 percent; and in third-order channels, logs retained 58 percent whereas small debris retained only 5 percent of total stored sediment (Table 8.1-2).

Sediment Sorting

There were no studies found in our search related to the effects of wood on sediment sorting in eastern Washington, but several studies performed in other regions could provide guidelines for future research in eastern Washington.

Table 8.1-2. Average sediment storage behind obstructions.
[kg/m^2 (% of total storage)] From Potts and Anderson (1990).

Type of Obstruction	Stream Order		
	First	**Second**	**Third**
Logs	7.6 (29)	26.1 (56)	19.8 (58)
Debris	8.6 (33)	11.9 (26)	1.8 (5)
Rock	9.7 (38)	8.3 (18)	12.4 (37)
Total	25.9 (100)	46.3 (100)	34.0 (100)

Buffington and Montgomery (1999) studied roughness effects on surface textures in plane-bed, wood-rich and wood-poor gravel-bed channels. Textural patches were classified using a standard method developed by the authors and grain sizes of each patch were determined from Wolman pebble counts of more than 100 grains. The study sites were separated into wood-poor (<0.03 pieces/m^2) and wood-rich categories (>0.03 pieces/m^2). They found that channels with greater roughness characteristics have finer reach-averaged grain sizes (Figure 8.1-3). Their study also reveals that wood-poor channels are composed of four textural types and 13 to 24 textural patches per reach, but wood-rich channels have three to seven different textural types and 17 to 55 textural patches within a reach (Figure 8.1-4, Table 8.1-3). The relationship between the presence of wood in a channel and textural composition is illustrated in Figure 8.1-5.

MacFarlane and Wohl (2003) evaluated flow resistance in step-pool channels in the western Cascades that lacked significant amounts of LWD. Alternatively, Curran and Wohl (2003) investigated flow resistance in step-pool channels in the Cascades with large amounts of LWD. Curran and Wohl (2003) incorporated the results of MacFarlane and Wohl (2003) in their analysis of the effect of LWD on particle sizes in step-pool channels. Both studies measured grain sizes by a random-walk method, modified from Wolman (1954), where 100 step-forming clasts and 100 pool-forming clasts were sampled. Results show that D_{50} and D_{85} for pools and steps (composite) and only steps are significantly lower in channels where LWD was present (Table 8.1-4).

House and Boehne (1986) studied the effects of instream structures on salmonid habitat in western Oregon. Bottom substrate was visually estimated in two different sites: an altered site with very little LWD and a relatively undisturbed site with large amounts of LWD. House and Boehne found that the presence of LWD influenced the composition of bottom substrate. The percentage of cobble-rubble, gravel, and fines in a wood-rich channel were higher in the wood-rich reach versus the wood-poor reach (Table 8.1-5).

Qualification of Literature Sources

The first part of this question (sediment storage) can be answered with additional quantitative analysis of existing data (#3). There is a sufficient source of scientific data to answer the question for the Columbia Basin of eastern Washington. However, in order to answer the question, numerical analysis of the data would be needed. The role of wood in the storage of

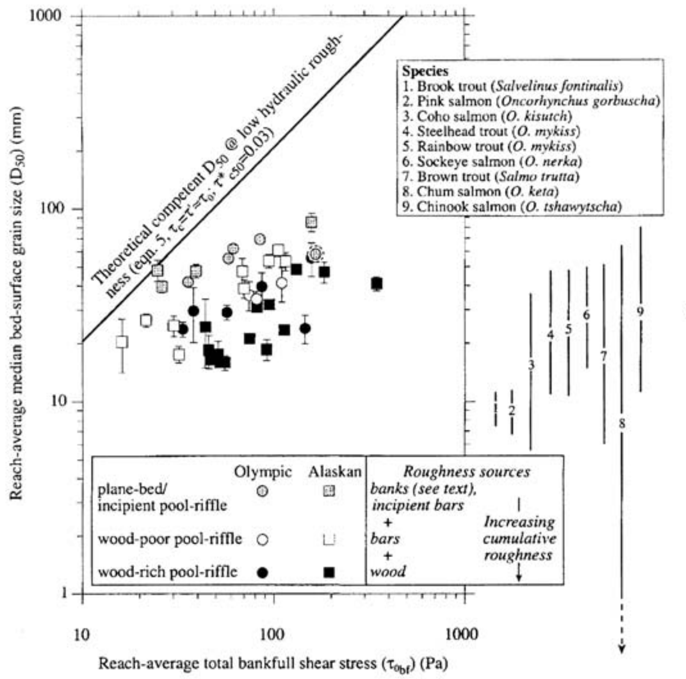

Figure 8.1-3. Relationship between median bed-surface grain size and total bank-full boundary shear stress.
Also shown are size ranges of preferred spawning gravels for different salmonid species (Kondolf and Wolman 1993). From Buffington and Montgomery (1999).

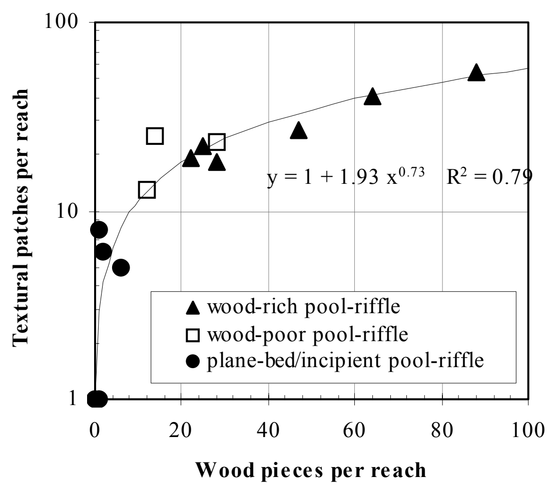

Figure 8.1-4. Frequency of textural patches versus wood pieces per reach for Olympic Peninsula channels.
Reach lengths varied between 60 and 154m. Adapted from Buffington and Montgomery (1999).

Table 8.1-3. Surface texture composition of the Olympic channels.
From Buffington and Montgomery (1999).

Channel	Texture*	Percentage of Bed	Frequency (Number/Reach)	D_{50},† mm	$\sigma_g(\phi)$†,‡
Plane-Bed/Incipient Pool-Riffle					
Dry 2	gC	100	1	67.1 (69.2)	1.24 (1.17)
Alder	G	0.4	1	~11	
	scG	9.0	4	21.8 (29.7)	1.76 (1.39)
	cG	90.6	1	56.1 (61.0)	1.58 (1.27)
Hoko 2	cG	100	1	54.8 (55.2)	1.34 (1.31)
Hoh 1	S	2	2	~2.0 (NA)	
	cgS	63	3	9.0 (42.7)	2.76 (1.26)
	cG	35	3	38.9 (40.3)	1.10 (1.05)
Hoh 2	S	4	2	~2.0 (NA)	
	cgS	4	1	9.0 (42.7)	2.76 (1.26)
	cG	0.5	1	38.9 (40.3)	1.10 (1.05)
	gC	91.5	1	61.4 (63.1)	1.54 (1.49)
Wood-Poor Pool-Riffle					
Skunk 2	S	9.33	9	<2.0 (8.5)	>0.65 (0.40)
	G	11.19	9	9.9 (12.8)	1.41 (1.05)
	csG	8.22	4	25.0 (27.8)	1.37 (0.98)
	cG	71.24	2	50.4 (51.5)	1.10 (1.05)
Hoko 1	sG	5.10	7	~6.0	
	G	13.87	9	13.1 (13.8)	0.98 (0.87)
	$cG_{mc\ vc}$	61.58	4	38.4 (39.2)	1.24 (1.20)
	$cG_{c\ vc}$	19.45	3	47.4 (47.7)	0.92 (0.92)
Pins 1	S	1.16	3	~2.0 (NA)	
	G_{cfm}	4.15	6	9.2 (11.0)	1.32 (1.02)
	$G_{fcm\text{-}fmc}$	2.58	3	12.7 (14.1)	1.15 (1.04)
	cG	92.11	1	33.3 (35.6)	1.57 (1.31)
Wood-Rich Pool-Riffle					
Pins 2	S	7.71	4	~2.0 (NA)	
	sG	3.22	3	7.1 (8.7)	0.92 (0.47)
	$cG_{m\ vcc}$	48.47	3	29.6 (30.4)	0.93 (0.88)
	$cG_{mc\ vc}$	40.61	7	52.4 (52.8)	1.01 (1.00)
Flu Hardy	Z	3.98	2	~0.06 (NA)	
	S	11.79	9	~2.0 (NA)	
	G_{cfm}	3.70	6	11.7 (12.0)	0.92 (0.90)
	$G_{mc\ vc}$	80.53	1	29.5 (29.9)	0.89 (0.85)
Mill	Z	1.63	2	~0.06 (NA)	
	S	15.89	21	~2.0 (NA)	
	$G_{cfm\text{-}vffm}$	11.77	25	8.4 (10.4)	0.93 (0.67)
	$G_{m\ vcc}$	62.57	2	23.7 (24.5)	1.04 (0.94)
	$G_{c\ vc}$	8.15	5	39.6 (39.6)	0.58 (0.58)
Dry 1	S	0.94	3	~2.0 (NA)	
	scG	4.79	2	9.3 (33.9)	2.34 (1.90)
	G	7.52	5	13.8 (15.7)	1.09 (0.87)
	cG	39.28	3	39.1 (39.6)	1.12 (1.09)
	gC	47.48	8	77.0 (77.0)	0.66 (0.66)
Skunk 1	S	16.15	32	~2.0 (NA)	
	G_{vcmc}	62.31	6	21.2 (22.0)	0.96 (0.84)
	$G_{m\ vcc}$	21.54	4	29.2 (29.2)	0.91 (0.91)
Cedar	Z	5.61	2	~0.06 (NA)	
	S	2.64	3	~2.0 (NA)	
	sG	1.08	6	6.6 (7.2)	0.98 (0.84)
	G_{vcmc}	12.80	11	17.6 (17.6)	0.65 (0.65)
	$G_{m\ vcc}$	64.19	1	26.6 (26.8)	0.70 (0.70)
	cG	6.15	1	35.3 (35.3)	0.82 (0.82)
	gC	7.53	3	74.4 (74.4)	0.89 (0.89)

*Textures are named using the *Buffington and Montgomery* [1999] classification scheme. Capital letters represent the dominant grain size (Z, silt; S, sand; G, gravel; and C, cobble), preceding lower case letters represent less abundant grain sizes, read as adjectives modifying the upper case noun (s, sandy; g, gravelly; and c, cobbley), and succeeding lower case subscripts further describe the grain size composition of the dominant size class (*vf*, very fine; *f*, fine; *m*, medium; *c*, coarse; and *vc*, very coarse). Order of lower case letters indicates relative abundance (least to greatest). For example, sG_{fm} is sandy, fine to medium gravel. Lower case subscripts are used to distinguish otherwise identical textural names (e.g., distinguishing coarse versus fine gravel textures). Sediment terms correspond with standard grain size classes [*Buffington and Montgomery*, 1999, Table 1]. NA indicates the entire suspension of a patch at bank-full flow.

†Values in parentheses are are for grain-size distributions with suspendable sizes removed (see text).

‡Here σ_g is the graphic standard deviation, defined as $(\phi_{84} - \phi_{16})/2$ [*Folk*, 1974], where ϕ_{84} and ϕ_{16} are the $\log_2$ grain sizes [*Krumbein*, 1936] for which 16% and 84%, respectively, of the surface grain sizes are finer.

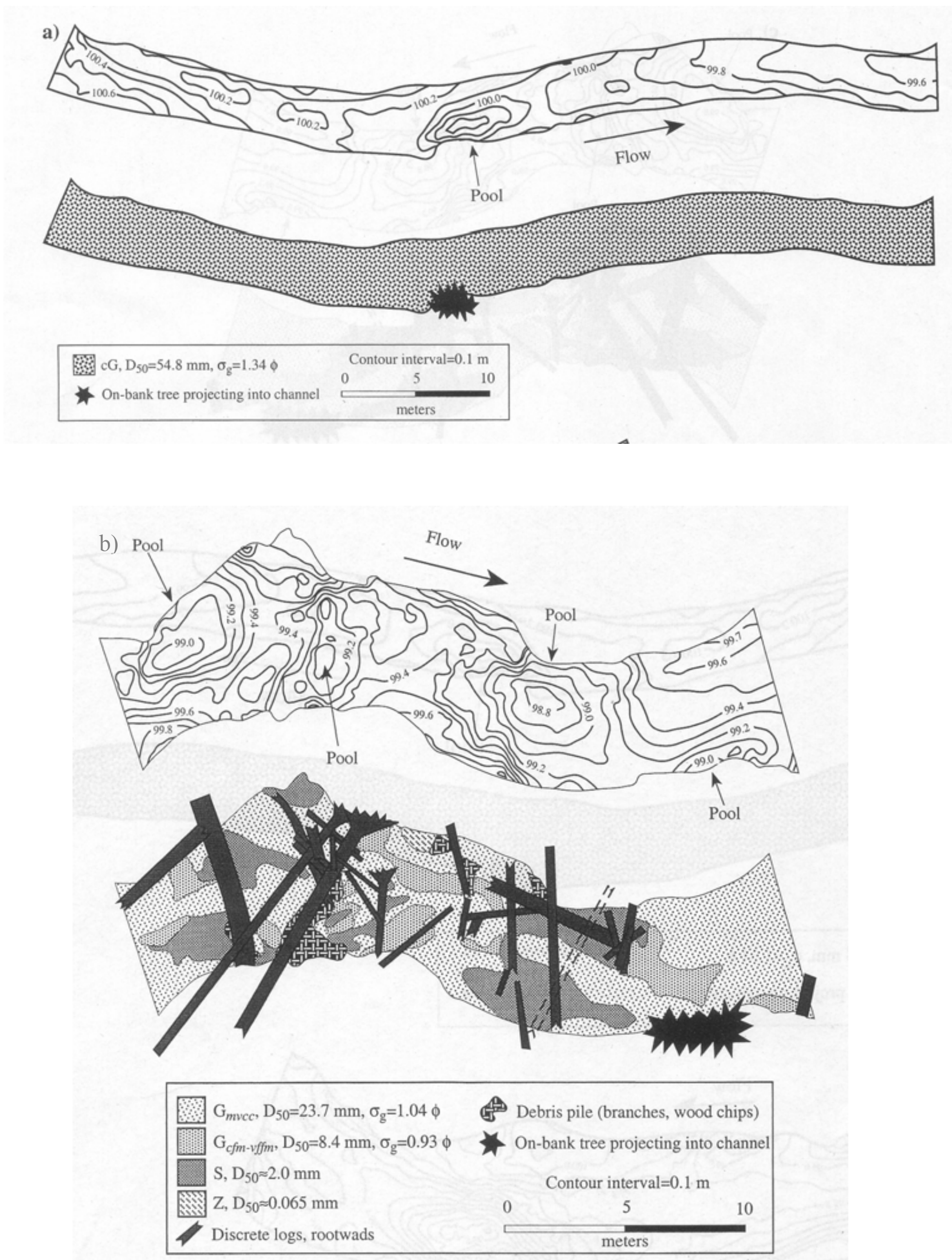

Figure 8.1-5. Textural maps of (a) wood-poor channel and (b) wood-rich channel.
From Buffington and Montgomery (1999).

sediment in eastern Washington channels can be assessed for high elevation (Pacific silver fir), small drainage area channels with additional quantitative analysis of existing data. Studies from analogous regions provide additional quantitative data from similar drainage areas and with Douglas-fir and ponderosa pine riparian forests.

Table 8.1-4. Mean channel substrate composition (in mm) for non-LWD and LWD-loaded channels.
From MacFarlane and Wohl (2003) and Curran and Wohl (2003).

	Composite D_{50}	Step D_{50}	Composite D_{85}	Step D_{85}
Mean (non-LWD)	140	252	329	423
Mean (LWD-loaded)	64	115	174	231
p-value (t-test)	<0.0001	<0.0001	<0.0001	<0.0001

Table 8.1-5. Bottom substrate composition for wood-poor and wood-rich sites.
From House and Boehne (1986).

Bottom Substrate (%)	Wood-poor	Wood-rich
Bedrock	0	5
Boulders (>30cm)	20	10
Cobble-rubble (7.6-30 cm)	50	40
Gravel (0.25-7.5cm)	25	30
Fines (<0.25cm)	5	15

The second part of this question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. Several studies exist that provide useful guidelines for further research.

Summary and Recommendations

Sediment Storage

Data from chesney (2000) indicates that, in eastern Washington managed forests, a relationship exits between the volume of instream wood and the volume of instream sediment. Further analysis on this data should be performed to clarify other relationships between instream wood and stored instream sediment. The data from chesney (2000) is limited, however, to high elevation sites with Pacific silver fir dominated riparian vegetation and small drainage areas. Additional data is needed for channels at lower elevations and within larger drainage areas (Figure 8.1-6).

Studies performed in analogous regions (Idaho and Montana) have found relationships between sediment accumulation and step composition and stream order. Megahan (1982) found that logs did not form the majority of the steps, but stored almost half of total stored sediment. Potts and

Anderson (1990) found similar trends with step composition, and they also found a relationship with stream order; logs retain over half of the sediment in 2nd and 3rd order streams, and debris steps have less of an influence on total sediment storage as stream order increases. These studies provide indications of likely relationships in eastern Washington forest communities. Verification of these relationships in eastern Washington is needed.

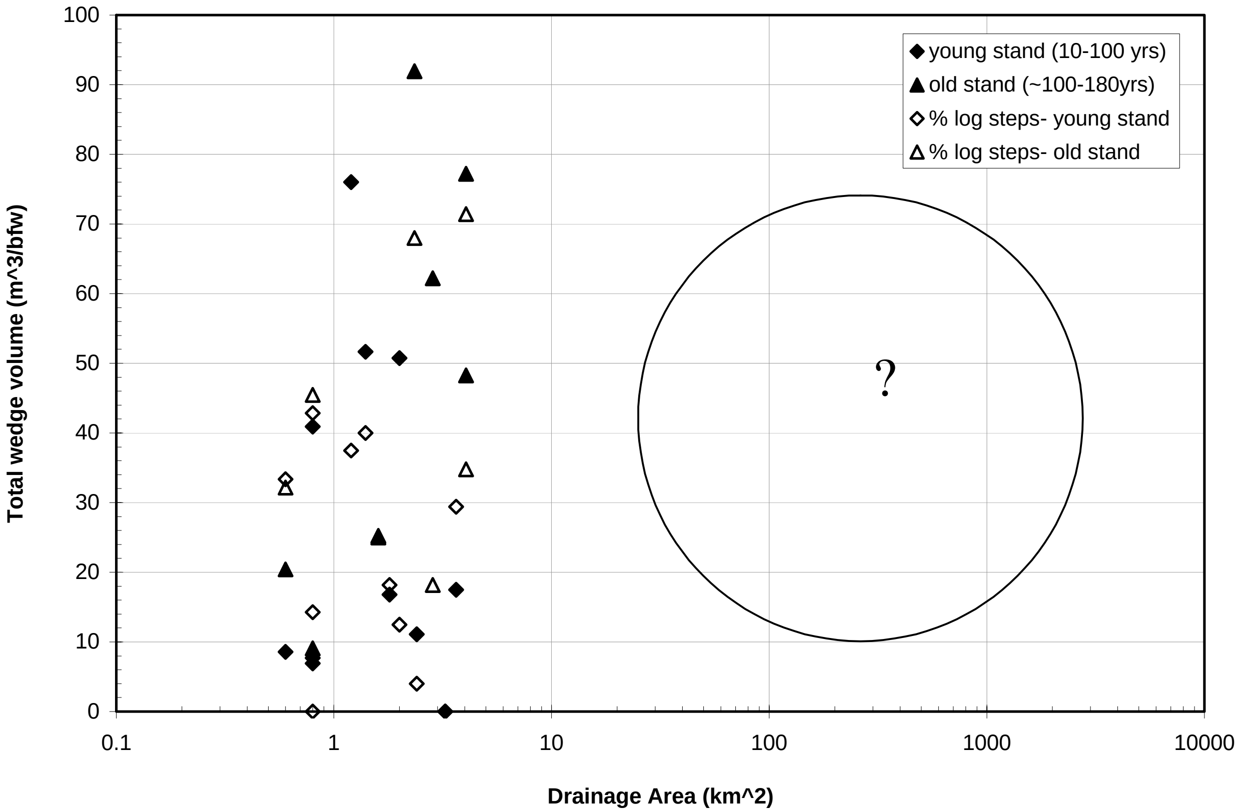

Figure 8.1-6. Relationship between total wedge volume (m^3/bfw) and drainage area (km2) by stand age.
Also presented is the percentage of log steps by stand age. Data from chesney (2000).

Sediment Sorting

Studies assessing the role of wood in sorting sediment were not found for eastern Washington streams; however, there have been numerous studies that quantify the relationship between wood and sediment sorting in non-analogous study regions. Buffington and Montgomery (1999) evaluated the relationship between channel roughness and grain-size, textural types and patches. MacFarlane and Wohl (2003) and Curran and Wohl (2003) display the influence of LWD on substrate composition for step-pool channels, and House and Boehne (1986) show the effects of instream structures on substrate composition. All of the studies found that channels with greater roughness characteristics have higher percentages of finer sediment; and Buffington and Montgomery (1999) found both greater numbers and types of textural patches in wood-rich channels. The processes quantitatively described in the studies mentioned above are predicted to be similar in eastern Washington channels, but further research is necessary to confirm these relationships.

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8.2 Question 27 Response

Does the role of wood in the storage and sorting of sediment affect the quality and/or quantity of spawning gravel in these streams? If so, in what way?

Summary of Literature Sources

Of the references reviewed, there were no quantitative studies found pertaining to eastern Washington or analogous regions; four quantitative studies and one qualitative study were found relevant to the subject of spawning gravels in the Pacific Northwest. Table 8.2-1 provides a summary of these references.

Summary of Quantitative Data

There were very few quantitative studies pertaining to the effects of wood on the quality and/or quantity of spawning gravel. Of the studies found, none were located in eastern Washington, but several may provide a useful example for developing future research efforts.

House and Boehne (1986), as mentioned in Question 26, studied the effects of instream structures on salmonid habitat in western Oregon. They found that stream-bed substrate composition, when qualified visually, was influenced by the presence of LWD; the stream section with abundant LWD contained 5 percent more useable spawning gravel than the wood-poor reach (Table 8.1-5).

Beechie and Sibley (1997) studied relationships between woody debris abundance and spawning gravel area in Northwest Washington streams. Surface area of gravel (16-64mm) patches were visually estimated and summarized as a percentage of total bankfull channel area. They found no correlations between percent gravel (100 x gravel area/channel area) and number of LWD/m, LWD volume/m, or LWD volume/m^2, but these results may be affected by the criteria used to quantify gravel patches. Spawning gravel area measured in this study excluded parts of the bed that are dewatered during the winter.

Buffington and Montgomery (1999), also referenced in Question 26, examined how hydraulic roughness affects bed-surface textures. Figure 8.1-3 shows that the presence of wood in a reach shifts the median grain size lower. In their study, the grain size distribution of wood-rich stream reaches was closer to the preferred D_{50} range of spawning salmonids than were stream reaches that were lacking in LWD. Utilization of the range of streambed sediments for spawning was not evaluated in the study.

Other studies qualitatively discuss the role of LWD in trapping sediment, as well as creating flow divergence that sweeps the fine sediment from the bed surface (Sedell and Swanson, 1984; Lisle, 1995). Lisle (1995) found that in-stream woody debris increased patchiness of bed material; and

Table 8.2-1. Summary of literature sources containing data relevant to question 27.

Reference	Location	Drainage Area (km^2)	Relevance	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach									
Beechie, T. and T.H. Sibley 1997	Borthwest WA – northern Cascades and Puget Sound	2.6 – 118.3		Lower elevations- western hemlock, Douglas-fir, Sitka spruce, western redcedar; Higher elevation- silver fir	<4	Headwater: granite intrusions, andesitic and dacitic volcanics, sandstones, shales; lover elevations: Pleistocene lacustrine clays, outwash sands and gravels, and tills		S,O	Yes
Buffington, J.M and D.R. Montgomery 1999	Olympic Peninsula, WA	w: 5.12 – 13.39m, h: 0.34 – 0.86m [c]	Sediment sorting	Sitka spruce, western hemlock, western redcedar, Douglas-fir	0.4 – 2.65	Eocene to Miocene marine basalts and sediments	Managed	S,O	Yes
	Southeastern AK	w: 4.6 – 29.12m, h:0.32 – 1.17m [c]	Sediment sorting	Sitka spruce, western hemlock	0.17 – 2.67	Major rock types ranging from Proterozoic to Quaternary	Managed and Unmanaged	S,O	Yes
House, R.A. and P.L. Boehne 1986	OR – Tobe Creek	9.27	Sediment sorting	Young alder (red alder) and mature mixed-conifer and bigleaf maple	3	Cobble/rubble	Managed	S,O	Yes
Lisle, T.E. 1995	Cascades Range, WA – Clearwater Creek	9.3 – 32.7	Fine sediment		0.47 – 0.88	Gravel, cobble, sand, pumice	Volcanic activity	S,Q	Yes
Sedell and Swanson 1984	Pacific Northwest							Q	Yes
Bisson, P.A., et al. 1987	Pacific Northwest							Q	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

although woody debris promoted sediment deposition, fine grained material was swept away by diverting flow.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary in order to answer the question.

Summary and Recommendations

Most of the studies reviewed here utilize visual estimates to describe bed composition. The exception is Buffington and Montgomery (1999), who use Wolman pebble counts to quantify distinct textural patches. A consistent and quantitative methodology needs to be established for further research efforts. The quantitative methodology presented in Buffington and Montgomery (1999) could serve as a model for evaluating the effect of LWD on substrate bed conditions in eastern Washington streams. This approach could be further validated by evaluating the characteristics and grain size distribution of substrate sediments preferred by salmonids for spawning.

We recommend that a study plan be developed to address questions 26 and 27 in eastern Washington forests. The study should include a statistically significant number of study sites in forests undisturbed by land use practices and in those that have known historic harvest practices.

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9.0 Riparian Channel and Condition

9.1 Question 28 Response

Does channel wood play a role in affecting the channel's dimensional stability (e.g., reducing channel scour and downcutting, increasing channel fill and bed elevation rise, maintaining a balance among channel responses)? If so, how? What numeric data are available to quantify this?

Summary of Literature Sources

Of the references reviewed, a total of 13 were found that had quantitative and/or descriptive information relating to the affect of channel wood on the channel's dimensional stability; of these, two had information relevant to eastern Washington, and one contained data from analogous regions. Table 9.1-1 provides a summary of these references.

Summary of Quantitative Data

Eastern Washington

Carlson et al. (1996) conducted a watershed analysis of the West Branch of the Little Spokane River located 25 miles north-northeast of Spokane, Washington. Although this study provides no quantitative data on the role of channel wood in affecting channel stability, several trends were noted in the watershed that are relevant to the question and eastern Washington. Based on field observations, the following effects of channel wood removal on channel stability were noted for the West Branch of the Little Spokane River:

- The loss of LWD from channels decreases the channel resistance to erosion
- LWD oriented parallel to the stream channel in streams in the assessment area commonly becomes incorporated into the stream banks and functions to resist bank erosion
- LWD embedded in the channel provides effective grade control in some reaches.

Channel incision was observed in stream segments lacking LWD in the West Branch, but an insufficient number of observations were made to quantitatively relate this to the number of LWD obstructions. The authors include in their summary that field observations in the West Branch WAU and the scientific literature indicate that LWD in steep streams dissipates stream energy and resists bank and bed erosion. The number of channel-steps created by LWD was

Table 9.1-1. Summary of literature sources containing data relevant to question 28.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Carlson et al. 1996	West Branch Little Spokane River	259	NE	Douglas-fir series, grand fir series, and western hemlock series	Variable (<1 – >20%)	Granitic	Both	S, Q	No
Stock et al. in press	Teanaway River in eastern Washington (also Oregon, and California)	ND [c]	SC	N/A	N/A	Gravel to bedrock	N/A	S, Q	Yes
Studies in Analogous Regions									
Hauer et al. 1999	Northwest Montana	16.12 – 232.89	Unknown	Not reported	Mean 1%	Sedimentary Rocks	Both	S, O	Yes
Analogous Process-based Approach									
Berg et al. 1998	Sierra Nevada, CA	Small headwater streams (2nd to 4th order)	Unknown	Mixed conifer and red-fir forests (west side); pine (east side)	2.1 – 7.8%	Not reported-stream substrate cobble, boulder and bedrock	Both	S	Yes
Bilby 1984	Washington Coast Range	90	WW	Not reported	1.5%	Not reported	Managed	S	Yes
Bilby and Ward 1989	Southwest Washington	0.4 – 68	WW	Old growth forests	1 – 18%	Volcanic	Unmanaged	S, O	Yes
Heede 1985	Arizona	Not reported	Unknown	Virgin coniferous forests	0.068 and 0.092	Volcanic	Unmanaged	S, O	Yes
Larson 2000	King County, WA	2.2 – 53.6	Unknown	Not reported-urban	0.006 – 0.046	Not reported	Both	S, O	No
MacDonald and Keller 1987	Northwest California	3.9	Unknown	Redwood	0.014	Not reported	Managed	Q	No
Madej et al. 1994	California	460 – 777	Unknown	Not reported	0.0005 – 0.0016	Glacial	Managed	Q, S	Yes
Nakamura and Swanson 1993	Western Oregon	0.96 – 60.5	Unknown	Douglas-fir, western hemlock, western redcedar, Pacific silver fir	3 – 21%	Not reported	Both	S	Yes
Rot et al. 2000	Western Cascades, WA			Old-growth			Unmanaged	S	Yes
Smith et al. 1993	Southeast Alaska	15.5	Unknown	Sitka spruce-western hemlock old-growth	0.010	Granitics, Argillite, and Limestone	Unmanaged	O S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

measured in five WAU streams with gradients between 5 and 20 percent as between 4 and 13 per 100 meters. This compares well with figures reported from the scientific literature of 1.2 to 17.4 per 100 meters (O'Connor and Harr 1994) and 11.9 per 100 meters (Megahan 1982). The average size of LWD creating steps was 26 to 42 cm.

Stock et al. (in press) collected information on channel incision in the Teanaway River in the Southeast Cascades region. The regional stream incision rate east of the Cascade crest is typically 0.15 to 0.25 millimeter/acre (mm/a). However, within the study area for the Stock et al. (in press) study, the Teanaway River had incised 1 to 2 meters into a low relief bedrock surface. Gravel in these reaches was abundant enough during 1936 field surveys by the Federal Bureau of Fisheries that ~65 percent of the streambed in the lower 11 km of the Teanaway was judged spawnable (McIntosh et al. 1995). Descriptions and a photograph of the adjacent Middle Fork at the beginning of the 20th century (Russell 1898) record abundant in-channel wood, common in Pacific Northwest rivers prior to logging and stream cleaning (e.g., Sedell and Luchessa 1981; Collins et al. 2002). In the Teanaway, timber companies began stream cleaning and logging activities early in the 20th century (Shideler 1986), transporting logs by river drives (1902-1916) and railroads (1917-1930). Disappearance of alluvium along much of the West Fork Teanaway and 1 to 2 meters of incision into the bedrock occurred sometime in the 20th century, likely as a result of these activities.

Analagous Regions

Hauer et al. (1999) measured LWD in 20 bull trout spawning stream reaches from logged and wilderness watersheds in northwest Montana to describe the characteristics and selected functions of LWD in these streams. Mean bankfull widths of stream reaches were 14.1 meters (Range 3.9-36.7). An X^2 analysis revealed that LWD pieces that were perpendicular to the current had a significantly higher frequency of bank attachment. They found these features to be particularly important, since perpendicular pieces were the most interactive with the stream channel in that they were often most responsible for change in streambed morphology and complexity. They found that as the number of pieces of LWD and the volume of LWD increased within a stream section, there was a corresponding increase in the bedslope of the section immediately downstream (Figure 9.1-1). The steepest bedslopes were associated with upstream aggregates of LWD, large snags with rootwads or large-diameter LWD oriented perpendicular to the stream. Each of these LWD structures performs important bed-forming functions, e.g., the retention of gravel on the upstream side of the structure and (or) the focus of stream flow and thus stream power and scour on the downstream bed material forming pools. Both of these factors lead to the aggradation of upstream gravel and cobble and the downstream degradation of bed material. These correlations between increased LWD piece frequency and volume and bedslope underscore the importance of LWD aggregates in stabilizing bedload.

Relevant Studies

Channels in which LWD forces pool formation and sediment storage are particularly sensitive to altered wood loading. For example, removal of LWD from forced pool-riffle channels may lead to either a pool-riffle or plane-bed morphology (Montgomery et al. 1995). Montgomery et al.

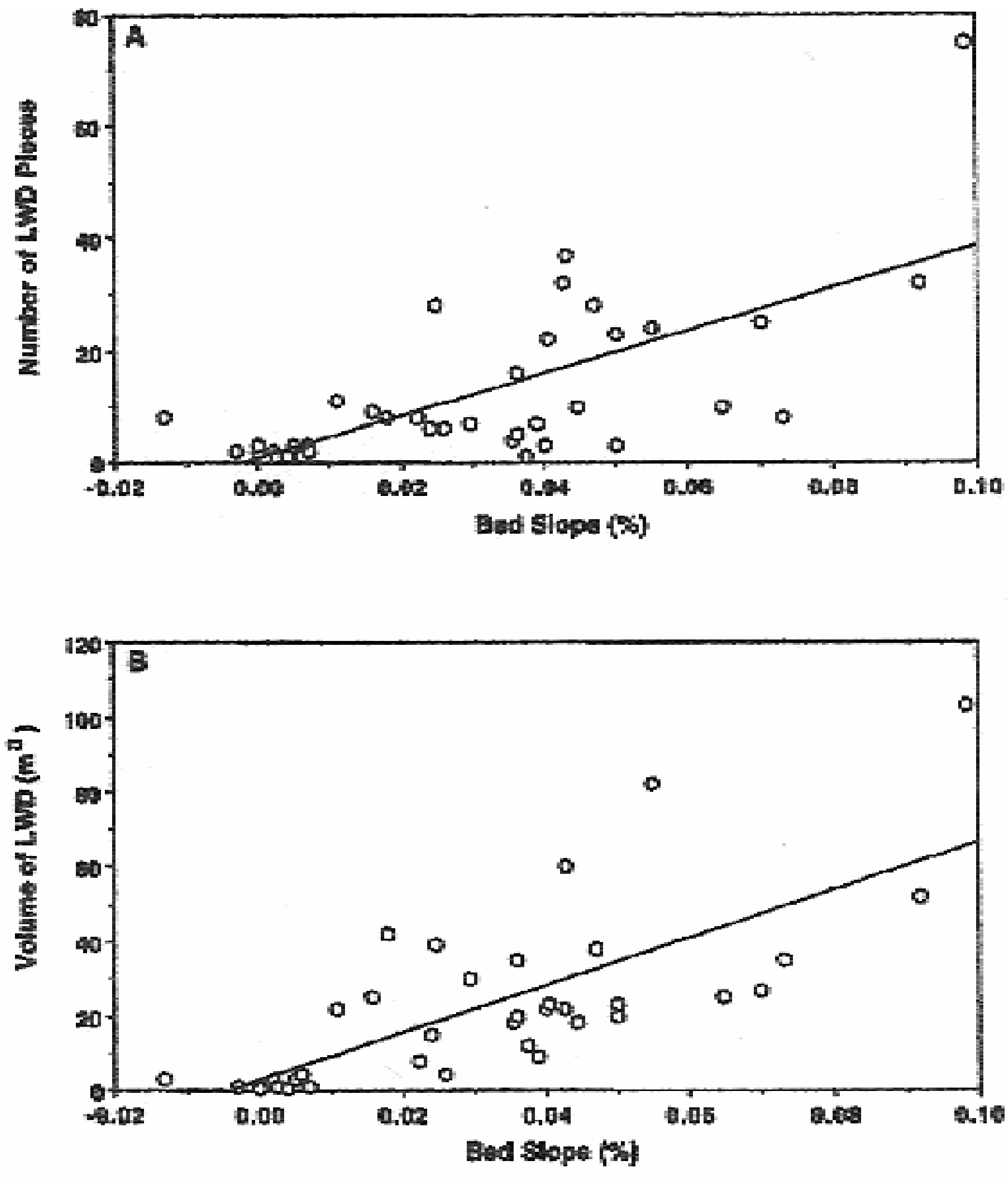

Figure 9.1-1. (A) Number of LWD pieces and (B) volume of LWD in the upstream 10-m stream section and the corresponding downstream bedslope.
Strong correlations were found between increasing numbers and volumes of LWD and increasing channel slopes downstream.

(1996) found that log jams forced alluvial streambeds in other-wise bedrock reaches of a mountain channel network in western Washington. Similarly, loss of LWD may transform a forced step-pool channel into a step-pool, cascade, or bedrock channel, depending on channel slope, discharge, and availability of coarse sediment (Montgomery et al. 1995).

Rot et al. (2000) studied the hierarchical relationship of five key elements at 21 sites in mature to old-growth riparian forests of the western Cascades, Washington: valley constraint, riparian landform, riparian plant community, channel type, and channel configuration. They found that channel type (bedrock, plane-bed, and forced pool-riffle) was closely related to channel configuration (especially large woody debris (LWD) volume, density, and LWD-formed pools) at the smallest spatial scale and related to valley constraint at the largest spatial scale. Valley constraint significantly influenced off-channel habitat (r^2=0.71) and LWD volume within forced pool-riffle channels (r^2=0.58).

Larson (2000) compared the effectiveness of the placement of in-stream LWD in six streams in western Washington. LWD added to the streams contributed most to grade control (11 to 23 percent) on the highest gradient streams (0.026-0.046) where the wood was spanning the full width of the channel. On the low gradient streams (0.005-0.008), LWD contributed little to grade control (0 to 6 percent of total elevation loss).

Berg et al. (1998) located and measured the stability and geomorphic function of almost 1700 pieces of woody debris on six streams located northwest of Lake Tahoe in the central Sierra Nevada. They reported that while over half of the LWD pieces in the study reaches were classified as having no geomorphic function, over 20 percent of the LWD was classified as armoring channel banks. These pieces may hold gravels, soil and fine sediment in place on the bank and thereby reduce bank erosion. The authors (Berg et al. 1998) note that steps in the high-gradient Sierra Nevada headwater reaches are more likely controlled by boulders and geologic factors.

Heede (1985) removed all log steps and fallen trees over a reach in a perennial mountain stream. He found that the removal of log steps in the channel led to an 8 percent increase in the formation of knickpoints. Incision and the upstream advancement of knickpoints resulted in a net increase of channel cross-sectional area of 6.2 percent. This study determined that the removal of log steps results in increased bedload movement and gravel bar formation, which replaced 74 percent of the removed log steps within five years.

MacDonald and Keller (1987) removed 70 m^3 LWD from a third order stream in Northwestern California to examine the mechanisms by which LWD controls channel morphology. The stream had an average width of 8.2 m. Following removal of LWD, the channel stabilized around other large roughness elements, including: major bend in the channel, sediment deposits associated with these bends, and a small amount of the original debris-stored sediment that was stabilized with vegetation prior to channel disturbance. Therefore, at low flows the net roughness of the reach where LWD was removed was not significantly lower than it was prior to debris removal. This was due to the combined effects of higher grain roughness, a slight decrease in bed slope, and the two bends located in the reach. They also noted that in the study creek, the net result of removal of LWD accumulations was a tendency for the channel pattern to evolve toward a state stabilized by bends at bedrock outcrops and LWD protected banks.

Bilby (1984) studied channel characteristics after winter high flow events in a fourth-order stream in western Washington post cleaning of logging debris from the stream. The stream, through the study reach had an average bankfull width of 11.5 meters and an average gradient of 1.5 percent. Table 9.1-2 shows changes in the cross-section post removal of LWD compared with a similar stream where no LWD was removed. Negative numbers indicate scour, positive numbers indicate fill. The general patterns is scouring and lowering of the bed probably due to the removal or alteration of debris that was retaining sediment. This was significant compared with the control stream; 25.4 cm per cross section change in the study stream compared with 3.3 cm cross section change in the control stream. A much larger reduction in the number of pools in the study reach compared with the control also occurred post LWD removal (Table 9.1-3). The author concludes that the immediate effects of debris alteration or removal on channel stability could be reduced by minimizing changes to pieces that are determining channel morphology.

Table 9.1-2. Cross-section changes during the winter post LWD removal in a western Washington stream.
Study reach is located in Salmon Creek. Fall River is a similar headwater stream with no disturbance occurring and serving as the control for changes in channel characteristics. Source: Bilby (1984).

Salmon Creek				Fall River	
	Change in Bed Elevation				
Cross Section	June – Nov. 14, 1980 (cm)	Nov. 15, 1980 – Jan. 11, 1981 (cm)	Net 1980-81 (cm)	Cross Section	Change in Bed Elevation 1980-1981 (cm)
1	11.11	-7.41	3.70	1	0.0
2	0.0	-13.61	-13.61	2	-8.19
3	-20.50	17.46	-3.04	3	2.37
4	29.38	-4.90	24.48	4	-8.67
5	37.50	-14.20	23.30	5	0.0
6	-8.73	-16.21	-24.93	6	1.67
7	-11.11	-24.44	-35.55	7	-1.36
8	-14.20	-65.99	-80.19	8	6.11
9	0.0	2.74	2.74	9	-1.15
10	1.16	-27.91	-26.75		
Average [a] elevation change per cross section	14.19	19.43	25.41		3.28

[a] Average elevation change values include both scour and bh numbers as positive values.

Table 9.1-3. Changes in channel morphology during the winter post LWD removal in a western Washington stream.
Study reach is located in Salmon Creek. Fall River is a similar headwater stream with no disturbance occurring and serving as the control for changes in channel characteristics. Source: Bilby (1984).

	Salmon Creek			Fall River	
Item	**7/17/1980**	**12/12/1980**	**1/6/1981**	**6/24/1980**	**12/19/1980**
Number of pools	29	17	19	22	24
Pools eliminated since last mapping		17	3		2
Pools formed since last mapping		5	5		4
Percent of pools formed by debris	86	77	79	73	71
Percent of stream area in pools	50	32	39	70	74
Percent of stream volume in pools	72	46	63	85	87
Number of riffles	33	28	31	16	14
Riffles estimated since last mapping		12	10		6
Riffles formed since last mapping		5	15		4
Percent of stream area in riffles	50	68	61	30	26
Percent of stream volume in riffles	28	54	37	15	13

Bilby and Ward (1989) examined how the characteristics and function of LWD changed in relation to stream size in second to fifth order streams in old-growth timber stands in western Washington. Channel widths range from 3.6 to 19.7 meters. Debris cascades functioning as grade control structures decreased in frequency with increasing stream size (Table 9.1-4). The likely causes of this decrease were a drop in the channel gradient and a change in the orientation of pieces of debris from perpendicular to downstream. The proportion of drop in streambed elevation caused by LWD cascades decreased only slightly from channels less than 7 meters wide to those 7 to 10 meters wide. In streams greater than 10 meters wide, debris cascades accounted for less than 5 percent of the total streambed drop over the length of the study sections.

Table 9.1-4. Change in the frequency of waterfalls associated with woody debris and in the proportion of channel drop caused by debris-formed waterfalls as a function of stream size in western Washington.

Channel Width (m)	Percent of Debris Pieces Forming Cascades	Percent of Total Channel Drop Attributable to Debris Cascades
<7	18.8	18.1
7 – 10	17.2	15.1
>10	3.1	4.5

Source: Bilby and Ward (1989).

Smith et al. (1993) removed woody debris from a small, gravel-bed stream in a forested basin to determine the effect on sediment redistribution and changes in bed topography. He found that removal of LWD, where it had been an important stabilizing factor, resulted in major changes in bed morphology that occurred almost immediately after removal. One change of debris removal was immediate scour followed by fill point bar development in some instances, exceeding the pretreatment bed downstream of removed debris. Another changes was the enlargement of point bars resulting in shift of thalweg flow and scour of the opposite stream bank, following channel widening (Figure 9.1-2). A loss of 5.2 m^3 of stream bank to bank erosion occurred following LWD removal. The average width of the bed was 3.0 meters prior to removal of LWD and 4.0 meters in 4 years following LWD removal. A gradient change from 0.010 prior to removal to 0.008 four-year following LWD removal also occurred.

Madej et al. (1994) compared the channel changes from occurring in two reaches of a river over a 70 year period. He found a striking difference in the abundance of large and small woody debris between the two study reaches. The impacted reach (39 percent bank erosion) had 12 pieces/km of river, and the unimpacted reach (17 percent bank erosion) (control reach) had 29 pieces/km.

Nakamura and Swanson (1993) studied the effects of LWD on channel morphology at five sites on the east slope of the Cascades in western Oregon. Average bankfull widths of study sites ranged from 7.6 to 24 meters. The effects of LWD on longitudinal and cross sectional profiles of streambeds were more pronounced in the medium-order streams (third to fifth order). In steep and bedrock confined streams interaction between the channel and LWD was limited. Width and gradient appeared to be maximized at LWD jam sites. Mean channel widths were 25 to 58 percent wider at LWD jam sites than sites with no LWD. LWD jam locations were 17 to 36 percent steeper than sites with no LWD.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. Several studies included in the above summary provide useful guidelines for further research.

Summary and Recommendations

Information from Carlson (1996) indicates that in the West Fork Spokane River in eastern Washington a relationship exits between LWD and the stability of the channel to balance channel responses. However, no quantitative data was presented. Additional data needs to be collected in this watershed to quantify the observed trends. Studies performed in other regions found relationships between LWD removal and stream channel dimensional alterations. Many of these studies documented changes in channel gradient due to the removal of LWD steps. The effect of LWD on channel stability and morphology in larger streams, where it is not spanning the channel, was found to not be as significant. Many of these studies occurred in forested streams

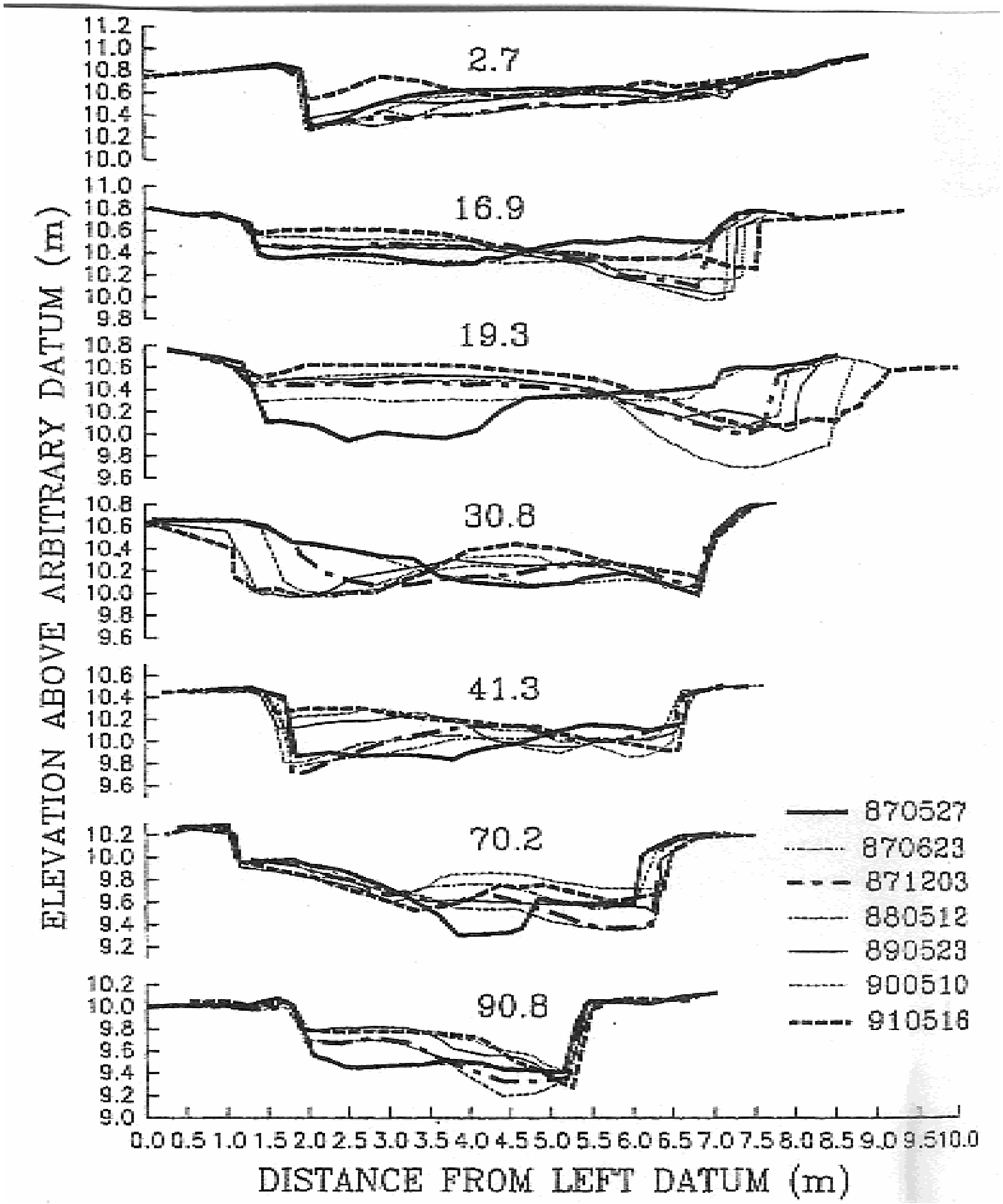

Figure 9.1-2. Cross-sectional surveys within gravel bed stream in forested basin. Perspective is looking downstream.
Labels indicate distance along the channel center line from the upstream edge of the study reach. 870527 refers to the study site project immediately following debris removal. 910516 refers to 4 year post debris removal at the completion of the study. Source: Smith et al. (1993).

with stream morphologies similar to those found in eastern Washington and these studies provide indications of likely relationships in eastern Washington forest communities; however, verification of these relationships in eastern Washington is needed.

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9.2 Question 29 Response

Does the function of wood to mitigate the effects of bed elevation change (channel scour or filling) vary with underlying geology, soil depth, stream width, steam flow characteristics, presence of adjacent riparian stands (root strength), channel morphology or other factors? If so, how? (We aren't looking for theories here, but real evidence. Provide numeric results for any studies that addressed this question.)

Summary of Literature Sources

Of the references reviewed, a total of 11 were found that had quantitative and/or descriptive information relating to wood volume; of these, one had information relevant to eastern Washington and none contained data from analogous regions. Table 9.2-1 provides a summary of these references.

Summary of Quantitative Data

In a recent review, Montgomery et al. (2003) summarized progress during the last few decades regarding fluvial processes and the influences of wood debris as a principal factor influencing channel profile and migration in forested landscapes. While intensive clearing and river management since the mid 1800s has greatly reduced the number of large logjams, they still form and can have substantial impacts on flooding and channel avulsions (Collins and Montgomery 2002, Abbe et al. 2003; Abbe et al. unpublished). Moreover, accumulation of wood debris in rivers is likely to become increasingly common due to adoption of stringent regulatory guidelines protecting riparian forests and stream restoration efforts that include wood placement, reforestation, re-introduction of normative flows, and dam removal. In regions such as the Pacific Northwest, the ubiquitous practice of stream clearing implemented since the late 1800s by private landowners and county, state and federal agencies became less common by the 1980s. Recent trends in river management will tend to increase wood debris recruitment and retention in streams and rivers. Such changes will introduce greater vertical variability to river channel bed elevations, and these changes will significantly influence the style, rates, and potential extent of channel migration corridors.

Geology

No data were found to relate how the function of wood to mitigate the effects of bed elevation change varies with the underlying geology. Berg et al. (1998) (see Question 28 response for study description) suggest that the limited role of woody debris in pool formation in the study reaches may relate to geologic factors as the primary controllers of pool formation in the study reaches, which may indicate that in certain types of geology, LWD does not play as important a role in the ability of wood to mitigate the affects of channel scour and downcutting.

Table 9.2-1. Summary of literature sources containing data relevant to question 29.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Carlson et al. 1996	West Branch Little Spokane River	259	NE	Douglas-fir series, grand fir series, and western hemlock series	Variable (<1 – >20%)	Granitic	Both	S, Q	No
Analogous Process-based Approach									
Abbe and Montgomery (unpublished)	Pacific Northwest Queets River	1,190	WW	Old growth temperate rain forest	Not reported	Not reported	Unmanaged	S	No
Abbe et al. 2003	Pacific Northwest Ozette River	Not reported	WW	Industrial timberland	0.1	Not reported	Managed	S	*In press*
Berg et al. 1998	Sierra Nevada, CA	Small headwater streams (2nd – 4th order)	Unknown	Mixed conifer and red-fir forests (west side); Pine (east side)	2.1 – 7.8%	Not reported-stream substrate cobble, boulder and bedrock	Both	S	Yes
Bilby and Ward 1989	Southwest Washington	0.4 – 68	WW	Old growth forests	1 – 18%	Volcanic	Unmanaged	S, O	Yes
Bilby and Ward 1991	Cascades, western Washington	0.4 – 137	WW	Old-growth, Clear-cut, and Second growth	Not reported	Not reported	Both	S, O	
Keller et al. 1995	Northern California	0.7 – 27.2	Unknown	Coastal redwood forests	0..5 – 0.12	Various	Both	S, O	Yes
Larson 2000	King County Washington	2.2 – 53.6	Unknown	Not reported-urban	0.006 – 0.046	Not reported	Both	S, O	No
Nakamura and Swanson 1993	Western Oregon	0.96 – 60.5	Unknown	Douglas-fir, western hemlock, western redcedar, Pacific silver fir	3 – 21%	Not reported	Both	S	Yes
Models/Flume Studies									
Cherry and Beschta	N/A: flume study	N/A	N/A	N/A	N/A	N/A	N/A	S, O	Yes
Fetherston 1995	N/A: model	N/A	N/A	N/A	N/A	N/A	N/A	S, O	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

Soil Depth

No data were found to relate how wood mitigates the effects of bed elevation change varies with soil depth.

Stream Width

Little data were found to relate how the function of wood to mitigate the effects of bed elevation change varies with stream width. In small, high gradient streams, the primary method by which LWD decreases shear stress is through the formation of step-pools. Bilby and Ward (1991) compared LWD in 70 stream reaches flowing through old-growth, clear-cut, and second-growth forests in western Washington. The proportion of pieces forming cascades (controlling grade, e.g., balancing scour and downcutting with sediment accumulation) was greater in streams less than 7 meters wide than in larger systems for all streams studies (includes old-growth, clear-cut and secondary growth) (*t*-test; $p<0.05$). This was also found in Bilby and Ward (1989), who reported that, in channels less than 7 m wide in western Washington, more than 15 percent of the total drop in elevation of a stream may be accounted for by summing the heights of LWD formed steps. Steps formed by LWD become less frequent in larger systems, accounting for only 5 percent of the elevation change in channels from 7 to 10 meters wide. Bilby and Ward (1991) reported that the proportion of the drop in elevation of a stream reach accounted for by adding together the heights of the cascades formed by LWD decreased with increasing stream size. In channels wider than 20 meters step-pools formed by LWD are few (Fetherston 1995). Old-growth sites displayed a greater cumulative elevation drop caused by LWD than the other stand-age classes in streams 7 to 10 meters wide and greater than the clear-cut sites in channels greater than 10 meters wide (*t*-test; $p<0.05$).

Bilby and Ward (1989) (study described in Question 28 response) found that nearly 40 percent of the pieces of wood in channels less than 7 meters wide were associated with sediment accumulations (Figure 9.2-1). Less than 30 percent of the pieces retained sediment in channels from 7 to 10 meters wide, and less than 20 percent retained sediment in channels greater than 10 meters wide. Nakamura and Swanson (1993) (study described in Question 28 response) found that in small (1^{st} to 2^{nd} order) streams, LWD forms small step structures and widens the valley floor with sediment accumulation. In medium-sized (3^{rd} to 4^{th} order) streams, the widening of the valley floor is associated with sideslope failure and sediment accumulation. In large (5^{th} or greater order) streams, the widening of the valley floor is associated with bank erosion and LWD contributes mainly to channel migration and the development of secondary channels (Nakamura and Swanson 1993) (Figure 9.2-2). This study also found that channels with key LWD are about 1-5 times wider than channels without key LWD (large pieces of LWD (with length exceeding channel width from which other pieces of debris accumulate around).

Stream Flow Characteristics

Bed elevation change by aggradation due to direct impoundment is well known (Montgomery et al. 1996), but LWD also affects water surface elevations and this can affect the potential for lateral channel movement.

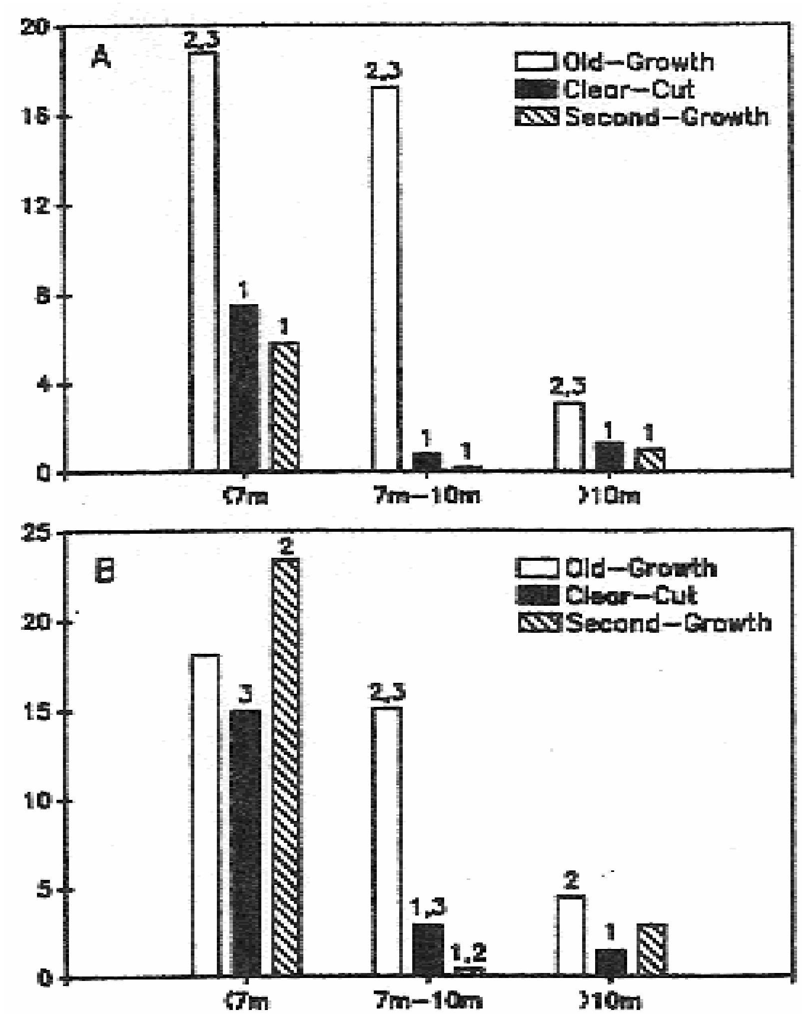

Figure 9.2-1. Proportion of the total drop in elevation of the surveyed stream sections counted for by the summed height of LWD-formed cascades for three age classes for each channel-width class.

Values significantly different (t-test; $p<0.05$) from corresponding values in other stand-classes are denoted with a number above the bar. X axis=Channel Width; Y axis=Cumulative elevation of cascades in reach in meters. Source: Bilby and Ward (1991).

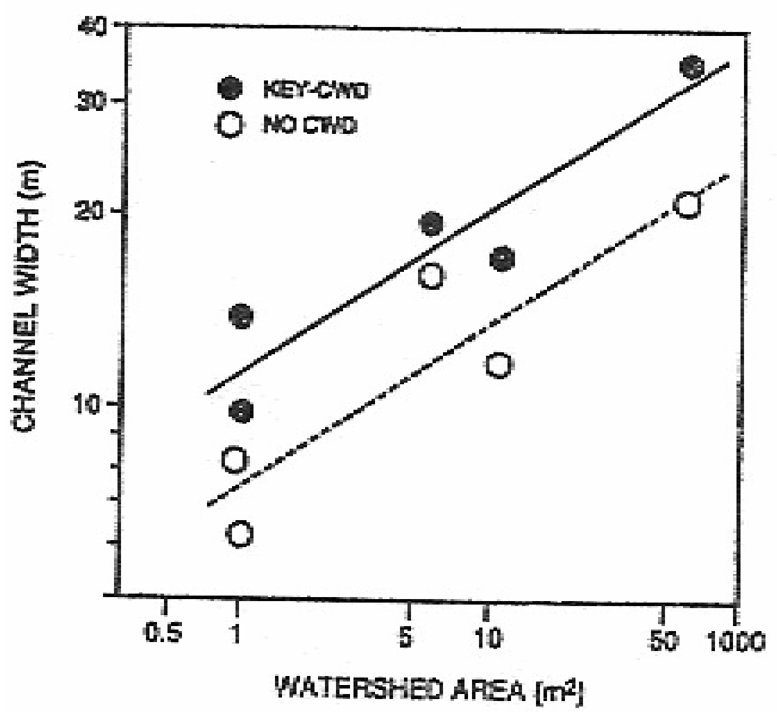

Figure 9.2-2. Regressions of average channel widths of reaches with no LWD (broken line) and key LWD (solid line) in terms of watershed area for streams in the Lookout Creek drainage basin in the Oregon Cascade Mountains.
Source: Nakamura and Swanson (1993).

Understanding the influence of wood on channel dynamics can begin with a very simple illustration of basic fluvial processes. For flow through a channel, conservation of mass dictates that:

$$Q_i = U_i \; A_i$$

where Q is discharge (m^3/s), A is cross-sectional area of flow (m^2), and U = mean flow velocity through channel cross-section (m/s).

Empirically, flow velocity can also be expressed as a function of hydraulic radius, R (m), water surface slope, S (m/m), and frictional resistance (boundary roughness) represented by Manning's *n*:

$$U = R^{2/3} \, S^{1/2} \, n^{-1}$$

Assuming a rectangular channel, such that $A = D^* W$, where D is the flow depth and W is the width of flow, and that $R \approx D$, the simple expression for continuity above can be rewritten as:

$$D^{5/3} \, W = Q \, K$$

where the function K is given by:

$$K = \left(\frac{n}{S^{1/2}} \right)$$

Increases in wood loading will increase roughness (n), while upstream of wood accumulations energy gradient (S) declines. Both changes increase the value of K. For any given discharge an increase in K must be compensated by an increase in flow depth and/or width. Therefore, wood accumulation that significantly influences roughness will increase width and depth of flow.

Logjams have been shown to have the most pronounced influence as hydraulic controls at lower flow discharges. An engineered log jam was placed in the Deschutes River in 2000. The logjam grew dramatically in winter 2000 to 2001, ultimately filling more than 400 m of the main-stem channel by February of 2001. River stage upstream of the logjam rose and led to concerns about flood hazards within the reach. Water level recording gages downstream and upstream of the logjam indicated that the logjam was raising water elevations approximately 1.4 m (4.5 feet) during low flow periods. This head differential due to the logjam diminishes with increasing discharge, probably since flows are already spreading out across the floodplain. Thus, the logjam's impact is most significant during low flows and much less significant during large magnitude floods (Abbe et al. 2003).

In the Queets River, Washington, Abbe and Montgomery (unpublished) found in their surveys that massive logjam complexes that extend across the entire width of the valley bottom can elevate the channel and floodplain, which allows relatively low-magnitude flows to deposit bedload sediments on surfaces which previously were not likely inundated during even low occurrence high flow events. At one location on a tributary to the Queets River recruitment of a key piece of LWD to the channel triggered aggradation such that within a year the channel rose over four meters. During this time, the maximum peak flow had a recurrence interval of less than 2 years.

Presence of Adjacent Riparian Stands (root strength)

Little data were found to relate how the function of wood to mitigate the effects of bed elevation change varies with the presence of adjacent riparian stands. Carlson et al. (1996) (study described in Question 28 response) reports that in the steepest and smallest streams, roots of riparian trees played an important role. In one reach, there were 6 LWD structures per 100 meters formed by roots that created channel steps (and therefore controlled channel stability). In the lower gradient segments, roots did not play a significant role in creating channel steps.

Bilby and Ward (1991) (study described in Question 28 response) found that the proportion of pieces of LWD forming grade-controlling cascades as significantly greater at sites with old-growth riparian vegetation than at the clear cut and second growth streams (t-test; $p<0.05$).

Channel Morphology

LWD in steep streams significantly concentrates potential energy expenditure over short reaches where accumulations of debris exist. In headwater reaches of drainage basins, approximately 30 to 60 percent of the total decrease in elevation of the channel may be associated with LWD. Thus, energy is dissipated at these locations, where it might otherwise cut a more deeply incised channel with unstable and eroding banks (Keller et al. 1995). Abbe and Montgomery (unpublished) found that the effects of log jams on channel aggradation were most dramatic in steep tributaries where valley spanning jams elevated channels between 5 and 11 meters, transforming boulder-cascade and step-pool reaches into gravel-bedded pool-riffle reaches.

Larson (2000) compared the effectiveness of the placement of in-stream LWD in six streams in western Washington to reverse local effects of watershed degradation. Added LWD contributed most to grade control (11 to 23 percent) on the highest gradient streams (0.026-0.046) where the wood was spanning the full width of the channel. On the low gradient streams (0.005-0.008), LWD contributed little to grade control (0 to 6 percent of total elevation loss).

Other Factors

The ability of wood to mitigate the effects of channel scour may also vary with the orientation of the LWD to stream flow. The orientation of the LWD to flow will determine where scour and downcuttting will occur and determine if the resulting scour is mitigating or resulting in erosion. In a flume study, Cherry and Beschta (1989) showed that LWD pointing upstream caused major flow disturbances, produced relatively large scour depths, and appeared to increase the potential for streambank erosion because of the deflection flow toward the side of the flume (considered a nonerodible bank in the study). Such orientation in an alluvial channel might cause a streambank to scour rapidly at high discharge. Logs pointing downstream or perpendicular to flow would be a more stabile position with respect to streambank erosion. In the flume study, a perpendicular orientation generally produced the most scour within the stream.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. Several studies included in the above summary provide useful guidelines for further research.

Summary and Recommendations

Very little data were found to relate how the function of wood to mitigate the effects of bed elevation change varies with geology, soil depth, stream width, stream flow characteristics, presence of adjacent riparian stands (root strength), channel morphology, or other factors. No data was found on this topic for eastern Washington. In general, qualitative and some quantitative information is available on this topic. The function of wood varies by channel morphology, which varies by underlying geology, stream flow characteristics and the presence and condition of adjacent riparian stands. The most information was found on this topic as the function of wood varies at controlling bed elevation at different in stream widths, with the importance of the function generally decreasing with increasing stream width. This is also a reflection of channel morphology and location within the watershed, therefore it is likely that all of the factors considered work together in determining the actual ability of wood to mitigate the effects of bed elevation change in a specific stream.

Wood loading rates are also affected by similar factors, such as; the number and size of trees in the riparian area, the rate of decomposition, geology, valley slope, landslide activity, channel width, stream flow characteristics, and upstream drainage area, therefore, examining wood loading data and combining it with instream wood data may provide information on the effects of different factors on the function of wood to mitigate bed elevation changes.

In addition, accumulation of LWD in streams and rivers is likely to become increasingly common due to increased protection of riparian forests and stream restoration activities. Therefore, the effects of LWD in stream channels on bed elevation changes will become more obvious in the future as wood is added to streams and interacts with stream flows to influence channel morphology.

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9.3 Question 30 Response

What role does downed wood play in the retaining sediment and keeping it from delivering to streams? (Provide summaries of numeric results of studies conducted to address this question.)

Summary of Literature Sources

Of the references reviewed, a total of 4 were found that had quantitative and/or descriptive information relating to downed wood in the floodplain retaining sediment. Eight articles were reviewed that are analogous process-based articles from across the United States that discuss removal of sediment from runoff in riparian areas, but do not specifically address the role of downed wood in retaining of sediment. There were no articles found that have information relevant to eastern Washington. Table 9.3-1 provides a summary of references with information potentially relevant to this question.

Summary of Quantitative Data

No quantitative data were found to address the role of downed wood outside of the channel on retaining and preventing sediment from entering the stream channel. A significant amount of literature exists on the transport of sediment in the stream as it relates to channel wood, but little information is available on non-channel wood and sediment retention (see Question 24 response). Also, a substantial amount of literature exists on the role of riparian buffers in storing and preventing sediment from discharging to streams (Daniels et al. 1996, Desbonnet et al. 1994, Quinn et al. 2000; Lee et al. 2000; Snyder 1998). Sediment retention depends on the following major factors:

- Width of the riparian area between the discharge of sediment and the stream
- The type of vegetation within the riparian area, and
- The slope of the riparian area
- Flow characteristics of runoff through the riparian area.

These studies have determined that riparian buffers of 100 feet in width can achieve rates of sediment retention from stormwater runoff of 75 to 100 percent, depending on site-specific conditions and buffer type. Several authors (e.g., Schultz et al. 1995; Lowrance 1992; Welsch 1991) indicate that the highest rates of removal occur in riparian areas that contain three distinct zones that are within 60 to 150 feet from the edge of a stream. These zones include: 1) Zone 1: a grassy filter strip at the outer edge of the buffer designed to maximize sheet flow; 2) Zone 2: a

Table 9.3-1. Summary of literature sources containing data relevant to question 30.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Studies in Analogous Regions									
Collins et al. 1981	Western WA and OR	Not reported	WW	Clearcut, blown-down and singed trees	0.16 – 0.66	Not reported-tephra and colluvium deposits	Both	S	No
Fetherston et al. 1995	Western WA	Not reported	WW	N/A	ND [c]	ND	ND	Q	Yes
Wilford 1984	Western WA	Not reported	WW	N/A	ND	ND	ND	Q	Yes
Maser and Sedell 1994	Western WA	Not reported	WW	N/A	ND	ND	ND	Q	Yes
Analagous Process-based Approach									
Daniels and Gilliam 1996	Eastern US	N/A	Eastern US	Hardwood forests	N/A	N/A	N/A	S, Q	Yes
Desbonnet et al. 1994	Eastern US	N/A	Coastal Zone Eastern US	Hardwood forests	N/A	N/A	N/A	S, Q	Yes
Lee et al. 2000	US	N/A	US	Various	N/A	N/A	N/A	S, Q	Yes
Lowrance 1992	Eastern US	N/A	Coastal Zone Eastern US	Various	N/A	N/A	N/A	S, Q	Yes
Quinn et al. 2000	Illinois	N/A	Eastern US	Hardwood forests	N/A	N/A	N/A	S, Q	Yes
Snyder 1998	Midwest US	N/A	Midwest US	Various	N/A	N/A	N/A	S, Q	Yes
Schultz et al. 1995	Washington	N/A	Washington	Various	N/A	N/A	N/A	S, Q	Yes
Welsch 1991	Pennsylvania	N/A	Eastern US	Various	N/A	N/A	N/A	S, Q	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.
[c] ND = no data given for the characteristic.

managed forested area designed to provide maximal surface roughness and serve as a transition zone to the next zone; and 3) Zone 3: a natural forested area adjacent to the aquatic resource. None of these studies specifically address downed logs and their effect on sediment retention in the riparian area.

Deposits of wood on the floodplain promote sediment retention (Fetherston et al. 1995). Wilford (1984) found that large woody debris on the upper streambank stores considerable amounts of sediment at the base of unstable hillslopes. Maser and Sedell (1994) reported that LWD anchored on the floodplain allows riparian vegetation to establish and that large, well-anchored wood also reduces the force of water during flooding, causing it to drop part of its sediment load on the downstream side of the wood.

Collins et al. (1981) studied erosion from hillslopes after the eruption of Mt. St. Helens in 1980. Erosion pins were located on three hillslopes covered with blown-down trees. Rates of erosion from these hillslopes covered with blown-down trees compared with rates of erosion from clearcut hillslopes. Rill erosion on all hillslopes with the blown-down tree cover was less than rill erosion on hillslopes clearcut prior to the eruption (Figure 9.3-1).

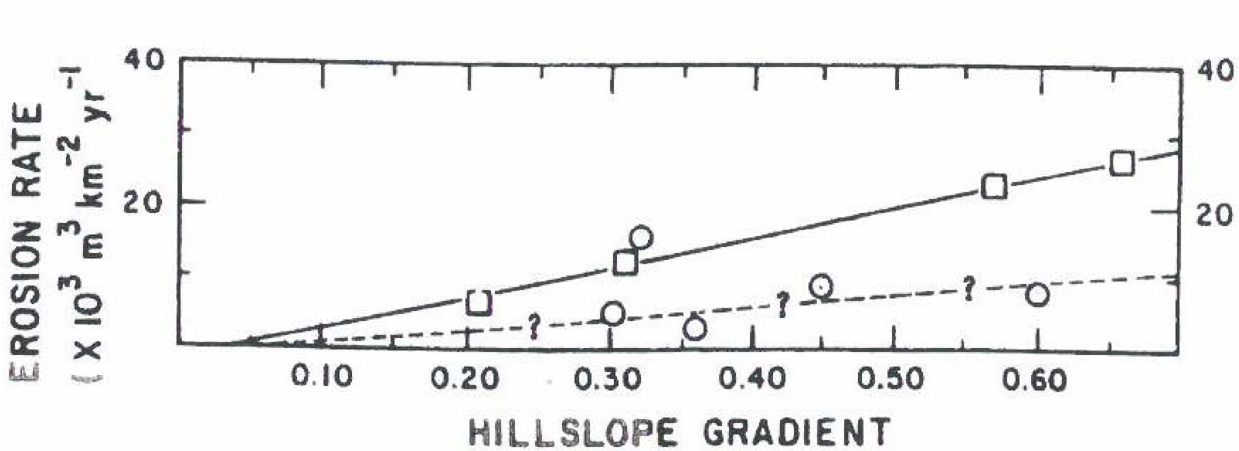

Figure 9.3-1. Rill erosion from hillslopes covered with large blown-down trees (circles) plotted against hillslope gradient and compared to rill erosion from hillslopes clearcut prior to the eruption (squares).
The silty 18 May airfall is the surface layer and tephra thickness is between 15 and 30 cm.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of scientific protocol and collection of additional data is necessary to answer this question. Several studies included in the above summary provide useful guidelines for further research.

Summary and Recommendations

No quantitative data on the role of downed wood on preventing the delivery of sediment to stream channels was found for eastern Washington. In addition, no data directly linking downed wood and sediment retention were found for other regions.

To better understand the role of downed wood in sediment storage, data on amounts of downed wood outside of the channel is required. In addition, study methods used in upland coarse woody debris as it relates to soil stabilization and riparian buffer literature may prove useful to collecting data relevant to this question. Although not much information was found on this question, it is likely that downed wood in the floodplain would play a similar role as vegetation in filtering and trapping sediment.

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10.0 Wood Recruitment and Mortality

10.1 Question 31 Response

What percent of wood recruited to eastside streams comes from a) bank erosion, b) wind throw, c) debris slides, d) suppression mortality in the adjacent riparian stands, e) insect mortality, f) disease mortality, g) snow/ice breakage and snow avalanches, and h) prolonged flooding (beavers?) f) fire mortality (g) animal mortality (e.g., cattle, beaver, porcupine and deer/elk)? Provide reported means, medians, ranges, standard deviations, and information on the distribution of data. Comment on the potential effects of assumptions in the studies. Discuss the effect of differences in study approaches on the results, and representativeness and comparability of various studies.

Summary of Literature Sources

Of the references reviewed, 22 studies were found that had quantitative and/or descriptive information relating to this question for what percent of wood is recruited to streams by various recruitment mechanisms. Of these, three had information relevant to eastern Washington and none contained data from analogous regions. Table 10.1-1 provides a summary of these references.

Summary of Quantitative Data

Eastern Washington Studies

Limited quantitative data is available on wood recruitment mechanisms and very few studies were found with quantitative information relevant to eastern Washington. Studies relevant to eastern Washington found during the literature search generally reported qualitative descriptions of various large wood recruitment mechanisms. Watershed assessments completed for the region provide examples of this. The Ahtanum watershed assessment completed for the Darland Mountain, Foundation Creek, and Cowich Watershed Assessment Units, located on the east slope of the Cascades, reported that large woody debris (LWD) recruitment in the lower portions of the drainages is dominated by streambank erosion (undercutting) and wind throw. In the upper portions of these drainages, wind throw becomes a more significant process and the importance of bank erosion decreases. This assessment also noted that historic photos show evidence of prolonged flooding due to beaver activity resulting in a transition from conifer to hardwood species, however, no quantitative data were provided to support this observation (McKinney 1997).

Flanagan et al (2002) recorded causal agents of tree mortality in their study of snag recruitment in subalpine forests on the eastern slope of the Washington Cascades and found that snow, ice, and wind created significantly more snags than insects, pathogens, animals, or fire. The second and third most common disturbance agents were bark beetles and root diseases. Schumaker and

Table 10.1-1. Summary of literature sources containing data relevant to question 31.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Flanagan et al. 2002	Wenatchee National Forest	NA	Northeast Cascades	Subalpine	Not reported	Upland Forest	N/A	S	No
Schumaker and Glass 1999	Stevens County Washington Onion Creek	149.7	Okanagan Highlands	Riparian forests mostly western hemlock/cedar	1 – 20%	Highly weathered basin granitics	Both	S	No
McKinney 1997	Ahtanum watershed	282.3	Southeast Cascades and Columbia Basin	Riparian	Not reported	Columbia River basalts and early Tertiary volcanic	Both	Q, S	No
Analagous Process Based									
Benda et al. 2002	Redwood National Park , Van Duzen watershed, Northern California	0.2 – 43 km^2	Unknown	Old growth redwood forests and second-growth forests	1 – 6%	Metamorphic and sedimentary rocks Riparian forest	Both	Q, S	Yes
Benda et al., 2003	Olympic Mountains, WA	1 – 16	WW	Unknown	2.5 – 8	Marine sedimentary and basaltic rocks	M, U	Q,S	Yes
Grette, G.B., 1985	Olympic Peninsula, WA	3.4 – 12.4	WW	Western hemlock; Sitka spruce; western redcedar; Douglas-fir; red alder	0.5 – 2.0	Not reported	Managed and Unmanaged	S,Q,O	Yes
Grizzel and Wolff 1998	Northwest Washington	Misc.	North Cascades	Western hemlock, western redcedar, red alder, and Douglas-fir	1 – 63%	Not reported	Unmanaged	S	Yes
Hairston-Strang and Adams 1998	Oregon	Not reported	Five regions	Conifer riparian areas	1 – 25%	Not reported	Managed	Q, S	Yes
Kraft 2002	Northeast U.S. and Canada	Not reported	Adirondack Mountains	Hardwood riparian areas	Not reported	Igneous and Metamorphic	Not reported	S	Yes

Table 10.1-1. Summary of literature sources containing data relevant to question 31 (continued).

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analagous Process Based (continued)									
Lienkaemper and Swanson 1987	Willamette National Forest, Oregon	0.1 – 60.5	Unknown	Douglas-fir, western hemlock, western redcedar	3 – 37	Tertiary volcanic rock	No-old growth	S	Yes
Martin and Benda 2001	Game Creek, southeast Alaska	132.5	Pacific coastal	Western hemlock, Sitka spruce	1 – 15%	Not reported	Both	S	Yes
May and Gresswell 2003	Southern Oregon Coast Range	3.9 km^2	Southern Oregon Coast Range	Old growth Douglas-fir, western hemlock, western redcedar.	Unknown	Riparian forests marine sedimentary rocks	No	S	Yes
McDade et al. 1990	Western Oregon and Washington	Not reported	Cascades Range	Douglas-fir, western redcedar, western hemlock	3 – 40 degrees	Not reported	Unmanaged	S	Yes
Murphy and Koski 1989	Southeast Alaska	Misc.	Pacific Coastal	Sitka spruce and western hemlock	.4 – 2.9 percent	Alluvium and bedrock (channels)	No-old growth	S	Yes
Naiman et al. 1986	Quebec, CA	673 km^2 and 19871 km^2	Unknown	Black and White spruce and balsam fir	1.5% average	Not reported	Unmanaged	S	Yes
Ohmann 2002	Coastal Oregon and Washington	Misc.	Pacific Coastal	Conifer stands	Misc.	Misc.	Not riparian - disturbed and undisturbed	S	No
Recruitment Models									
Benda and Sias 1998	Pacific Northwest	N/A	N/A	N/A	N/A	N/A	N/A	Model	No
Benda and Sias 2003	Pacific Northwest	N/A	N/A	N/A	N/A	N/A	N/A	Model	Yes
Bragg 2000	Bridger Teton National Forest Wyoming	10.3	Unknown	Subalpine fir, Engelmann spruce, lodgepole pine	3.5% average				

Table 10.1-1. Summary of literature sources containing data relevant to question 31 (continued).

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Recruitment Models (continued)									
Welty et al. 2002	Pacific Northwest	N/A	Unknown	Riparian	N/A	N/A	N/A	Model	Yes
Van Sickle and Gregory 1990	Oregon Cascades Mountains	N/A	Unknown	Old-growth conifer stands	N/A	N/A	N/A	Model	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

Glass (1999) established permanent plots in different types of riparian timber stands in the Onion Creek watershed in eastern Washington (Stevens County) to obtain baseline data and to track future rates of large woody debris recruitment during "normal" years and episodic events. The data presented in the report represents the riparian conditions from which future changes will be compared. This report defined disturbance events as any event (wind, rain, snow storm, fire, heavy snow load, etc.) that is believed to have a high probability of causing tree fall. Little data is available in the report concerning various recruitment mechanisms for LWD delivery to streams; however, the study intends to revisit plots following disturbance events in the future as funding allows to collect this data.

Analogous Studies Outside Eastern Washington

The following studies provide information relevant to large wood recruitment mechanisms delivering wood to streams, but are not specific to eastern Washington. Most of the literature available on various recruitment mechanisms made a distinction between chronic and episodic processes by which wood enters a stream (Bisson et al. 1987). Chronic processes, such as tree mortality and bank undercutting (Murphy and Koski 1989) generally deliver single pieces or relatively small numbers of trees at frequent time intervals. Episodic processes usually add large amounts of wood to streams rapidly in severe, but infrequent events, such as wind throw (Harmon et al. 1986), wildfire (Agee 1993), severe floods, landslides and debris flows (Keller and Swanson 1979; Benda and Sias 1998, Benda et al. 2003). Most literature sources focused on chronic input from the immediate adjacent riparian zone (Reeves et al. 2003). Relevant studies reporting quantitative information on large wood recruitment by the various recruitment mechanisms are described below.

Recruitment Due to Bank Erosion, Wind Throw, Debris Slides, and Suppression Mortality

Murphy and Koski (1989) studied the input and depletion of wood from southeast Alaska streams. The processes by which LWD entered the channel was identified as bank erosion (undercut trees), wind throw (pieces not from the lower bank), mortality (fallen recently but already partially decayed) or landslide. Bank erosion and wind throw were the most frequent processes that added LWD to the stream channel. Together these processes were associated with an average of 73 percent of all LWD with an identified source, while tree mortality accounted for 23 percent and landslide accounted for 4 percent. Bank erosion was the most frequent source of LWD recruitment in the larger alluvial channels included in the study, where it accounted for 52 percent to 60 percent of the total LWD to alluvial streams. The terrestrial processes of wind throw, mortality, and landslides were the most frequent sources of LWD in the bedrock channels, where these processes accounted for 70 percent to 86 percent of LWD. Martin and Benda (2001) found similar results in southeast Alaska, with bank erosion and mortality being the dominant recruitment mechanisms in all study segments in Game Creek basin, accounting for 60 percent and 39 percent of total volume, respectively; while landslides only supplied 1 percent of the total volume.

May and Gresswell (2003) studied the relative contribution of processes that recruit and redistribute wood to streams and the spatial variance of these processes in small colluvial streams compared with larger alluvial streams in the southern Oregon Coast Range. They found that slope instability and wind throw were the dominant mechanisms for wood recruitment to small colluvial channels (Figure 10.1-1) in old growth Douglas-fir and western hemlock forests in the southern Coast Range of Oregon. The larger alluvial channel included in the study received wood from a greater variety of sources, and wind throw was the dominant process for wood recruitment from the local hillslopes and riparian areas along the alluvial stream. In addition, field evidence showed that the LWD recruited by wind throw was in many different states of decay, which suggests that input did not occur in a single catastrophic event, but was spread over multiple decades (chronic inputs).

Reeves et al. (2003) assessed 1284 pieces of large wood in the lower 8.7 km of main stem Cummins Creek in the central Coast Range of Oregon to identify sources of wood in the creek. Of these, 905 (65.4 percent, total volume 6,147 m^3) were determined to be from upslope sources (areas above the valley floor delivered by mass movements) and 479 (34.6 percent, total volume 7,090 m^3) were from streamside sources (riparian zone immediately adjacent to the channel). The findings are similar to results of recent studies in Washington and northern California. Landslides delivered more than 80 percent of the number of large wood pieces to a stream in the Olympic National Park, Washington (Benda et al. 2003) and in the Redwood National Forest (Benda et al. 2002). Reeves et al. (2003) attributed the difference in mean volume of the pieces of wood of each source type (riparian vs. upslope) to the fire history and topography of the watershed.

Lienkaemper and Swanson (1987) observed wood input and distribution for seven to nine years in old-growth Douglas-fir forests in the central western Cascades Range in Oregon. They found that 66 percent of new tree falls were in areas not subject to bank erosion and accounted for 69 percent (136.4 m^3) of the total volume added. The recruitment mechanisms were thought to be wind, possibly coupled with stem or root decay. Further, 34 percent of the total number of trees and 31 percent (61.3 m^3) of the total volume of trees added to the stream grew adjacent to the stream. The authors, however, did not conclude that bank erosion was the cause for streamside recruitment, as lateral cutting of the high-gradient channel types included in the study is very limited. Rather, the recruitment mechanisms for these trees were thought to result from instability due to asymmetry of the rooting environment of a stable streambank and the tilt of trees growing into the open canopy space above streams which could result in a higher susceptibility of large trees to wind throw. At the larger site (stream order 5) in the study, bank erosion was determined to be a major factor in all but one occurrence of new wood recruited to the stream. Other sources have found similar results, where much of the LWD in unconfined channels is introduced by undercutting of trees on the bank (Grette 1985 and Murphy and Koski 1989).

Rates of wind throw are variable. Hairston-Strang and Adams (1998) assumed 30 percent of trees are wind thrown over 10 years in their study of the ability of riparian buffers to recruited LWD to streams in Oregon. This rate was based on several observed riparian wind throw and LWD input rates, reported in the literature. The Hariston-Strang and Adams (1998) study reported the following rates of wind throw from other studies; McDade et al. (1990) found that 89 percent of the pieces observed in the study were delivered to the stream by wind throw and other processes unrelated to bank erosion; Andrus and Froehlich (1992) reported that, in the Oregon Coast Range, wind had damaged 0 to 72 percent of the initial live basal area of streamside buffers within 1-6 years after logging, with most losses being <20 percent; and a study completed by Timber, Fish and Wildlife in Washington harvest units, which found that 82 percent of 91 buffers surveyed had less than 10 percent of the trees blown down within 2 years after harvesting, with only one site exceeding 50 percent loss (TFW Field Implementation Committee 1994). Grizzel and Wolff (1998) quantified the abundance of instream LWD due to wind throw in buffer strips on the west slope of the north Cascades in Washington and reported that wind throw increased total in-stream LWD pieces by 52 percent. Infrequent, severe windstorms in the Pacific coastal ecoregion have been responsible for leveling very large areas of forest (Harmon et al. 1986).

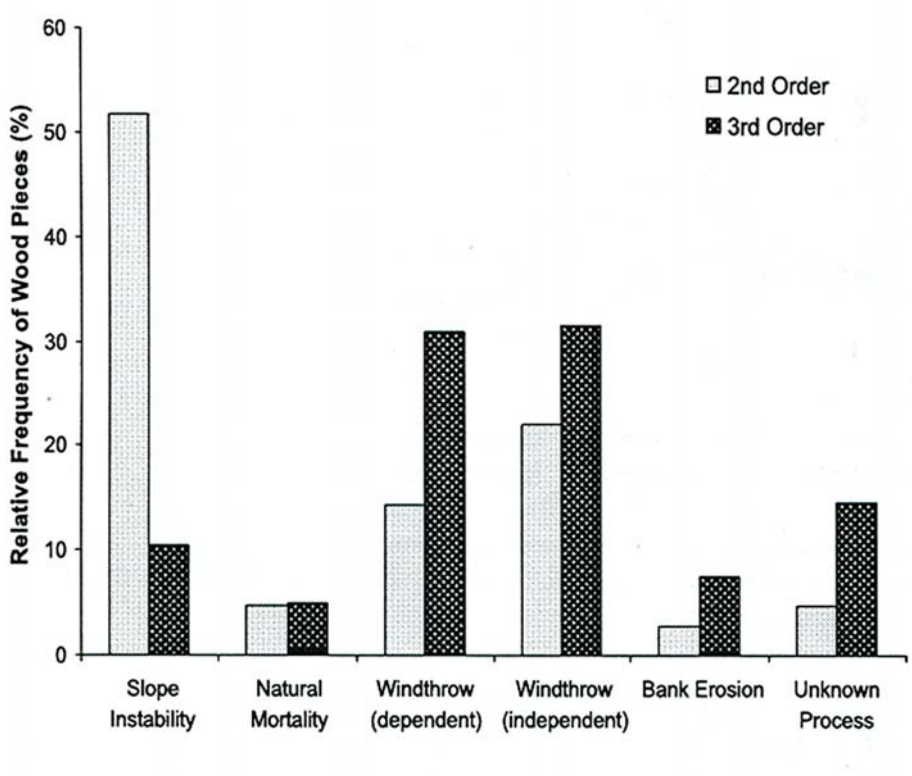

Figure 10.1-1. Bar graph of relative frequency of wood pieces in % vs. recruitment process-slope instability, natural mortality, wind throw (dependent), wind throw (independent) bank erosion, and unknown.
The graph depicts wood delivered to colluvial (second-order) and alluvial (third-order) channels from different recruitment processes in the local hillslopes and riparian areas (May and Gresswell 2003). Wind throw (independent) refers to a single uprooted tree. Wind throw (dependent) refers to numerous uprooted trees in a larger wind throw patch, often located further upslope and knocking down trees growing closer to the channel. Unknown process refers to tree boles that extended into the local forest (e.g., not fluvially derived) but no recruitment process could be identified (May and Gresswell 2003).

LWD Recruitment Due to Tree Mortality from Insects and Disease

Little information exists on LWD recruitment to streams due to insect and other tree diseases. Much of the information on tree mortality exists in snag recruitment literature, which may provide information relevant to wood recruitment to streams. Ohman (2002) found that rates of mortality of tree recruitment snags varied by cause of death (Table 10.1-2) in numerous sites across western Washington and Oregon. The study found that trees killed by insects, animals, and suppression from other vegetation were more likely to remain standing as snags (e.g., not as likely to recruit to streams). Trees killed by weather (including wind throw) and root disease were most likely to fall down soon after death (e.g., more likely to recruit to streams). Nearly half of all mortality trees fell within ten years of death. In undisturbed stands, 30 percent of snags fell down over the 10 year period.

Table 10.1-2. Fate of mortality trees by cause of death over a 10-year period in western Washington.

Cause of Death	Still Standing (Percent)	Fall Down (Percent)
Insects	96	4
Root disease	52	48
Other rots	63	37
Animals	100	0
Weather	28	72
Suppression	79	21
Other/Unknown	61	39
All causes	56	44

LWD Recruitment Due to Snow/Ice Breakage and Animal Mortality

Very little information was found that looked at LWD recruitment to streams due to fire, snow or ice storms, prolonged flooding, such as from beaver dam construction, or from animal mortality. While data and information on fire is abundant, very few studies were found that looked at fire in riparian areas and no studies were found that related fire to large wood recruitment to streams. Snow and ice storms and resultant breakage have not been widely recognized as a source of wood for aquatic systems (Kraft et al. 2002). The only study found that documented amounts of debris from a snow or ice storm was in the northeastern U.S. and eastern Canada after a major ice storm in 1998. This study related the number of debris dams to the proportion of trees with canopy damage and found a linear relationship for first order streams (N=30, R2 =0.13, $p < 0.05$) and third order streams (N=11, R2 = 0.55, $p < 0.01$) (Kraft et al. 2002). The authors concluded their results support the observation by others that disturbances such as the 1998 ice storm are responsible for dominant inputs of woody debris, usually exceeding background levels of wood input (Benda et al. 1998; Bragg 2000).

The effects of beaver on riparian vegetation has been well documented, however, the effects of prolonged flooding caused by beaver dams on timber mortality is very limited. One study estimated that as much as 50-60 percent of the wood input categorized as wind-induced was actually from conditions changed by beaver including the trees surrounding the original stream channel eventually falling into the pond due to elevated water tables (Lawrence 1954 as reported in Naiman and Hobbie 1986). In addition, the only study found relating LWD recruitment to animal caused mortality was a study by Naiman and Hobbie (1986), who attempted to quantify the importance of beaver as an agent transferring wood to streams in comparison to other possible agents in Quebec, Canada (i.e., wind and erosion). They found that beaver cut 53.1 percent of the fine wood mass of trembling aspen, 56.2 percent of the willow, 12.4 percent of the alder, 16.5 percent of the paper birch, and <1 percent of the conifers. For coarse wood, beaver were an important input agent only for trembling aspen (36.7 percent), with wind throw and erosion being the main recruitment mechanism for all other tree species considered in the study.

LWD Recruitment Models

Various models are available that estimate the recruitment of LWD to streams based on different recruitment mechanisms and stand types (Bragg 2000; Welty et al. 2002; Van Sickle and Gregory 1990). All these models incorporate the wood mass balance or wood budget (volumetric change over time over some channel length) equation, which is governed by the rate of stochastic inputs by episodic fire and wind, forest stand mortality, bank erosion, landsliding, and fluvial inputs, minus the rate of fluvial export, storage on valley floors, wood decay and abrasion. These studies rarely include data sets on the various recruitment mechanisms, rather, mortality rates for the region, typically by tree species were used as in these models. There is a need in all these models for empirical data (on various ecoregions, altitudies, aspects, etc.) to verify and calibrate model outputs.

Benda and Sias (1998, 2003) developed a quantitative framework for evaluating the mass balance of in-stream organic debris over large temporal and spatial scales. This work included solving mathematical equations with parameters appropriate for temperate Pacific Northwest Regions. This work included modeling various erosion rates to determine amounts of large wood recruited to a stream through this mechanism. A low bank erosion rate of 1 cm/yr, which is representative of steep mountain stream channels, was found to recruit about 15 percent of the total wood, while a .5 m/yr^{-1} rate, more representative of a low-gradient channel, is necessary to provide a greater percentage of LWD recruitment to a stream and dominate wood loading (i.e. greater than 50 percent) (Benda and Sias 2003).

As described above, in channels with low bank erosion rates (1 cm/year), wood loading is dominated by stand mortality. These channels also receive punctuated inputs from episodic fires. In environments with these low bank erosion rates, wood recruitment may be relatively low without other disturbances occurring such as fire, landslides or wind throw. In contrast, the higher bank erosion rate dominates wood recruitment and is represented by an almost uniform distribution of wood recruitment, de-emphasizing the effects of episodic disturbances, such as fires, in LWD recruitment. In general, the importance of wood recruitment by stand mortality should decrease downstream, in proportion to the rate of increase in bank erosion.

Other predictions included in this study are that in areas of longer fire rotation (500 years), toppling of fire-killed trees comprises only 15 percent of the long-term wood budget, yet chronic stand mortality that affects the large standing forest biomass ensures a continues input of large volumes of wood to a stream. In contrast, toppling of fire-killed trees in forest environments with shorter fire rotations (150 years, which is more applicable to regions of eastern Washington) comprise about 50 percent of the wood budget (Figure 10.1-2). Benda and Sias (2003) also concluded that recruitment from debris flows represent the single largest point source of woody debris delivery to streams. However, the contribution from debris flows (estimated to be about 12 percent of the long-term wood budget) is limited by their long return interval.

Bragg (2000) uses a manipulated forest growth and yield model to translate information into the components comprising riparian LWD recruitment to compare the percent of LWD input from catastrophic disturbances compared with individualistic (chronic) inputs. Bragg modeled LWD recruitment to streams after catastrophic disturbance for a small headwater stream in the Intermountain West (Wyoming). Similar to Benda and Sias (1998, 2003), he also found that catastrophic disturbances markedly altered the patterns of LWD recruitment, with peaks in LWD recruitment occurring a few decades after a major disturbance occurs (Figure 10.1-3).

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. Due to the lack of specific data and information pertaining to recruitment mechanisms for large woody debris and the length of time required to study this in natural settings, it will take significant time to answer this question for eastern Washington.

Current studies lack consistency making it hard to compare between studies. In general, studies lack a description of the criteria for classifying large woody debris as being from a particular recruitment process. In addition, many studies used wind throw to include all fallen trees, despite the cause of death. Therefore, wind throw in many studies likely includes trees killed by other mechanisms such as insects, disease, fire, and suppression from the adjacent riparian stand.

Summary and Recommendations

To summarize, no studies were found that provided answers to this question for eastern Washington. Other studies divided recruitment mechanisms into small scale chronic input processes and larger episodic input processes. Wind throw and streambank erosion were the two recruitment mechanisms most often evaluated in studies. In general, wind throw accounts for the highest percentage of chronic wood recruitment to small, steep streams, and streambank erosion accounts for the highest percentage of chronic wood recruitment to larger, low gradient streams. Debris slides also account for a higher percent of LWD recruitment in steep streams compared with low gradient streams. No quantitative information was found for suppression mortality, insect mortality, disease morality, snow/ice breakage, mortality due to prolonged flooding, such

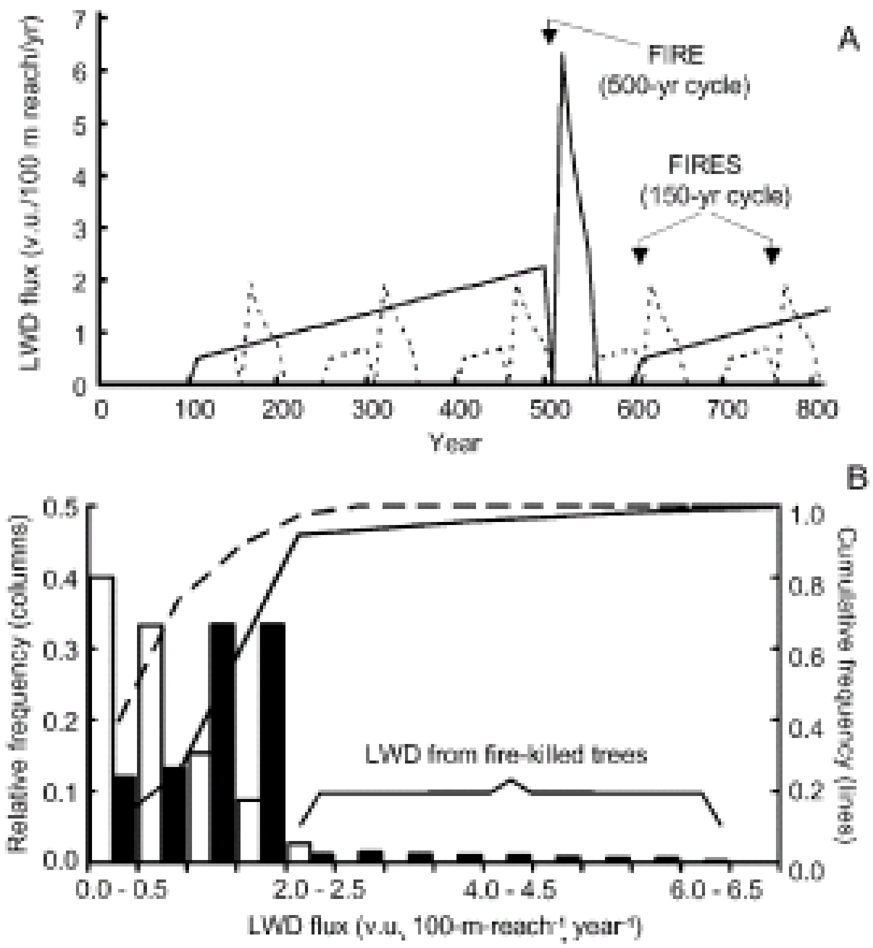

Figure 10.1-2. The modeled recruitment flux (volume per time) of LWD delivered to a 100 meter segment of stream for 150 year (more applicable to eastern Washington) and 500 year fire cycles.

The gradual increases in recruitment flux represent chronic stand mortality (outside the influence of fire caused recruitment). Abrupt increases represent pulses of wood from fire-killed trees toppling over on an interval of 40 year. The abrupt decline prior to the pulse represents a cessation of growth when all trees are killed and there is a lag before the killed trees begin to fall. (B) shows the corresponding frequency distribution of wood recruitment flux using the entire time series. The solid bars represent flux occurring from the 500-year fire cycle (Benda and Sias 2003).

as from beaver dam ponding, and animal mortality as relevant to recruitment of LWD to the stream channel. Literature is available for insect and disease mortality in upland snag recruitment research, which may be relevant to large wood recruitment in future studies. The effects of fire in riparian areas is just recently being studied. Episodic recruitment mechanisms such as fire and avalanches can account for a very high percentage of the LWD recruitment to a stream, but these events are temporally and spatially difficult to predict.

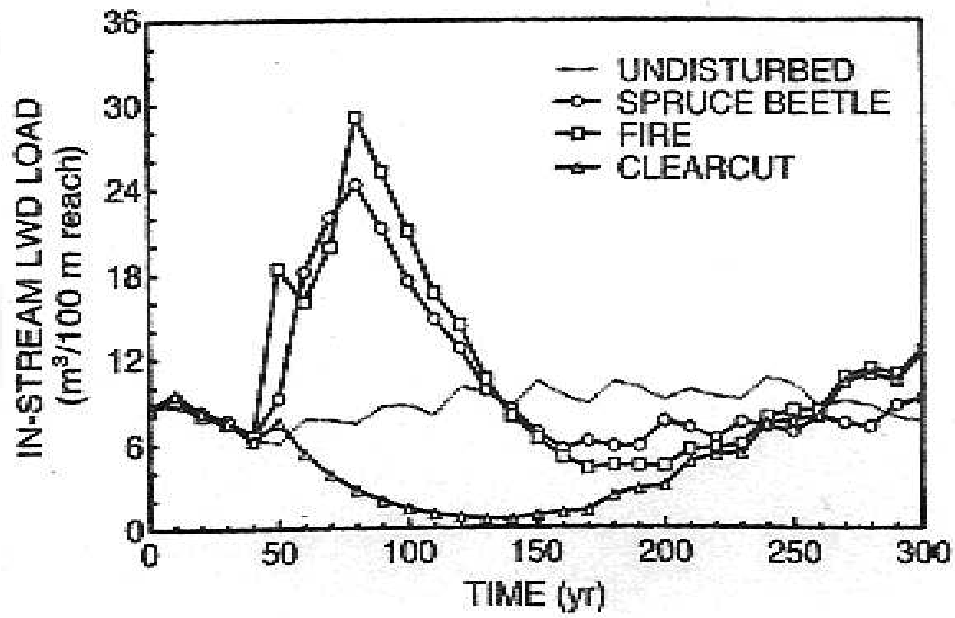

Figure 10.1-3. In-stream LWD loads as a function of disturbance type throughout the simulation period.
The peak channel LWD volumes do not come immediately after the disturbance (at time 0), but rather 30 years later as the continuing input of snags killed by the natural catastrophes sustain delivery of LWD to the stream (Bragg 2000).

An answer to this question would require a substantial amount of data collection beyond the scope of this literature review. It is difficult to define the full structure of variability in woody debris in streams by field measurements alone since only a single point in time is considered. Because fires, wind, and floods both recruit to streams and initiate forests, the time scale over which to consider long-term wood recruitment is decades to centuries. Furthermore, because stream transport integrates numerous wood sources, the appropriate spatial scale is the channel network (i.e., watershed).

To determine percent LWD recruitment from chronic mechanisms in would require long-term monitoring of a wide range of riparian stands. Studies would require plots in riparian stands to determine percentages of large wood recruited through chronic mechanisms (bank erosion, disease, insect mortality, wind throw, ice and snow breakage, suppression mortality, and fire occurring in riparian stands). Determining the percent of large wood recruited to streams from large episodic disturbances such as avalanches and debris slides, which may recruit trees from greater distances would require larger scale studies. Episodic recruitment mechanisms are likely best studied on a case study basis as the occurrence and location of these disturbances is difficult to predict. Methods for establishing baseline plots to monitor large wood recruitment are provided in Schumaker and Glass (1999).

The effectiveness monitoring and evaluation program (Smith 1998) includes riparian stand survey methodology developed by TFW in Washington that records the mortality agent for all downed trees. The parameters used in this survey methodology include wind throw, bank erosion, suppression mortality, sun scald, hit by another tree, mass wasting, snow avalanche, debris torrent, lightning, ice/snow damage, insect/disease, animal damage, logging damage, and timber harvest. Wind throw is considered the default mortality agent in lack of other evidence. The methodology is not specified for a particular region. Producing protocols for classifying recruitment mechanisms to accompany this inventory may be a way to collect large scale data.

In addition, information outside of LWD recruitment literature, which is currently available for eastern Washington may be useful in answering this question and aid in future study design. Harrod et al. (1998) recommend a method for estimating snag density in dry forests east of the Cascades Range based on historical disturbance regime of frequent, low-intensity fires. Hessburg et al. (1999) mapped and characterized historical and current vegetation composition and structure of 337 randomly sampled subwatersheds in 43 subbasins in Washington. The study assessed landscape vulnerability to defoliator, bark beetle, dwarf mistletoe, root disease, blister rust, and stem decay disturbances. Hayes and Daterman (2001) discuss bark beetles in eastern Washington and stand susceptibility. Hessburg et al. (1994) has documented insect and pathogen by forest series, a data set which may help in future estimates or LWD recruitment due to insects and pathogens. Hemstrom (2001) discusses vegetative patterns for eastern Washington in relation to disturbance.

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10.2 Question 32 Response

Do the primary recruitment mechanisms for wood vary by region, elevation, aspect, and/or stand type? Provide specific examples and numeric summaries of study results.

Summary of Literature Sources

Of the references reviewed, a total of eight studies were found that had quantitative and/or descriptive information relating to recruitment mechanisms varying by region, elevation, aspect, and/or stand type. Of these, two had information relevant to eastern Washington and none contained data from analogous regions. Table 10.2-1 provides a summary of these references.

Summary of Quantitative Data

Region

No studies were found that related the mechanisms of LWD recruitment to regions in eastern Washington. Input processes vary considerably depending on riparian tree species composition, soil stability, valley form, lateral channel mobility, and streamside management history (Bisson et al. 1987). Patterns of tree mortality vary regionally because the relative importance of catastrophic and chronic agents varies widely with forest type (Harmon et al. 1986). Therefore, it is likely that recruitment mechanisms will have great variability across regions and within regions in eastern Washington.

Elevation

No studies were found that related the mechanisms of LWD recruitment to elevation in eastern Washington. Very little information was found on this relationship for areas outside of eastern Washington as well. Keller and Swanson (1979) reported a study in the McKenzie River system in western Oregon that looked at old-growth Douglas-fir forests. A series of five sample points along the stream revealed a systematic decrease in coarse organic debris loading (kg/m^2) in a downstream direction (decreasing elevation). The study found that coarse woody debris (>10 cm diameter) concentrations were 48 times higher in a first order tributary (higher elevation) than in the sixth order mainstem river (lower elevation). The study accounted for the increase in stream area per unit of length by sampling longer sections of stream in wider, lower elevation reaches of the river. Figure 10.2-1 shows the importance of various recruitment mechanisms by stream order and distance from the headwaters (decreasing elevation).

Aspect

No studies were found that related the mechanisms of LWD recruitment to streams by aspect. Some relevant information, however, was found in snag recruitment studies conducted in eastern Washington. For example, Flanagan et al. (2002) recorded snag species, locations and causal

Table 10.2-1. Summary of literature sources containing data relevant to question 32.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Bilby and Wasserman 1989	Eastern Washington	Not reported	Forest lands throughout eastern WA	Not reported	Not reported	Not reported	Both	S	No
Everett et al. 1999	North Cascades, Okanagan National Forest	Not reported	NC	Not reported	Not reported	Not reported	Non-riparian	S	Yes
Flanagan et al. 2000	North Cascades, Entiat watershed	Not reported (average upland plot size 316 ha ± 181 ha)	NC	Whitebark pine, subalpine larch, subalpine fir, mountain hemlock, Pacific silver fir	Not reported	Not reported	Non-riparian	S	No
McKinney 1997	Ahtanum watershed, eastslope Cascades Mountains, Washington	103.4 km^2	SC and CB	Riparian coniferous and hardwood forests	Not reported	Columbia River basalts and early Tertiary volcanic	Both	Q, S	No
Analogous Process-based Approach									
Grette, G.B. 1985	Olympic Peninsula, WA	3.4 – 12.4	WW	Western hemlock; Sitka spruce; western redcedar; Douglas-fir; red alder	0.5 – 2.0		Managed and Unmanaged	S,Q,O	Yes
Grizzel and Wolff 1998	Northwest Washington	Misc.	North Cascades	Western hemlock, western redcedar, red alder, and Douglas-fir	1 – 63%	Unknown	Unmanaged	S	Yes
Keller and Swanson 1979	McKenzie River, western Oregon	1,024 km^2	Pacific coastal	Old-growth Douglas-fir	0 – 6%	Not reported	Not reported	Q, S	Yes
Rot 1995									

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington

[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

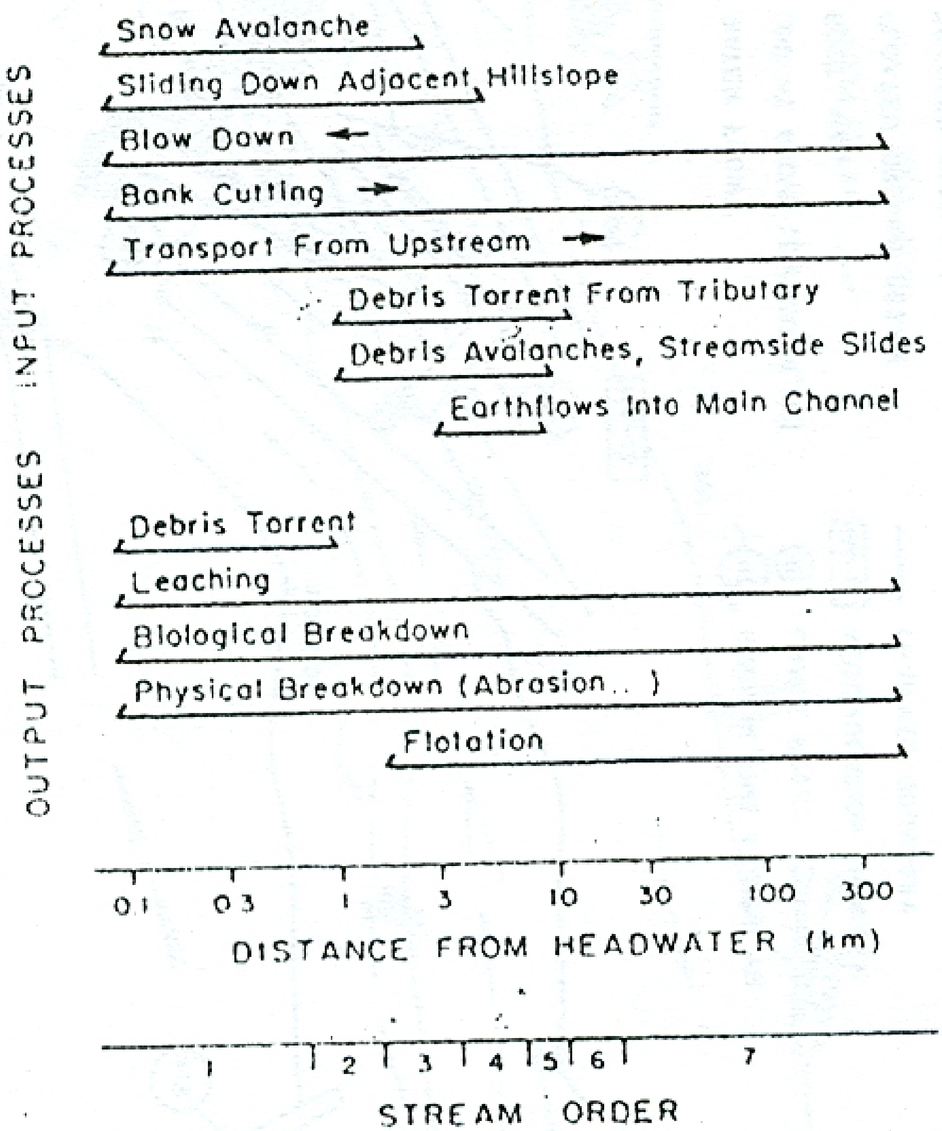

Figure 10.2-1. Debris input and output processes according to stream order in the McKenzie River System, Oregon.
Arrows indicate direction of increasing importance. From Keller and Swanson (1979).

agents of tree mortality in subalpine forests in the Entiat watershed on the eastern slope of the Cascades in eastern Washington. They found that snag densities of intermediate and suppressed snags was significantly higher ($p < 0.05$) for steep (>50 percent) south-facing slopes (Table 10.2-2). However, more weather caused tree mortality occurred on northerly aspects than southerly aspects ($p <0.5$) and on mid slopes than on either upper or lower slopes ($p <0.05$) (Flanagan et al. 2002). This study did not relate snag densities, snag fall or cause of tree mortality to LWD recruitment in streams.

Table 10.2-2. Total number of snags per hectare as related to percent slope and slope aspect for subalpine forests in the Entiat watershed on the east slope of the Cascades, Washington.

Aspect	Slope (Percent)		
	10-30	30-50	50+
North	41	43	54
South	50	57	88

Source: Flanagan et al. (2002).

Stand Type

No studies were found that related the mechanisms of LWD recruitment to streams by stand type. Once again, the most relevant information for eastern Washington was found in snag recruitment studies. For example, Everett et al. (1999) who studied snag numbers at 26 wildfire locations ranging from one to 81 years old on the east slope of the Cascades Range, found the longevity of snags was greater for thin-barked Englemann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*) and lodgepole pine (*Pinus contorta*) than thick-barked Douglas-fir (*Pseudotsuga menzesii*) and ponderosa pine (*Pinus ponderosa*). With larger diameter snags, however, Douglas-fir persisted longer than Engelmann spruce (dbh ≥ 41 cm, 40 percent standing after 80 years). Although the information is not related to LWD recruitment to streams, reports of tree mortality found in snag literature can provide useful data to determine potential wood recruitment in future studies.

In the Ahtanum watershed assessment located on the east slope of the Cascades in Washington McKinney (1997) suggests that LWD recruitment and the tree species mix found in the riparian zone may be used to determine stand succession. Stand succession, in turn, will influence future LWD recruitment. The assessment suggests that the principals used in the successional charts (Riparian Function module) for western Washington are also applicable to eastern Washington, and by determining the relative proportions of shade-tolerant to shade-intolerant species the approximate years to recruitment for the trees in an existing riparian stand can be estimated (McKinney 1997). In the Ahtanum watershed, field inventory data indicates that lower elevation riparian zones along mainstems are dominated by hardwoods (due to historic impacts) interspersed with young Douglas-fir and/or grand fir. It is expected that in 100+ years, precluding any disturbance, these areas will be dominated by conifers. Lower elevations of dry, north-slope tributaries to mainstems are dominated by Oregon white oak and ponderosa pine.

High elevation, slightly wet sites may have more Douglas-fir in the understory than low elevation, dry sites (actual conifer species composition in the understory depends on local fire suppression). The upper reaches are dominated by conifers with understories of conifers. Based on this data, the assessment concludes that the current potential for riparian stands to provide LWD to streams decreases as one moves northward. The higher elevation stream reaches (above 3000 feet) tend to be more capable of providing LWD to the stream network than lower elevation mainstem and tributary reaches.

Bilby and Wasserman (1989) examined a total of 72 stream sections east of the Cascades Mountains for the purpose of obtaining information to justify riparian management regulations for eastern Washington. They collected data on the riparian system bordering the surveyed streams by establishing 4 to 6 plots at 20 meter intervals on alternating sides of the stream. Plots measured 6 meters wide and extended 30 meters perpendicular to the stream, beginning at the stream's edge. They measured the diameter, height, and species of each tree with a dbh over 10 cm within each plot. They observed a linear (r^2=0.41) relationship between density of trees in the streamside area and LWD frequency (Figure 10.2-2), with number of pieces of LWD per meter increasing with the number of stems/hectare in the adjacent riparian forest.

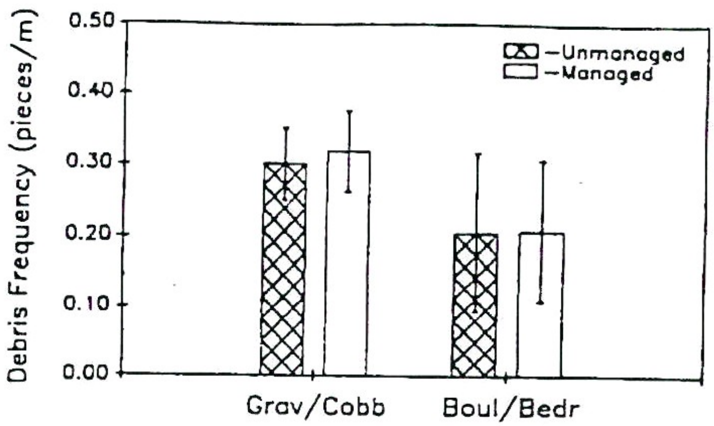

Figure 10.2-2. Relationship between tree density in the riparian area and large organic debris (LOD) frequency in the stream for sites in eastern Washington with gravel/cobble beds.
The curve has the equation LOD frequency=0.0003 tree density + 0.151; r^2=0.41. Source: Bilby and Wasserman (1989).

Other studies have found that the rate at which chronic input (bank erosion, mortality from suppression, insects, disease, fire, storms and wind throw) processes deliver LWD to a channel are a function of the successional stage of the riparian stand. Grette (1985) found that Red alder (*Alnus rubra*), a common early-successional species in riparian areas in the Pacific coastal ecoregion, has a relatively short life span and begins to die and contribute LWD to the channel approximately 60 years after stand establishment. Shade tolerant conifers such as western redcedar (*Thuja plicata*) or western hemlock (*Tsuga heterophylla*) establish in the alder understory, then occupy the site and contribute wood to the channel as a result of stem suppression. Evidence suggests that stem suppression is the major process contributing LWD to stream channels in the western Cascades of Washington in stands up to 300 years old (Rot 1995). In stands older than this, mortality of dominant trees due to disease and wind throw is the primary process delivering wood to channels (Harmon et al. 1986).

Numerous studies have looked at wind throw as an agent of tree mortality, and looked at the susceptibility of different tree species to wind throw, but few have related it to LWD recruitment to streams. Grizzel and Wolff (1998) looked at wind throw in riparian forest buffer strips in northwest Washington. In this study, wind throw affected 33 percent of the total riparian buffer trees across the 40 study sites. The level of wind throw varied among tree species. Pacific silver fir (*Abies amabilis*) and western hemlock experienced the highest levels of wind throw at 37.3 and 36 percent of total stems affected. Bigleaf maple (*Acer macrophyllum*) was least subject to wind throw, with only 7.5 percent of trees uprooted or broken. Wind throw occurred at intermediate levels for red alder (17.2 percent), Douglas-fir (20.2 percent) and western redcedar (21.8 percent). Average diameter of wind thrown trees were significantly greater than standing trees for four of the six most common species ($p<0.001$) (Table 10.2-3) and 67 percent of all wind throw trees fell to the north, northeast, or northwest. Only 3 percent fell towards the south. Riparian buffer wind throw increased the number of in-channel large woody debris at these sites by 34 percent.

Table 10.2-3. Comparison of mean diameter at breast height (cm) and standard deviations (SD) of standing and wind thrown trees and mean diameter (cm) of in-channel woody debris deposited pre- and post- harvest in 40 forest buffers associated with non-fish bearing streams in northwest Washington. (From Grizzel and Wolff 1998)

Species	Standing Trees		Windthrown Trees		P-value
	Diameter	SD	Diameter	SD	
Bigleaf maple	32.5	8.6	32.3	3.6	0.450
Douglas-fir	38.9	11.4	42.2	7.4	<0.001
Red alder	33.0	12.2	34.8	8.1	<0.001
Western redcedar	29.2	13.5	30.7	7.9	0.003
Pacific silver fir	28.4	4.6	33.8	4.6	<0.001
Western hemlock	30.2	13.7	30.0	11.2	0.114
	Pre-harvest		Post-harvest		
LWD	30.0	20.8	24.9	13.7	<0.001

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. Due to the lack of specific data and information pertaining to recruitment mechanisms for large woody debris and the length of time required to study this in natural settings, it will take significant time to answer this question for eastern Washington.

Current studies lack consistency making it hard to compare between studies. In general, studies lack a description of the criteria for classifying large woody debris as being from a particular recruitment process. In addition, many studies used wind throw to include all fallen trees, despite the cause of death. Therefore, wind throw in many studies likely includes trees killed by other mechanisms such as insects, disease, fire, and suppression from the adjacent riparian stand.

Summary and Recommendations

No studies were found that related the mechanisms of LWD recruitment to streams by region, elevation, aspect and/or stand type for eastern Washington. A general assumption, however, can be made concerning LWD recruitment to streams as related to elevation. This assumption relates to the increased importance of bank erosion in a down stream (decreased elevation) direction as illustrated by Keller and Swanson (1979) and demonstrated in numerous other studies. Some relevant information was found for eastern Washington in snag recruitment studies on tree mortality at different topographical aspects (Flanagan et al. 2002), however tree mortality was not related to LWD recruitment to streams. Other relevant information for eastern Washington found in snag recruitment studies provided information on individual tree species or stand types and focused primarily on wind throw mortality (Grizzel and Wolff 1998).

A significant amount of data appears to be available for eastern Washington concerning tree mortality through various mechanisms, including weather, fire, disease, and insects. The information available on upland areas may be helpful in future mapping or studies of chronic and episodic disturbances leading to LWD recruitment to streams. For example, in Everett et al.'s (1999) snag recruitment study, they used a sampling design to identify differences in snag densities within burns based on aspect, slope, and micro-topography. Snag fall rates are a function of snag size, tree species, cause of mortality, season of mortality, and the micro-environment. This study did not relate snag fall rates to LWD recruitment to streams, but the methods used and information may be useful in developing future studies. Snag fall rates have been defined for different tree species and sites, but snag longevity is a site specific process that needs to be determined for each area of interest. Data collected on fire history in eastern Washington may also contain useful information. For example, Agee (1994) found that species in subalpine forests are very intolerant of fire, with mortality being the usual result of fire in these systems. In contrast, in lower elevation forests of ponderosa pine and Douglas-fir, fire-scarred trees are not commonly found in subalpine forests. Therefore, subalpine fir systems may be more likely to recruit LWD to streams post-fire than ponderosa pine and Douglas-fir dominated systems.

References

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10.3 Question 33 Response

What is the size of wood that is recruited through these various recruitment mechanisms? (Provide distributions of study results if available.)

Summary of Literature Sources

Of the references reviewed, four studies were found that had quantitative and/or descriptive information relating to the size of wood that is recruited through the various recruitment mechanisms; of these, none had information relevant to eastern Washington and none contained data from analogous regions. Table 10.3-1 provides a summary of the references reviewed.

Summary of Quantitative Data

Very little quantitative data were found on the distribution of sizes of LWD pieces recruited to streams through the various recruitment mechanisms. Many studies have recorded the size of wood recruited to streams and compared the size to various features of the riparian area and stream, but few studies were found that compared the size of individual LWD pieces to the recruitment process.

Grizzel and Wolff (1998) (study described in Question 31) studied 40 riparian buffers along small streams (less than 3 meters in bankfull width) in northwest Washington that had been clearcut in the adjacent uplands within the 3 years previous to the study. The average buffer width was 29 meters. Sites were second-growth forest stands ranging in age from 40 to 60 years. The most common species within the buffers were western hemlock, western redcedar, red alder, and Douglas-fir. The study determined the average diameter of wind thrown LWD recruited to streams from these riparian buffers to be 24.9 cm (SD=13.7).

Reeves et al. (2003) (study described in Question 31) compared the total number of pieces of wood delivered to a fourth-order stream in Oregon from upslope sources compared to streamside sources. The study site is located in a federal wilderness area and is pristine except for small clear-cut timber harvest units dating back to the late 1950s and early 1970s (total of 6 percent of the watershed). Upslope trees are primarily Douglas-fir and western hemlock ranging in age from 150-160 years (dating from the last large wildfire). The riparian areas are dominated by Sitka spruce, red alder, and bigleaf maple and are older than the trees in the adjacent upland areas. They found a total of 449 pieces derived from streamside sources with a mean (SD) volume/piece (m^3) of wood of 15.2 (20.2). Of 563 total pieces determined to be from upslope sources, the mean (SD) volume/pieces (m^3) was 5.4 (4.3). The estimated mean volume of streamside pieces was almost three times that of upslope-derived pieces.

May and Gresswell (2003) (study described in Question 31) compared the volume of individual LWD pieces recruited to colluvial and alluvial channels through different recruitment

Table 10.3-1. Summary of literature sources containing data relevant to question 33.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach									
Grizzel and Wolff 1998	Northwest Washington	Misc.	North Cascades	Western hemlock, western redcedar, red alder, and Douglas-fir	1 – 63%	Unknown	Unmanaged	S	Yes
May and Gresswell 2003	Southern Oregon Coast Range	3.9 km^2	Southern Oregon Coast Range	Old growth Douglas-fir, western hemlock, western redcedar.	Unknown	Riparian forests marine sedimentary rocks	Unmanaged	S	Yes
Murphy and Koski 1989	Southeast Alaska	Misc.	Unknown	Sitka spruce and western hemlock	0.4 – 2.9%	Alluvium and bedrock (channels)	Unmanaged	S	Yes
Reeves et al. 2003	Cummins Creek, coastal Oregon	21.5 km^2	Coastal Oregon	Upland: Douglas-fir and western hemlock Riparian: Sitka spruce, red alder and bigleaf maple	1.2 – 3.6	Basalt	Unmanaged	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington

[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

mechanisms. The largest pieces (median piece volume of 2.75 m^3) were recruited from the hillslopes and riparian areas directly adjacent to the stream. Recruitment mechanisms of these pieces include slope instability, natural mortality, wind throw, and bank erosion. Pieces transported from a debris flow (median piece volume 0.77 m^3) and from unknown sources (median piece volume 0.63 m^3) were intermediate in size, and pieces redistributed by fluvial processes had the smallest median volume per piece (0.25 m^3). Unknown sources appeared to be broken branches or the top of trees that experienced substantial breakage. No mechanism for breakage was included in the study. The median volume of wood pieces was significantly different among these sources ($p<.05$ Kruskal-Wallis multiple comparisons test).

Murphy and Koski (1989) (study described in Question 31) did not directly study the relationship between LWD size and recruitment mechanism, but collected data that would allow this comparison to be made. The study reports the number of pieces of LWD derived from four input processes (bank erosion, wind throw, mortality and landslide) by channel type (B1, B3, B6, C1, C2 and C3). The study also provides a summary table for mean number of LWD pieces by diameter class for the six channel types, therefore, it would be possible to determine the size classes of LWD within each recruitment process.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

In summary, very little information is available on the size of trees recruited to streams through the various recruitment mechanisms. The size of wood recruited to streams is dependent on riparian stand characteristics, location, and the recurrence interval of the various recruitment processes. In general, the larger the trees in a riparian stand, the larger the pieces will be for all input processes. For example, chronic inputs of LWD greater than 50 cm in diameter due to tree mortality are more common in maturing, old-growth forests than in young second-growth stands, where many trees have not attained a large size (Bisson et al. 1987). One of the most important results apparent in the available literature is that largest and most functional pieces of LWD are recruited from hillslopes and riparian areas directly adjacent to streams and not delivered from upstream areas. This conclusion emphasizes the importance of preserving trees in channel migration zones and riparian buffers, if functional instream wood is to be sustained.

The return interval of input processes is very important in determining the total volume of wood delivered to a stream. Catastrophic events are relatively rare (10 to 100+ years recurrence interval) but can add large volumes over short periods of time, episodic events occur more frequently (1 to 10 years recurrence interval), and chronic events have a recurrence interval of less than one year, but deliver relatively small volumes of LWD to the channel (Bisson et al.

1987). Some generalizations can be made about the size of individual pieces delivered through different recruitment mechanisms. For example, wind throw and bank erosion are more likely to result in the delivery of larger pieces of wood to a stream when compared with snow or ice storms, debris slides or snow avalanches where only branches are broken from the tree or trees are broken into many pieces during transport (Bisson et al. 1987).

A simple study plan that documents recruitment mechanisms along channel reaches representative of eastern Washington ecoregions and different channel size, gradient and confinement is recommended. Selected study sites could be used to address many of the questions that require additional information. Recruitment mechanisms can be divided in to the following categories when recorded in the field (e.g., Abbe 2000):

- Landslide – evidence of slope failure entering stream
- Bank erosion – localized erosion, tree with rootwad in stream
- Tree fall – tree with rootwad on bank or hillslope
- Wind throw – multiple fallen trees with parallel boles and rootwads on bank or hillslope
- Branch litter – branches or stems partially in stream not attached to tree
- Debris flow – large chaotic accumulation of LWD at downstream end of matrix supported debris flow deposit and upstream channel scour where debris flow passed
- Fluid transport – LWD deposited in channel with no apparent other source, particularly LWD racked up on channel obstructions.

Another study that is needed concerns recruitment by bank erosion. This study could be done by identifying the amount of riparian land eroded over time in aerial photographs, estimating the amount of timber that occupied that land and thus entered the stream. This quantity can then be compared to the quantity of LWD found in the stream to determine what percentage of instream LWD could be accounted for by bank erosion versus fluid inputs or other mechanisms.

References

Abbe, T.B. 2000. Patterns, mechanics, and geomorphic effects of wood debris accumulation in a forest river system. Unpublished Ph.D. dissertation. University of Washington, Seattle, Washington.

Bisson, P., R. Bilby, M. Bryant, C. Dolloff, G. Grete, R.A. House, M.L. Murphy, K.V. Koski, and J.R. Sedell. 1987. Large woody debris in forested streams in the PNW: past, present, and future. pp 143-190 *in* E.O. Salo and T.W. Cundy, eds., Streamside Management: forestry and fishery interactions.

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Murphy, M.L. and K.V. Koski. 1989. Inputs and depletion of woody debris in Alaska Streams and implications for streamside management. North American Journal of Fisheries Management 9:427-436.

Reeves, G., K. Burnett, and E. McGarry. 2003. Sources of large wood in the main stem of a fourth-order watershed in coastal Oregon. Canadian Journal of Forest Research 33:1363-1370.

10.4 Question 34 Response

What is the distribution of distances from a stream that wood recruits through the various recruitment mechanisms?

Summary of Literature Sources

Of the references reviewed, a total of three were found that had quantitative and/or descriptive information relating to distances from a stream that wood recruits through the various recruitment mechanisms. None had information relevant to eastern Washington or analogous regions. Table 10.4-1 provides a summary of these references.

Summary of Quantitative Data

Very little data exist on the distance to streams that wood recruits through the various recruitment mechanisms. In general, bank erosion would require the shortest recruitment distance and landslides and snow avalanches would be the recruitment mechanisms capable of recruiting debris the greatest distance from its source.

May and Gresswell (2003) (study described in Question 31) found that processes of LWD recruitment associated with slope instability tended to deliver wood from further upslope than other processes (pooled median source distance=40 meters), followed by independent and dependent wind throw (pooled median source distance=2 meters), and natural mortality (pooled median source distance=18 meters), and bank erosion occurred closest to the channel bank (pooled median source distance=2 meters) (Figure 10.4-1), though they did not appear to account for long-term channel migration relative to other processes. They found that slope instability and bank erosion had significantly different median source distances compared with all other recruitment processes ($p<0.05$ Kruskal-Wallis multiple comparisons test). The source distances for wood recruited by natural mortality and wind throw were similar ($p>0.05$ Kruskal-Wallis multiple comparisons test). May and Gresswell's results for the third-order alluvial channel were similar to distances observed by McDade et al. (1990). McDade et al. (1990) (study described in Question 31) found that 11 percent of recruited debris originated within 1 m of the bank, and was most likely delivered to the stream through bank erosion. This study measured the source distance of all pieces of LWD in the study reach, but did not relate source distances to a particular recruitment mechanism. They attributed source distance differences to varying tree heights of old-growth conifer, mature conifer, and mature hardwood tree species (discussed in Question 35).

Murphy and Koski (1989) studied the input and depletion of wood from southeast Alaska streams and identified the source of LWD and measured the distance from the stream to the source whenever possible. Almost all (99 percent) identified sources of LWD were within 30 m of the stream bank. Nearly one-half of the LWD pieces were from trees that had stood on the lower bank (<1 m away) and 95 percent were from trees within 20 m of the stream. Murphy and

Table 10.4-1. Summary of literature sources containing data relevant to question 34.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Process-based Approach									
McDade et al. 1990	Western Oregon and WW	Not reported	Cascades Range	Douglas-fir, western redcedar, western hemlock	3 – 40 degrees	Not reported	Unmanaged	S	Yes
May and Gresswell 2003	Southern Oregon Coast Range	3.9 km^2	Southern Oregon Coast Range	Old growth Douglas-fir, western hemlock, western redcedar.	Unknown	Riparian forests marine sedimentary rocks	Unmanaged	S	Yes
Murphy and Koski 1989	Southeast Alaska	Misc.	Unknown	Sitka spruce and western hemlock	0.4 – 2.9%	Alluvium and bedrock (channels)	Unmanaged	S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington.
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

Koski (1989) did not directly study the relationship between LWD source distance and recruitment mechanism, but the data they collected would allow these comparisons to be made. The study reports the number of pieces of LWD derived from four input processes (bank erosion, wind throw, mortality and landslide) by channel type (B1, B3, B6, C1, C2, and C3). The study also provides a summary table of the percentages of LWD from sources at given distances (<1 meter, 1-5 meters, 6-10 meters, 11-15 meters, 16-20 meters, and >20 meters) for the six channel types, therefore, the study collected the data necessary to determine the size classes of LWD for each recruitment process.

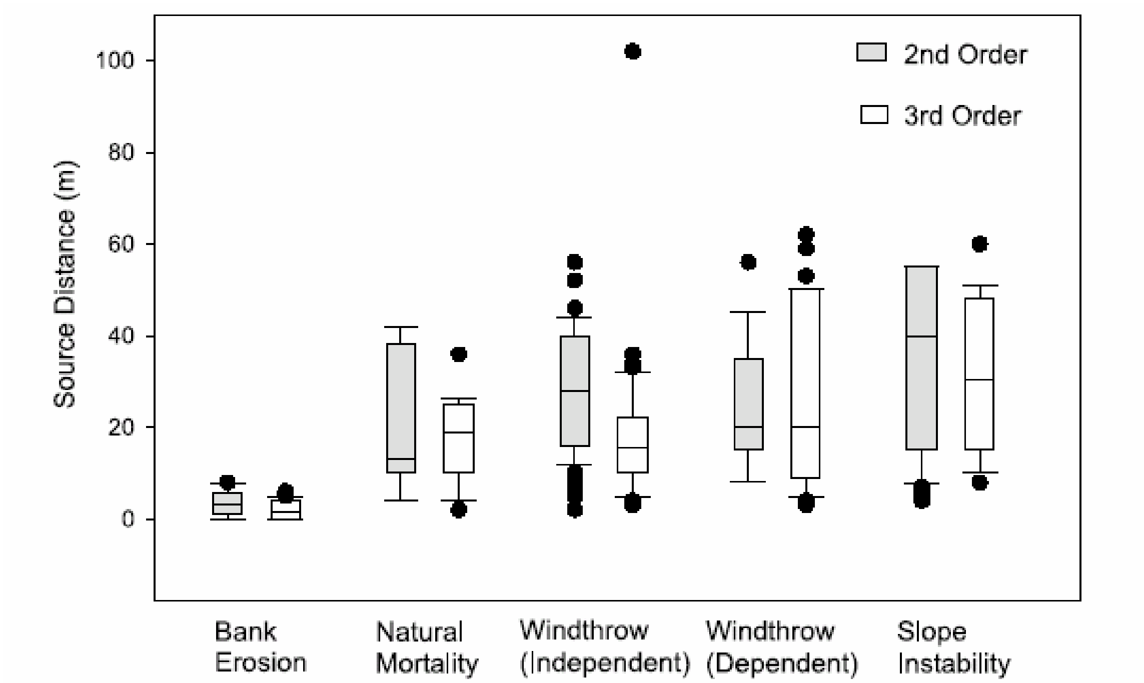

Figure 10.4-1. Box-and-whisker plots of the source distance of large wood with different recruitment mechanisms.
The lower boundary of the box represents the 25th percentile, the mid-line represents the median, and the upper boundary of the box represents the 75th percentile. The lower whisker represents the 10th percentile, upper whisker represents the 90th percentile, and circles represent outlying points. For wind throw, the median source distance was significantly different in second- and third-order channels ($p<0.05$ Kruskal-Wallis multiple comparisons test). For bank erosion and slope instability, the median source distance was significantly different from all other recruitment mechanisms ($p<0.05$ Kruskal-Wallis multiple comparisons test) (May and Gresswell 2003).

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question.

Development of a scientific protocol and collection of additional data is necessary to answer this question. Due to the lack of specific data and information pertaining to recruitment mechanisms for large woody debris and the length of time required to study this in natural settings, it will take significant time to answer this question for eastern Washington.

Summary and Recommendations

In summary, while a significant amount of literature is available on source distances for LWD recruitment, only one study was found that related source distance of LWD to different recruitment processes. This study found that source distances were greatest for slope instability and least for wood recruited through bank erosion.

More work is necessary to quantify the temporal contribution associated with bank erosion versus other processes and how the wood itself can influence (decrease or increase) bank erosion. Abbe (2000) describes how in-situ wood deposits can lead directly to additional bank erosion and wood recruitment as a stream attempts to go around wood obstructing channel.

Developing monitoring programs, such as those suggested in Morgan and Smith (1997) are likely the best way to answer this question.

References

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May, C. and R. Gresswell. 2003. Large wood recruitment and redistribution in headwater streams in the southern Oregon Coast Range, U.S.A. Canadian Journal of Forest Resources 33:1352-1362.

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Morgan, A. and D. Smith. 1997. Trends in disturbance and recovery of selected salmonid habitat attributes related to forest practices. TFW-AM9-97-002. Prepared by Northwest Indian Fisheries Commission for Timber Fish and Wildlife Ambient Monitoring Program.

Murphy, M.L. and K.V. Koski. 1989. Inputs and depletion of woody debris in Alaska Streams and implications for streamside management. North American Journal of Fisheries Management 9:427-436.

10.5 Question 35 Response

Do the distances that wood recruits to an eastside stream vary with region, stand type, stand age, and/or topography? If so, in what way? Provide numeric data where available.

Summary of Literature Sources

Of the references reviewed, a total of nine studies were found that had quantitative and/or descriptive information relating to the variation of distances that wood recruits to streams due to region, stand type, stand age and/or topography. Of these, two had information relevant to eastern Washington and seven contained data from analogous studies. Table 10.5-1 provides a summary of these references.

Summary of Quantitative Data

Eastern Washington Studies

Two studies were found that provided quantitative or qualitative information relative to this question for eastern Washington. Schumaker and Glass (1999) compared recruitment between mixed conifer, western redcedar, and mature redcedar stands in the 150 km^2 Onion Creek Watershed in northeastern Washington. They found the mixed conifer stands recruited the most wood to the bankfull channel (1.1 pieces/bankfull width). Western redcedar was the most common species observed as downed wood, and recruited 0.30 to 0.45 pieces/bankfull width to the channel. Of the downed wood observed, a total of 11 percent was recruited to the bankfull channel. Most of the trees that fell originated between 10 and 20 meters slope distance from the channel. Most instream wood observed in the study was small in diameter and less than 5 meters in length.

Watershed assessments completed in eastern Washington provide some quantitative and qualitative information relevant to this question. For example, McKinney (1997) used aerial photographs to characterize riparian vegetation according to its type, size and density in order to assign recruitment potential ratings based on the vegetative condition of the riparian stand. This assessment concluded that in areas dominated by more chronic recruitment processes (see Question 31), the primary factor affecting the source distance to LWD recruitment relationship is tree height. Therefore, recruitment was found to vary with tree age and tree species, with younger trees being shorter in height and with some species capable of attaining greater heights than other species. The Ahtanum watershed assessment (McKinney 1997) related the "mature conifer" category reported in the McDade et al. (1990) with mature conifer classes used in the eastern Washington watershed assessment and determined that recruitment of LWD from mature conifers in the Ahtanum watershed follows the same pattern of recruitment as reported by McDade (Table 10.5-2).

Table 10.5-1. Summary of literature sources containing data relevant to question 35.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
McKinney 1997	Ahtanum watershed, eastslope Cascades Mountains, Washington	103.4	SC, CB	Riparian coniferous and hardwood forests	Not reported	Columbia River basalts and early Tertiary volcanic	Both	Q, S	No
Schumaker and Glass 1999	Onion Creek Watershed, Stevens County Washington	149.7	Okanagan Highlands	Riparian forests mostly western hemlock/cedar	1 – 20%	Highly weathered basin granitics	Both	S	No
Analogous Process-based Approach									
Benda et al. 2002	Redwood National Park, Van Duzen watershed, Northern California	0.2 – 43	Unknown	Old growth redwood forests and second-growth forests	1 – 6%	Metamorphic and sedimentary rocks Riparian forest	Both	Q, S	Yes
Fleece 2002	McDonald-Dunn Forest near Corvallis, OR	48	Willamette Valley	Coniferous	Not reported	Not reported	Not reported	S	Yes
May and Gresswell 2003	Southern Oregon Coast Range	3.9	Southern Oregon Coast Range	Old growth Douglas-fir, western hemlock, western redcedar	Not reported	Riparian forests marine sedimentary rocks	No	S	Yes
McDade et al. 1990	Western Oregon and Washington	Unknown	Cascades Range	Douglas-fir, western hemlock, and western redcedar in eastern WA, OR, Sitka spruce, western hemlock	3 – 40 degrees	Not reported	Unmanaged	S	Yes
Murphy and Koski 1989	Southeast Alaska	Misc.	Pacific Coastal	Sitka spruce and western hemlock	0.4 – 2.9%	Alluvium and bedrock (channels)	No-old growth	S	Yes
Reeves et al. 2003	Cummins Creek, central Oregon coast	21.5	Pacific coastal	Douglas-fir and western hemlock in uplands; Sitka spruce, red alder, and bigleaf maple in riparian areas	2.5% mean	Basalt	Both	S	Yes
Robison and Beschta 1990	Pacific Northwest	N/A Model	Pacific coastal	Douglas-fir, ponderosa pine, white fir, sugar pine, Incense-cedar	N/A Model	N/A Model	N/A Model	Q, S	Yes

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

Table 10.5-2. Cumulative distribution of large woody debris source distances from origin to stream bank for mature conifers in forest of western Washington and Oregon.
(Data from McDade et al. 1990; table reported in McKinney 1997.) Recruitment potential increases with tree height, therefore, recruitment distance is dependent on tree age and species.

Distance from Streambank to LWD Point of Origin (feet)	Recruitment (Cumulative percent of LWD pieces originating from the corresponding distance)
10	17
20	26
30	47
40	60
50	70
60	77
70	82
80	88
90	90
100	92
110	94
120	96
130	98
140	99
150	99

The relationship between species and age to LWD recruitment has been demonstrated in other studies and LWD recruitment models outside of eastern Washington as well (McDade et al. 1990; Murphy and Koski 1989; Robison and Beschta 1990; Van Sickle and Gregory 1990; Harmon et al. 1986).

Stand Type and Age

Very little quantitative data were found relating to stand type and age. Riparian and hillslope areas which can deliver LWD to a channel vary based on species composition and age of vegetation, topography, aspect, and geology of the streamside area, characteristics and dynamics (vertical and lateral migration) of the channel, direction of the prevailing wind, and recruitment process (Steinblums 1984; Grete 1985; Murphy and Koski 1989; McDade et al. 1990; Benda et al. 2002). Both empirical and theoretical analyses of the probability of input of LWD to a channel as a function of distance from the streambank have been developed (Murphy and Koski 1989; McDade et al. 1990; Robison and Beschta 1990; Van Sickle and Gregory 1990; Fleece 2002). In general, these analyses suggest that the primary zone of input is equivalent to the height of the tallest trees growing along the stream. For example, Robison and Beschta (1990) used geometric and empirical equations, based on tree size and distance from the stream to determine the conditional probability of a tree adding LWD to a stream in the Pacific Northwest. Using Douglas-fir species as an example, they showed that the probability of a tree adding LWD to a stream decreases with distance from the stream and increases with basal area (Figure 10.5-1).

The McDade et al. (1990) study (described in Question 31) examined mature and old growth stands of conifers and hardwoods. The study concluded that source distances for LWD recruitment were greatest for old-growth conifers and least in mature hardwoods (Table 10.5-2). The study also found that 83 percent of the hardwood pieces originated within 10 meters of the stream channel, as compared with 53 percent for conifer species. All hardwood species were delivered from within 25 meters of the channel, but 13 percent of the conifer pieces had a source distance greater than 25 meters. For all sites in the study, 70 percent of woody debris originated within 20 meters of the channel and 11 percent originated within one meter of the bank. Maximum observed source distance was 60.5 meters in old-growth stands (Table 10.5-2). No significant association was found between source distance and stream order; however the study only focused on relatively stable channels where bank erosion was not a significant factor.

Table 10.5-3. Median values of debris-related variables and slope steepness, according to slope class, stand-debris type, and stream order.
Source: McDade et al. (1990).

	Side-slope class		Stand–debris type			Stream order		
	Steep ($N=630$)	Gentle ($N=626$)	Old-growth conifer ($N=619$)	Mature conifer ($N=551$)	Mature hardwood ($N=86$)	First ($N=423$)	Second ($N=450$)	Third ($N=383$)
Source distance, origin to stream (m)	10.0	9.2	10.4	9.8	3.6	9.7	9.3	11.0
Piece length (m)	15.0	20.7	20.7	15.9	11.4	16.9	16.6	20.0
Piece diameter (cm)	50.0	45.0	65.0	35.0	32.0	42.0	46.0	53.0
Side-slope steepness (degrees)	35.0	8.0	17.5	20.0	0.0	20.0	20.0	10.0
Origin to piece distance (m)								
For moved pieces only	7.0	4.6	7.0	5.0	5.1	5.2	5.6	5.7
Percentage of pieces that moved[a]	52	33	43	45	35	46	44	38

NOTE: Underlined values indicate that there was no significant difference ($p > 0.05$) in distribution locations (Wilcoxon test for two levels, Kruskal–Wallis test for three levels).
[a]Values are percentages, with significance evaluated by χ^2-test of independence.

Other studies have reported the distances wood recruits to streams based on stand age. Fleece (2002) used light detection and ranging (LIDAR) data to model the rate at which large wood enters streams. He compared the model predictions to other reported values and found that he reported similar amounts and distances as other studies (Murphy and Koski 1989), but greater cumulative frequency of recruitment at shorter distances than those reported in McDade (1987). He attributed this difference to the stands in his study area which, on average, were much younger and shorter than McDade's (1987), with a median age of 60 years (only 13 of 179 stands were greater than 200 years old).

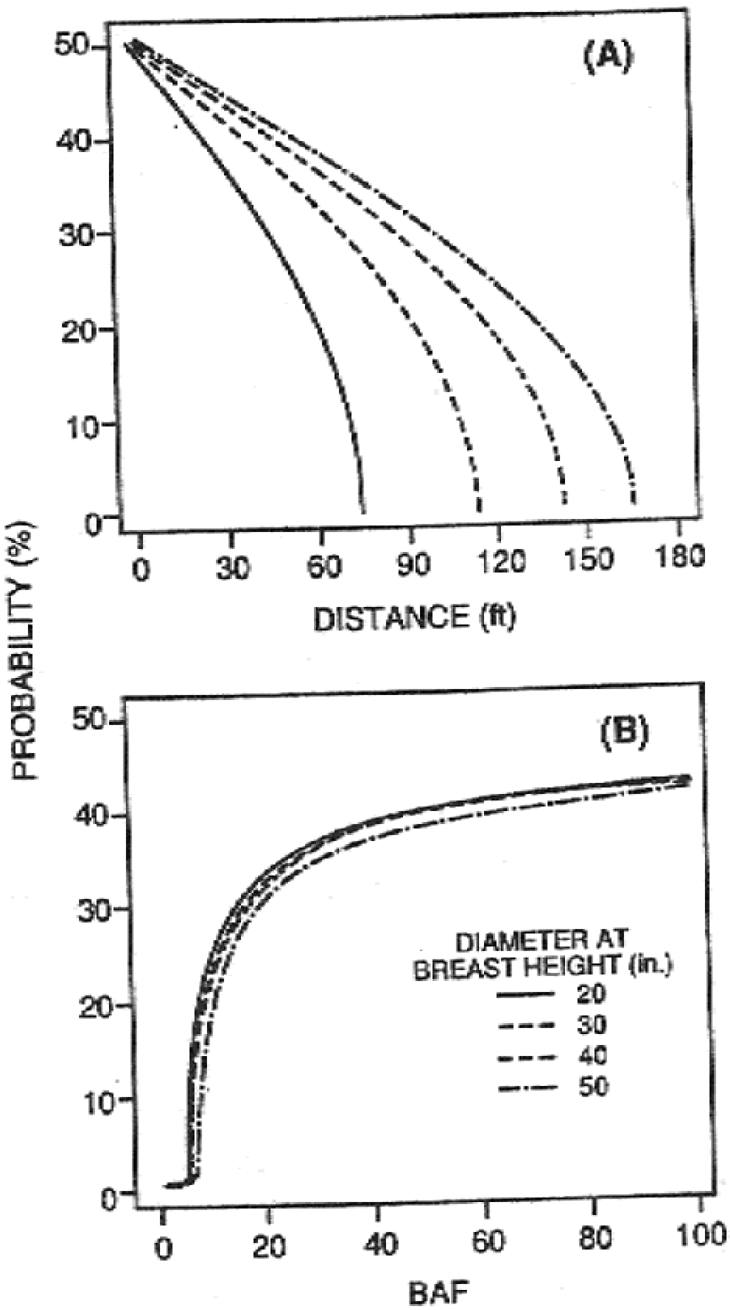

Figure 10.5-1. The probability of coarse woody debris from a Douglas-fir tree entering a mountain stream in relation to: (A) distance from stream and (B) basal area factor (BAF) for selected dbh.
Source: Robison and Beschta (1990).

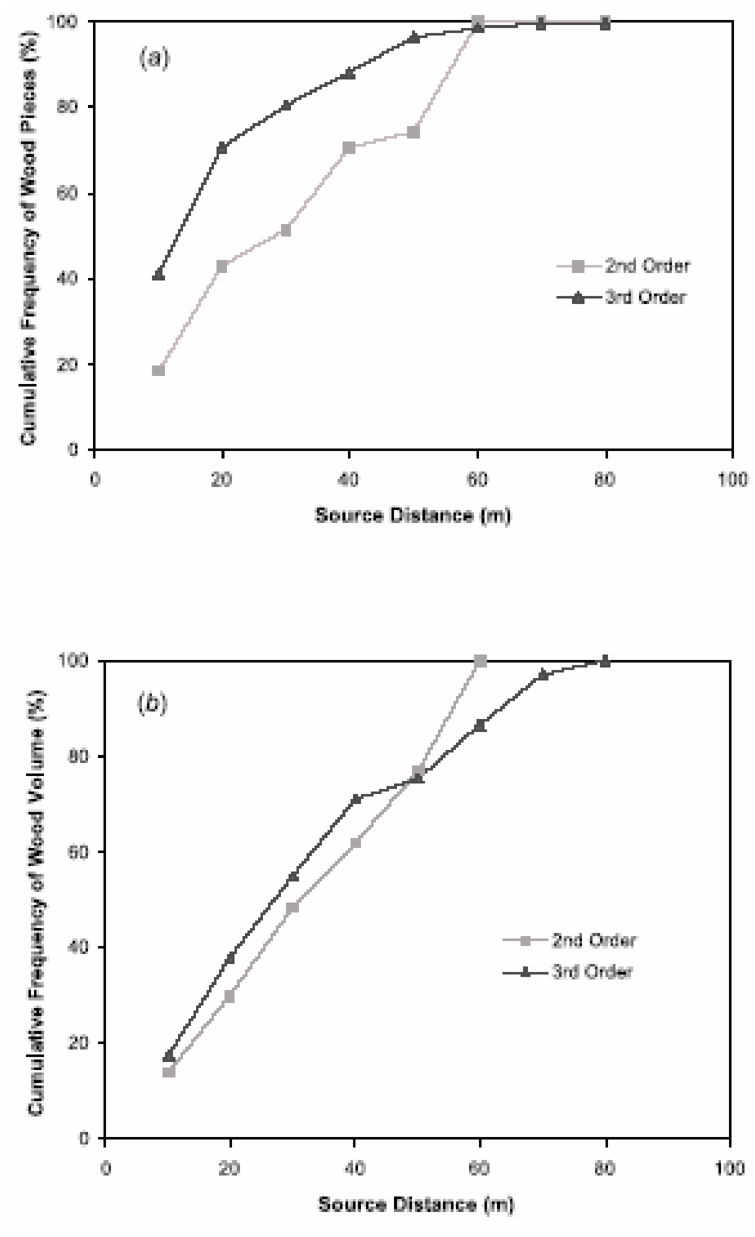

Figure 10.5-2. The source distance of large wood (a) pieces and (b) volume for second-order colluvial tributaries and the third-order mainstem channel in the North Fork of Cherry Creek basin in the southern Coast Range of Oregon. Distributions of the source distance of wood pieces were significantly different between colluvial and alluvial channels. The source distance of wood was also significantly different when comparing wood volume between colluvial and alluvial channels (May and Gresswell 2003).

Topography

Topography has also been shown to affect the distance LWD recruits to a stream. Stands located on steep slopes should tend to lose material to downslope areas and accumulate large woody debris from upslope areas (Harmon et al. 1986). McDade et al. (1990) (study described in Question 31) found that a significantly greater percentage of pieces moved toward the stream on steep slopes compared with gentle slopes, but there was no significant differences between source distances on steep and gentle side slopes. Reeves et al. (2003) found that streamside-derived wood (compared with upslope wood further from the channel) was most prevalent in the lower reaches of the watershed, where the valley floor is wider than other parts of the watershed and the surrounding hillslopes are less steep than the upper portions of the watershed.

May and Gresswell (2003) compared the processes that deliver wood to colluvial channels with larger, lower gradient alluvial channels. Colluvial channels occupy convergent topography on steep hillslopes. Runoff into and through colluvial channels is primarily conveyed by subsurface flow. Alluvial channels have significantly lower gradients and are dominated by overland flow. This study found that distributions of the source distance of wood pieces were significantly different between colluvial and alluvial channels ($p<0.05$). In colluvial streams, 80 percent of wood pieces and 80 percent of the total volume of wood originated from trees rooted within 50 meters of the channel. In the alluvial channel, 80 percent of the pieces of wood originated from within 30 meters of the channel; however this accounted for only 50 percent of the total volume of wood (Figure 10.5-2). This indicates that recruitment distances tend to be greater from steeper hillslopes than from lower gradient slopes.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

In summary, very little quantitative data or qualitative information was found to answer this question for eastern Washington. In eastern Washington, watershed assessments contained the most relevant information. Other studies have found a general relationship between LWD recruitment and tree height and size. This corresponds with both stand type and stand age. Older stands typically recruit more LWD to streams and from further distances. Conifer stands typically deliver LWD from greater distances to streams compared with hardwood species because conifers are typically taller in size. In general, the distance from a stream that LWD recruitment occurs increases in steeper watersheds compared with gentler sloped watersheds.

See Question 31 for recommendations of further study. Region, topography, stand type, and stand age of study sites should be included in all future studies of LWD recruitment in eastern Washington.

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10.6 Question 36 Response

Historically and currently, what was the contribution from trees killed by flooding at beaver ponds and logjams to the in-stream wood load in terms of percentages?

Summary of Literature Sources

Of the references reviewed, none were found that had quantitative and/or descriptive information relating to the historic and current contribution to instream LWD from trees killed by flooding at beaver ponds and logjams in eastern Washington or analogous regions.

Summary of Quantitative Data

No quantitative studies were found to address this question for eastern Washington. While some studies are available that describe LWD recruitment due to spring runoff flooding (Johnson et al. 2000), none were found that described recruitment due to ponding behind beaver dams or log jams. Beaver activity has been blamed for flooding which kills low land timber (Bhat 1993), but no studies quantifying this were found. Beaver in eastern Washington may occur in nearly all ecosystems present, including spruce-fir, aspen-birch, Douglas-fir, ponderosa pine, western white pine, fir-spruce, larch, and hardwood forests. The forest service reports a beaver species specific to Washington; *Castor Canadensis ssp. pacificus Rhoads*.

Beaver ponds increase the surface area of water and increase the water table behind the dam (Pollock 2003), which is likely the primary cause of tree mortality and LWD recruitment from beaver ponds. While no information on tree mortality due to flooding was found specific to eastern Washington, some relevant studies were found during the literature review. Much of this literature focuses on the effects of beaver on altered hydrology and riparian areas. For example, Naiman (1986) summarizes the effects of beaver on ecosystems, including modifications to the riparian zone such as changes in species composition and the growth form of plants and the quantity of inputs from the riparian area in the form of fine and coarse woody debris. This study, described in Question 31, looked at beaver occupied sites in a nearly pristine watershed in Quebec. Vegetation in the watershed is dominated by black and white spruce and balsam fir. Hardwood species include paper birch, trembling aspen, speckled alder, and willow. They found the density of dams on small streams averaged 10.6/km and that beaver are a causal agent of LWD recruitment to the streams and ponds through cutting of riparian trees. A significant amount of literature is available on beaver tree preference and size of trees cut by beaver. Barnes and Dribble (1988) found that beavers selected stems in the 4 to 6 cm diameter class, which is smaller than the minimum size of LWD used in some studies.

Studies of the ecology of beavers are numerous and may be useful in future studies of beaver caused riparian flooding and LWD recruitment to streams. Stream characteristics such as gradient, depth, and width are determining factors in habitat use by beaver, with beavers preferring lower gradient (<15 percent), wide valley bottoms (Munther 1981). Sampson (1994) found that in 29 watersheds, the cumulative area of impact from wetlands created by beaver was 4.1 km2, or 1.24 percent of the total low elevation area (below 60 meters). Stream size is also an important factor that may prove useful in future studies of beaver caused flooding on LWD recruitment. In western Montana, most major beaver influences exist in fourth order or smaller stream with channels less than a 4 percent gradient. In larger streams, beaver may establish temporary dams and modify vegetative characteristics, but do little to change hydrologic regimes, channel structure or water tables (Munther 1981). In addition, the deposition of fine sediments in ponds created in smaller streams, in conjunction with the higher water table, create riparian communities that exceed the size of those lost by the inundation of the ponds (Neff 1957). Therefore, it can be assumed that tree mortality from flooding is more likely to occur in small streams, where a greater forested area may be filled with sediment and flooded.

In addition, beavers can affect future LWD recruitment through their manipulations of the riparian zone. Beavers are selective in their choice of woody plants, which often results in a major reduction in density of those preferred species for future populations. Selective logging of aspen and willows changes their relative abundance and frequency in a stand and alters the riparian community. Johnston and Naiman (1990) found that after six years of beaver foraging, which removed 40 percent of the above ground biomass of the forest, the density and biomass of quaking aspen diminished, while the density and biomass of species which beaver did not cut, such as black ash and alder increased. Beaver can also affect plant community succession. When certain tree species are targeted by beaver, gaps in the canopy can be created allowing in sun, which will favor sun-loving speices converting mid-successional stands to early successional stands (Pastor and Naiman 1992). If the forest is already dominated by early successional species such as aspen and willow, with an understory of late-successional tree seedling beaver do not prefer, such as fir and spruce, then beaver cutting will hasten succession by removing the trees that hinder the growth of the understory seedlings (Pastor and Naiman 1992).

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

In summary, no information is available to directly address this question for eastern Washington. More information is likely available on the historic and current distribution of beaver and beaver dams in eastern Washington, but no information was found that looked at this question or collected data needed to address this question. While numerous studies have been conducted on the effects of beaver on hydrology, geomorphology and riparian stand characteristics, quantification of tree mortality and LWD recruitment to streams due to the creation of beaver ponds was lacking. However, the information on beaver ecology and alterations to the adjacent riparian zones may contain information useful to the development of future LWD recruitment studies.

A study of tree mortality at historic and current beaver dam sites representative of eastern Washington ecoregions, is recommended to answer this question.

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10.7 Question 37 Response

What percent of fire killed trees in a) stand replacing fires and b) low intensity understory fires recruit to streams? Provide data summaries.

Summary of Literature Sources

Of the references reviewed, a total of three studies were found that had quantitative and/or descriptive information relating to the percent of fire killed trees in stand replacing and low intensity fires that recruit to streams. Of these, none had information relevant to eastern Washington and one contained data from analogous regions. Table 10.7-1 provides a summary of these references.

Summary of Quantitative Data

No quantitative data was found relating fire killed trees in stand replacing and low intensity fires to LWD recruitment in eastern Washington streams and very little information was found for analogous or other regions. In an assessment of post-fire conditions on the Bitterroot National Forest after the fires of 2000, the authors provide a qualitative comparison of effects to LWD from low severity burns, moderate severity burns, and high severity burns (Table 10.7-2). They report that in the moderate and high severity sections of stream, woody debris has increased due to burned trees falling into streams and from felling of snags during the suppression effort (BNF 2000). They predict in these areas that woody debris is likely to increase for one to two decades and then be followed by at least 50 years of no woody debris recruitment until the new forest canopy has matured. This has also been shown in other studies, predominantly those modeling LWD inputs (Benda and Sias 1998) (see Question 31).

Olson (2000) reconstructed the historical occurrence of fire within riparian forests along different sized streams in three national forests in Oregon. Two sites were located in dry, low-severity fire regime forests in the Blue Mountains of northeastern Oregon and the third site was located in a more mesic, moderate-severity fire regime forest on the western slope of the south Oregon Cascades. She found that fire was common historically in riparian zones of eastern Oregon, with an interval ranging between 13 and 14 years. She also concluded that coarse woody debris recruitment within these riparian forests and the subsequent addition of LWD to streams is likely to have followed cycles comparable to the length of the historical fire return intervals. In the drier forests, coarse woody debris input into the system was likely to be rather small but continuous, with a rather short residence time. Within the mesic forest types, fire intervals were longer and more variable in length with patches of higher severity fire. This would have resulted in higher amounts of tree mortality in these forests. She concluded that it was therefore possible that coarse woody debris creation could have been more patchy in places (lagging a few years after the fire). This is similar to the lag time shown in models described in Q31. She estimated that recruitment from the drier, more frequent fire regime was likely to be every 19 years, and roughly every 38 years in the more mesic, wetter riparian forest.

Table 10.7-1. Summary of literature sources containing data relevant to question 37.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Analogous Regions									
Bitterroot National Forest 2000	Bitterroot mountains, western Montana	Not reported	Rocky Mountains	Not reported	Not reported	Not reported	Not reported	Q	No
Analogous Process-based Approach									
Benda and Sias 1998	Pacific Northwest	N/A	N/A	N/A	N/A	N/A	N/A	Model	No
Olson 2000	Eastern Oregon	Not reported	Blue Mountains, southern Cascades	Ponderosa pine and Douglas-fir	Average 48% in riparian areas and 16% in upslope areas	Igneous, sedimentary and metamorphic parent materials	Not reported	S, O	No
Wright et al. 2002	Central Oregon Cascades	Not reported	Cascades	Western hemlock and Pacific silver fir	Not reported	Not reported	Not riparian	Q, S	No

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington

[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

Table 10.7-2. Effects of different severity burns on recruitment of LWD to streams in the Bitterroot watershed, western Montana.

Fish Habitat Variable	Low Severity Burn	Moderate Severity Burn	High Severity Burn
Large woody debris	Little to no recruitment of woody debris following fire, future recruitment rates similar to pre-fire conditions	Post-fire recruitment of woody debris is intermediate and patchy; long-term recruitment is more consistent than in the high severity areas because some of the surviving mature trees will die and fall into the streams while the burned canopy recovers	Large pulses of woody debris recruitment during the first two decades, followed by almost no recruitment for at least 80 years until mature trees are back on the site

Wright et al. (2002) modeled how coarse woody debris (CWD) was affected by different fire regimes in the central Oregon Cascades, but did not relate this to recruitment of that wood to stream channels. Their field measurements indicate that on average the mixed-severity fire regime had about half as much CWD as sites with the stand-replacing regime (this difference was not statistically significant). However, the model predicted a more similar CWD mass between the two regimes than was found in the field data.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. No data on LWD recruitment to streams by high and low intensity fires was found for eastern Washington.

Summary and Recommendations

In summary, no quantitative information is available to answer this question. Qualitative information comparing LWD recruitment between high intensity fires and low intensity fires showed that LWD recruitment is higher immediately after high intensity fires, but decreases after a few decades. Another study, reporting in upland areas, found that CWD was greater in areas burned in high intensity fires compared with low intensity fires.

We recommend an empirical approach to studying this question, which would include looking at recruitment rates in burned watersheds vs. watersheds with no fire occurrence and further comparing fire types in the burned watersheds.

References

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10.8 Question 38 Response

Is there a difference in the durability associated with "fire hardened" wood recruited to streams? Quantify the differences.

Summary of Literature Sources

Of the references reviewed, none were found that had quantitative and/or descriptive information relating to the durability associated with "fire hardened" wood recruited to streams.

Summary of Quantitative Data

No quantitative data was found.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

No data was found to summarize. An answer to this question could be obtained in many different ways. We recommend an empirical approach to this question where fire hardened wood is submerged in both controlled (laboratory) and natural (multiple watersheds) settings to determine the durability of the wood to varying flow regimes and length of time submerged. This question could further be investigated in areas where "fire hardened" wood has been recruited to a stream by testing the wood for durability and relating that to time since the fire and comparing the durability with non-hardened recruited trees of the same species and similar size.

10.9 Question 39 Response

What is the distribution of recruitment distances for recruitment of fire killed trees?

Summary of Literature Sources

Of the references reviewed, none were found that had quantitative and/or descriptive information relating to the distribution of recruitment distances for recruitment of fire killed trees.

Summary of Quantitative Data

No quantitative data was found.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question. No data were found on recruitment distances of fire-killed trees from eastern Washington.

Summary and Recommendations

No data was found to summarize. An answer to this question could be obtained in many different ways. It is likely that recruitment distances for fire killed trees are similar to those discussed in Question 34 for other causes of tree mortality. The distance that fire-killed trees recruit to a stream should be included in the paired watershed study approach recommended for Questions 37 and 40.

10.10 Question 40 Response

Do recruitment rates or recruitment distances vary with fire intensity, adjacent stand characteristics, ecoregion, and/or topography? If so quantify the relationship.

Summary of Literature Sources

Of the references reviewed, none were found that had quantitative and/or descriptive information relating to the variation in LWD recruitment rates and distances with fire intensity, adjacent stand characteristics, ecoregion, and/or topography. Some relevant studies on fire-killed snag recruitment for eastern Washington are included (Table 10.10-1).

Summary of Quantitative Data

No quantitative data was found that related recruitment rates or distances with fire intensity, adjacent stand characteristics, ecoregion, and/or topography for eastern Washington. In addition, very little information on fire in riparian areas is available. Everett (2001) studied fire on the eastslope of the Cascades and found that plant association groups in the riparian forest had 35 to 42 percent fewer fire disturbance events than the same plant associations upslope. They determined that fire disturbance regimes of sideslope and riparian forest are quantitatively different, but interconnected through shared fire disturbance events. Shared fire events between the two sideslope (65 percent east/west, 54 percent north/south) on either side of the riparian, and riparian fire events shared with sideslope forests (58 to 79 percent among valley types, 64-76 percent among aspects). This suggests continuity in fires disturbance between sideslope and the adjacent riparian forests (Everett 2001).

Olson (2000), described in Question 37, concluded that coarse woody debris recruitment within riparian forests due to fire, and the subsequent addition of LWD to streams is likely to have followed cycles comparable to the length of the historical fire return intervals determined for the sites. She found that recruitment rates were likely higher in areas with more severe fire, although more patchy (every 38 years). Sites with low return intervals likely had a smaller, but more consistent rate of coarse woody debris recruitment (every 19 years).

Everett et al. (1999) studied snag recruitment in 26 burned areas on the east slope of the Cascades in Washington. They found the number of snags on a site varied within the site in response to aspect, slope, micro-topography and species composition. They also found that snag recruitment (time after death until snag falls and is recruited as LWD or CWD) differs by species. For example, 40 percent of Douglas-fir snags were still standing 80 years post-fire. They did not study snag recruitment as LWD to streams.

In addition, many models of LWD recruitment include fire as an input mechanism and look at fires of varying intensity and in different stand types to determine LWD recruitment rates (see Question 31).

Table 10.10-1. Summary of literature sources containing data relevant to question 40.

Reference	Location	Drainage Area (km^2)	Region [a]	Forest Type	Channel Slope of Study Reaches (%)	Substrate	Is Riparian Area Managed or Unmanaged?	Type of Data [b]	Peer Reviewed?
Eastern Washington Studies									
Everett et al. 1999	East slope Cascades	Not reported	NE, NC	Predominantly Douglas-fir and subalpine fir	Not reported	Not reported	Not riparian	S	Yes
Everett et al. 2001	East slope Cascades	Not reported	NE, NC	Douglas-fir and ponderosa pine	0 – 50%	Not reported	Not reported	S	No
Analogous Region									
Olson 2000	Eastern Oregon	Not reported	Blue Mountains, southern Cascades	Ponderosa pine and Douglas-fir	Average 48% in riparian areas and 16% in upslope areas	Igneous, sedimentary and metamorphic parent materials	Not reported	S, O	No

[a] Region is the major basin in which the study was performed: NC: Northeast Cascades; SC: Southeast Cascades; CB: Columbia Basin; NE: Northeast Corner; OH: Okanogan Highlands; BM: Blue Mountains; WW: western Washington
[b] Q – qualitative descriptions, S – summarized numeric values, O – original data provided.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). There is insufficient data from eastern Washington or analogous regions to answer the question. Development of a scientific protocol and collection of additional data is necessary to answer this question.

Summary and Recommendations

In summary, very little information is available that related fire to LWD recruitment to streams.

Much information on fires in eastern Washington is available that may be useful in study development. For example, Everett et al. 2000 studied the altered fire regimes in Douglas-fir/ponderosa pine forests on the east slope of the Cascades and found that the historic (pre-settlement) fire return interval at 50-60 percent of the study areas was 6-7 years. Schellhaas et al. (2001) describes the historical fire regimes and the effects of fire and fire exclusion in supalpine forests communities along the east slopes of the Cascades of north central Washington state. Agee has done a significant amount of work on fire ecology in eastern Washington, including work on fire intensity, and topography, such as aspect and slope steepness. Ultimately, LWD recruitment to streams from fire mortality depends on the amount of tree mortality that occurs during a fire, which depends on the type of fire, its intensity, stand structure and species present (Harmon et al. 1986). Literature is available for eastern Washington on all these topics, however, none were found that related tree mortality to LWD recruitment.

We recommend an empirical approach to studying this question, which would include looking at recruitment rates in burned watersheds versus unburned watersheds.

References

Everett, R., J. Lehmkuhl, R. Schellhaas, P. Ohlson, D. Keenum, H. Riesterer, and D. Spurbeck. 1999. Snag dynamics in a chronosequence of 26 wildfires on the east slope of the Cascade Range in Washington State, USA. International Journal of Wildland Fire 9(4):223-234.

Everett, R., R. Schellhaas, D. Keenum, D. Spurbeck, and P. Ohlson. 2000. Fire history in the ponderosa pine/Douglas-fir forests on the east slope of the Washington Cascades. Forest Ecology and Management 129:207-225.

Everett, R., R. Schellhaas, P. Ohlson, D. Spurbeck, and D. Keenum. 2001. Continuity in fire disturbance between riparian and adjacent sideslopes in the Douglas-fir Forest Series. USDA Forest Service, Pacific Northwest Research Station, Wenatchee Forestry Sciences Laboratory, Wenatchee, Washington.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Olson, D. 2000. Fire in riparian zones: a comparison of historical fire occurrence in riparian and upslope forests in the Blue Mountains and southern Cascades of Oregon. M.S. Thesis. University of Washington, Seattle, Washington.

Schellhaas, R., D. Spurbeck, P. Ohlson, D. Keenum, and H. Riesterer. 2001. Fire disturbance effects in subalpine forests of north central Washington. USDA Forest Service, Region 6, Okanogan and Wenatchee National Forests.

10.11 Question 41 Response

Do tree species differ in rates of branch mortality, branch breakage, branch detachment (abscission, or the degree to which dead or dying branches remain attached to the trunk, leading to branch fall or branch rain)? Do tree species vary in rates of dead branch retention, affecting rates of branch fall (branch rain)? List all branch rain datasets measuring rates of branch fall that become in-channel wood, near-channel wood, and upland wood?"

Summary of Literature Sources

Of the references reviewed, none were found that had quantitative and/or descriptive information comparing branch mortality, breakage and detachment between tree species and leading to branch rain delivery of LWD to streams, riparian areas or uplands.

Summary of Quantitative Data

No quantitative data was found.

Qualification of Literature Sources

This question cannot be answered with the information currently available (#4). No data was found comparing rates of branch mortality, breakage and detachment between different tree species. Development of scientific protocol and data collection is necessary to answer this question.

Summary and Recommendations

No data was found to summarize.

11.0 Summary

SAGE initiated this project to identify the current state of knowledge regarding instream wood, wood recruitment, and the function of wood in streams in eastern Washington. The specific intent of the project is to assess the quantitative information supporting this state of knowledge. Each of the 41 questions presented by SAGE to asses the state of knowledge regarding the function of wood in streams in eastern Washington was evaluated using the same protocol which focused on identifying quantifiable independent and dependent variables that could be compared over a range of regions, stream sizes, and forest types. Answers for each of the questions were categorized into the following responses:

1. Question can be answered now for a particular region (e.g., Blue Mountains) of eastern Washington.

2. Question can be answered with additional quantitative analysis of existing data. There is a sufficient source of scientific data to answer question for particular region in eastern Washington. However, in order to answer the question, numerical analysis of the data would be needed. A suggested numeric analysis would be provided for resource management guidelines.

3. Question can be answered based on studies in analogous regions but there is not sufficient data from a region within eastern Washington to sufficiently answer the question. Next step is collection of eastern Washington data set identical to existing data set from analogous regions and comparison of data. If correlation is sufficiently close, numerical analysis of existing information can provide basis for resource management guidelines.

4. Question cannot be answered with the information currently available. Insufficient data from eastern Washington or analogous regions is available. Development of scientific protocol and collection of additional data is necessary to answer the question. Where possible, the Herrera team provided a suggested protocol for conducting a study to answer this question.

Table 11-1 provides a summary of the quality of quantitative data available to address each of the questions. A number of the 41 questions have multiple components; where the quality of quantitative data available to address each component within a question is inconsistent separate question responses are provided. Table 11-1 shows that there is insufficient data available to adequately answer the majority of questions posed by SAGE. Even though relatively little quantitative information on wood debris and riparian conditions for eastern Washington streams was found, many of the questions could be at least partially answered with data from other regions. For a number of the question responses, where there is insufficient data available to answer the question, relevant empirical and theoretical information and applicable protocols and methodologies are drawn from published and unpublished studies to address the questions and make recommendations for additional work that will advance the state of knowledge in eastern Washington.

Table 11-1. Summary qualification of responses to research questions.

		Qualification of Literature Sources [a]			
Topic	**Question**	**1**	**2**	**3**	**4**
Wood Loading	1	■			
	2	■			
	3		■		
	4		■		■
	5		■		
	6				■
	7				■
Wood Distribution	8a		■		
	8b				■
	9				■
	10				■
In-stream Manipulation	11				■
	12				■
Decay Rates	13				■
	14				■
	15				■
	16				■
Wood Transport	17				■
	18a			■	
	18b				■
	19				■
Pool Formation	20	■			
	21				■
	22				■
	23				■
	24				■
	25				■
Bedload Transport and Sediment	26a			■	
	26b				■
	27				■

Table 11.0-1. Summary qualification of responses to research questions (continued).

		Qualification of Literature Sources [a]			
Topic	**Question**	**1**	**2**	**3**	**4**
Riparian Channel and Condition	28				
	29				
	30				
Wood Recruitment/ Mortality	31				
	32				
	33				
	34				
	35				
	36				
	37				
	38				
	39				
	40				
	41				

1. Question can be answered now for a particular region (e.g., Blue Mountains) of eastern Washington
2. Question can be answered with additional quantitative analysis of existing data. There is a sufficient source of scientific data to answer question for particular region in eastern Washington. However, in order to answer the question, numerical analysis of the data would be needed. A suggested numeric analysis would be provided for resource management guidelines.
3. Question can be answered based on studies in analogous regions but there is not sufficient data from a region within eastern Washington to sufficiently answer the question. Next step is collection of eastern Washington data set identical to existing data set from analogous regions and comparison of data. If correlation is sufficiently close, numerical analysis of existing information can provide basis for resource management guidelines.
4. Question cannot be answered with the information currently available. Insufficient data from eastern Washington or analogous regions is available. Development of scientific protocol and data collection is necessary in order to answer the question. Where possible, the Herrera team provided a suggested protocol for conducting a study to answer this question.

APPENDIX A

Research Questions

Research Questions

Questions have been broken into nine themes or categories in order to organize the search topics. In general, SAGE is interested in not only a verbal discussion of the information available, but also information regarding the specific means, medians, ranges, standard deviations, and information on the distribution of data as reported, where available and reported in the reviewed literature. SAGE also asks for comment on the potential effects of assumptions in the studies and discussion of the effect of differences in study approaches on the results and the comparability of various studies. The Contractor should assume that SAGE wants all information described in this paragraph for all questions. Where large amounts of information are available, creative approaches for tabulating study results are of interest.

I. Wood Loading (Channel Wood Characteristics)

1. Is there a correlation between wood volume and/or number of pieces of wood in the stream and the adjacent riparian community? If so quantify the relationship.

2. What is the range of current wood loads in eastside forested streams (by wood size class if possible)? Quantify mean, median, range, and standard deviation to the extent possible. Discuss effects of variations in sample methods on results and the range of results found in various investigations.

3. Recognizing that fire suppression activities, beaver removal, and livestock introduction have influenced almost all areas of eastern Washington, how do wood loads in the streams adjacent to unlogged forest stands differ from stands which have been logged within the last 40 years? Is there data available regarding the quantity of wood in streams adjacent to stands where no harvest, fire suppression, beaver removal, or livestock grazing has occurred?

4. How do wood loads in streams differ between those with clear-cuts adjacent to the riparian buffer zone and those with partial cuts adjacent to the riparian buffers?

5. Do wood loads vary with the species of tree (Douglas-fir, cedar, Ponderosa pine, larch, etc.) in the adjacent riparian stands? How?

6. What was the historical (pre-harvest, pre-fire suppression, pre-beaver removal, and pre- livestock introduction) condition of streams with regard to wood loads in eastside forested streams? If data are available to address this, provide summaries of the data including mean, mode, range, standard

deviation, and data distribution (normal, log-normal etc.). Discuss strengths and weaknesses of various approaches used to estimate the historical condition. Discuss assumptions made and the likely validity of those assumptions.

7. Did the historical abundance of riparian and in-stream wood vary with stand type (dry Ponderosa pine forests, Douglas-fir/Grand fir forests, subalpine forests, etc.) and ecoregions? If so, how?

II. Wood Distribution

8. What portions of the wood loads affect channel morphology? In other words, what portion of wood is of functional size to affect pool formation, sediment sorting, channel stability? How does this vary with stream size and/or channel morphology? Provide quantification of the findings of various studies. Discuss how variations in data collection methods may affect interpretation of study results.

9. What is the normal distribution of sizes (length, volume) of functional wood in eastside streams? Provide quantification of the findings of various studies. Discuss how variations in data collection methods may affect interpretation of study results.

10. Does size distribution vary with stream size, and/or channel morphology (e.g., Rosgen stream types)? If so, quantify the relationship. Discuss how variations in data collection methods may affect interpretation of study results.

III. In-stream Manipulation

11. What role has stream cleaning (removing wood to improve fish passage or prevent flooding) and harvest of firewood from streams played in the current wood loads in eastside streams? Has the effect of these activities on in-stream wood loads been quantified? If so, provide numeric summaries of information. Also, discuss assumptions made in studies conducted to estimate these effects and the potential implications of these assumptions on study results. If more than one method has been used to estimate these effects, discuss the effect of variations in methods on study results.

12. If possible, quantify the extent of stream cleaning and beaver dam removal in Eastern Washington forested streams.

IV. Decay Rates

13. What is the expected decay rate of wood in eastside streams? (Summarize available numeric information.)

14. How do decay rates vary with the size of a piece of wood? (Summarize available numeric information, and/or qualitative datasets [e.g., repeat imagery] in support of quantitative outcomes.)

15. Does decay rate vary with species of tree (e.g., cedar, pine, cottonwood)? (Summarize available numeric information.)

16. Does the cause of tree fall/mortality influence decay rate (fire-scarred wood vs. disease-killed trees)? (Summarize available numeric information, and/or qualitative datasets [e.g., repeat imagery] in support of quantitative outcomes.)

V. Transport

17. What are the mechanisms for the transport of wood downstream? Provide any available quantitative (numeric) information regarding the rates of downstream transport. Document qualitative (imagery) information that supports these datasets.

18. Does the rate of transport vary with wood size, stream size, or channel morphology? If so, how? Quantify.

19. What portion of the wood that is transported out of a stream reach becomes functional wood downstream? Does this vary with the size of the pieces of wood? Provide summaries of available numeric information. Document qualitative (imagery) information that supports these datasets.

VI. Pool Formation

20. What is the distribution of sizes and characteristics of pools in eastside streams? Is it significantly different than westside streams? Provide summaries of numeric information.

21. What is the relationship between stream flow, wood, and the pools formed? Provide summaries of numeric information.

22. What is the distribution of residual pool volumes? Is it significantly different than westside streams? Provide summaries of numeric information.

23. Do pool sizes and volumes vary by ecoregion, stream size, and/or channel morphology? If so, in what way? Provide summaries of numeric information.

24. Is there a correlation between wood volume and/or number of pieces of wood in the stream segment and the number and/or volume of pools in that stream segment? If so, what is the relationship? Provide summaries of numeric information.

25. Is there a correlation between wood volume and/or number of pieces of wood in the stream segment and residual pool volume in that stream segment? If so, how are they correlated? Provide summaries of numeric information.

VII. Bedload Transport and Sediment

26. What role does wood play in storage and sorting of sediment in Eastern Washington streams? Quantify the relationship, if possible.

27. Does the role of wood in the storage and sorting of sediment affect the quality and/or quantity of spawning gravel in these streams? If so, in what way?

VIII. Riparian Channel and Condition

28. Does channel wood play a role in affecting the channel's dimensional stability (e.g., reducing channel scour and downcutting, increasing channel fill and bed elevation rise, maintaining a balance among channel responses)? If so, how? What numeric data are available to quantify this?

29. Does the function of wood to mitigate the effects of bed elevation change (channel scour or filling) vary with underlying geology, soil depth, stream width, steam flow characteristics, presence of adjacent riparian stands (root strength), channel morphology or other factors? If so, how? (We aren't looking for theories here, but real evidence. Provide numeric results for any studies that addressed this question)

30. What role does downed wood play in the retaining sediment and keeping it from delivering to streams? (Provide summaries of numeric results of studies conducted to address this question.)

IX. Wood Recruitment/Mortality

31. What percent of wood recruited to eastside streams comes from a) bank erosion, b) wind throw, c) debris slides, d) suppression mortality in the adjacent riparian stands, e) insect mortality, f) disease mortality, g) snow/ice breakage and snow avalanches, and h) prolonged flooding (beavers?), f) fire mortality, (g) animal mortality (e.g., cattle, beaver, porcupine and deer/elk)? Provide reported means, medians, ranges, standard deviations, and information on the distribution of data. Comment on the potential effects of assumptions in the studies. Discuss the effect of differences in study approaches on the results, and representativeness and comparability of various studies.

32. Do the primary recruitment mechanisms for wood vary by region, elevation, aspect, and/or stand type? Provide specific examples and numeric summaries of study results.

33. What is the size of wood that is recruited through these various recruitment mechanisms? (Provide distributions of study results if available.)

34. What is the distribution of distances from a stream that wood recruits through the various recruitment mechanisms?

35. Do the distances that wood recruits to an eastside stream vary with region, stand type, stand age, and/or topography? If so, in what way? Provide numeric data where available.

36. Historically and currently, what was the contribution from trees killed by flooding at beaver ponds and logjams to the in-stream wood load in terms of percentages?

37. What percent of fire killed trees in a) stand replacing fires and b) low intensity understory fires recruit to streams? Provide data summaries.

38. Is there a difference in the durability associated with “fire hardened” wood recruited to streams? Quantify the differences.

39. What is the distribution of recruitment distances for recruitment of fire killed trees?

40. Do recruitment rates or recruitment distances vary with fire intensity, adjacent stand characteristics, ecoregion, and/or topography? If so, quantify the relationship.

41. Do tree species differ in rates of branch mortality, branch breakage, branch detachment (abscission, or the degree to which dead or dying branches remain attached to the trunk, leading to branch fall or branch rain)? Do tree species vary in rates of dead branch retention, affecting rates of branch fall (branch rain)? List all branch rain datasets measuring rates of branch fall that become in-channel wood, near-channel wood, and upland wood.

APPENDIX B

Source Tracking Log

Table B1. Source tracking log of databases.

Database	Internet Site (if applicable)	Topics Covered	Format of References Collected (paper, ProCite database, EndNote database, etc.)	How Many Citations?	Number of References on Eastern Washington?	Number that have Quantitative Data?	Number of References on Potentially Analogous Regions?	Number that have Quantitative Data?
University of California Wood and streams database		Comprehensive bibliography of wood in streams	MS Word	100+	Unknown	Unknown	Unknown	Unknown
NACSI headwaters		Variety of forest and stream related topics	MS Word	100+	Unknown	Unknown	Unknown	Unknown
Wood in World Rivers		Comprehensive bibliography of wood in streams	Paper	100+	Unknown	Unknown	Unknown	Unknown
USFS database (webcat)	http://sirsi.fs.fed.us/uhtbin/webcat	Large woody debris - nationwide	ProCite	47	2	Haven't yet reviewed	12	Haven't yet reviewed
NOAA Library	http://www.lib.noaa.gov/	Large woody debris - nationwide	None collected	1	0	0	1	Unknown
Canadian Geomorphology Research Group Database	http://cgrg.geog.uvic.ca/cgi-bin/search.cgi	Large woody debris - Canada	Electronic list of citations	4	0		4	Unknown
LaGrande USFS research- metadatabase of USFS research	www.srsfs.usda.gov/pubs	Variety of forest and stream related topics	PDF file	1	0	0	1	1
Lassettre - UC Berkeley master's thesis on LWD with annotated bibliography		A synthesis and review of large woody debris references - national and international	ProCite	100+	Unknown	Unknown	Unknown	Unknown
California Dept. of Forestry Annotated Bibliography of Ecology, Management, and Physical Effects of LWD in Streams		Ecology, management and physical effects of wood in streams	Electronic papers	300+	Unknown	Unknown	Unknown	Unknown

Table B1. Source tracking log of databases (continued).

Database	Internet Site (if applicable)	Topics Covered	Format of References Collected (paper, ProCite database, EndNote database, etc.)	How Many Citations?	Number of References on Eastern Washington?	Number that have Quantitative Data?	Number of References on Potentially Analogous Regions?	Number that have Quantitative Data?
University of WA Center for Water and Watershed Studies Urban Issues ESA Document Database		Variety of forest and stream related topics	Not yet collected					
CMER Riparian Disturbance Database		Riparian disturbance	ProCite	487	Possibly 487	Unknown	Unknown	Unknown
GEOREF		Variety of forestry-related topics	ProCite	18	1	1	11	2
WATER RESOURCES ABSTRACTS- CSA		Stream-related topics	ProCite	11	Unknown	Unknown	7	5
CGRG Bibliography of Canadian Geomorphology	http://cgrg.geog.uvic.ca/cgi-bin/search.cgi	Variety of forestry-related topics	ProCite	8	Unknown	Unknown	6	6
GEOBASE		Variety of forestry-related topics	ProCite	27	1	1	17	8
GEOREF		Variety of forestry-related topics	ProCite	4	Unknown	Unknown	3	2
WRA		Variety of forestry-related topics	ProCite	11	Unknown	Unknown	8	4
WRW		Variety of forestry-related topics	ProCite	11	Unknown	Unknown	10	7
UW College of Forest Resources Rural Tech Initiative	http://www.ruraltech.org/	Variety of forestry-related topics	Electronic papers	2	Unknown	Unknown	Unknown	Unknown
USFWS library website	http://library.fws.gov/	Variety of forestry-related topics	Electronic papers	+100	Unknown	Unknown	Unknown	Unknown

Table B1. Source tracking log of databases (continued).

Database	Internet Site (if applicable)	Topics Covered	Format of References Collected (paper, ProCite database, EndNote database, etc.)	How Many Citations?	Number of References on Eastern Washington?	Number that have Quantitative Data?	Number of References on Potentially Analogous Regions?	Number that have Quantitative Data?
US EPA Region 10 Library	http://www.epa.gov/region10/	Variety of forestry-related topics	Paper	10	Unknown	Unknown	Unknown	Unknown
USFS PNW Research Station general technical reports and scientific reports	http://www.fs.fed.us/pnw/publications/gtrs.shtml; http://www.fs.fed.us/pnw/publications	Variety of forestry-related topics	Electronic papers	3	Unknown	Unknown	Unknown	Unknown
Biosis			Electronic database	50	Unknown	Unknown	Unknown	Unknown
Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings	http://www.for.gov.bc.ca/hre/pubs/pubs/1238.htm		Paper	1	Unknown	Unknown	Unknown	Unknown
USFS Boise Aquatic Sciences Labs	http://www.fs.fed.us/rm/boise/teams/fisheries/fire/workshop_papers.htm		Paper	1	Unknown	Unknown	Unknown	Unknown
WA DNR Library database	http://www.dnr.wa.gov/geology/washbib.htm		Paper	+30	Unknown	Unknown	Unknown	Unknown
WA Dept. of Ecology publications list, 1976-2003	http://www.ecy.wa.gov/biblio/wr1976.html		Paper	3	Unknown	Unknown	Unknown	Unknown
Lassettre Thesis- LWD Bibliography	received from Berkeley classmate		Paper, ProCite	+50	Unknown	Unknown	Unknown	Unknown
Google search engine	www.google.com		Electronic papers	3	Unknown	Unknown	Unknown	Unknown
DNR Type 5 Stream and Small Wetland Literature Review		Large woody debris; headwater streams	HTML list of references held at 10K	Approx 50	0	Unknown	Unknown	Unknown
Agricoloa, UW Libraries		Large woody debris, riparian, forests, eastern Washington	MS Word	7	7	7	N/A	N/A

Table B1. Source tracking log of databases (continued).

Database	Internet Site (if applicable)	Topics Covered	Format of References Collected (paper, ProCite database, EndNote database, etc.)	How Many Citations?	Number of References on Eastern Washington?	Number that have Quantitative Data?	Number of References on Potentially Analogous Regions?	Number that have Quantitative Data?
UW Libraries Catalog		Large woody debris, riparian, forests, eastern Washington	MS Word	3	3	3	N/A	N/A
Annotated Bibliography on the Ecology, Management, and Physical Effects of Large Woody Debris (LWD) in Stream Ecosystems	http://www.cnr.berkeley.edu/forestry/woodbiblio.html	Large woody debris, Washington	MS Word	1	1	1	N/A	N/A
M.J. Fox's database		Large woody debris, riparian, Washington	MS Word	13	13	11	N/A	N/A

Table B2. Source tracking log of institutions.

Institution	Contact Complete?	Individual Contact?	Internet Address?	Topics Covered	Information on Eastern Washington? (Y/N)	Is Information Quantitative? (Y/N)	Information from Analogous Regions? (Y/N)	Is Information Quantitative? (Y/N)
University of Washington	Y	Contacted through library, individuals						
University of Washington College of Forest Resources Rural Technology Intitiativewebsite	Y	No	http://www.ruraltech.org/	Found O'Neil Thesis some background info on riparian forests of EW; mode is rates of fire and disease in riparian areas based on various policy scenarios	Y	Y	N	
University of Colorado	Y	See individuals		Variety of wood and stream related topics				
Univ. of Montana libraries	N			Variety of wood and stream related topics				
Northwest and Alaska Fisheries Library	Y			Fisheries and stream information				
USFS Aquatic Lab in Wenatchee	Y	Rick Wood-Smith		Fisheries and stream information				
USFS Boise Aquatic Sciences Labs	Y	No	http://www.fs.fed.us/rm/boise/teams/fisheries/fire/workshop_papers.htm	Fire and riparian forests	Y	Y	Y	Y
USEPA Region 10 Library	Y	No	http://www.epa.gov/region10/	11 documents on woody debris; 3 relevant to Western WA/OR; none for E. WA	N		Y	Unknown
USDA Forest Service Library	Y	No	contacted through database	Forestry related information				
USDA USFS Pacific Northwest Research Institute	Y	No	http://www.fs.fed.us/pnw/publications	Several reports more general fire ecology and land management; a few dealt directly with LWD	Y	Y	Y	Y

Table B2. Source tracking log of institutions (continued).

Institution	Contact Complete?	Individual Contact?	Internet Address?	Topics Covered	Information on Eastern Washington? (Y/N)	Is Information Quantitative? (Y/N)	Information from Analogous Regions? (Y/N)	Is Information Quantitative? (Y/N)
Bureau of Land Management Library	Y	No		Land management information				
USFWS Library	Y	No	http://library.fws.gov/	Fisheries and stream information	N		N	
Yakama Tribe	Y	Jim Mathews - see "individuals" sheet		Fisheries and stream information				
Colville Tribe	N	Kris Ray		Fisheries and stream information				
Spokane Tribe	N			Fisheries and stream information				
Kalispel Tribe	Y	Todd Baldwin		Large Woody Debris in Pend Oreille county	Y	Y		
Adams County	N			Unknown				
Asotin County	Obtained Watershed Analysis	No		Watershed data				
Benton County	N			Unknown				
Chelan County	N			Unknown				
Columbia County	Obtained Watershed Analysis	No		Watershed data				
Douglas County	N			Unknown				
Ferry County	N			Unknown				
Franklin County	N			Unknown				
Garfield County	N			Unknown				
Grant County	N			Unknown				

Table B2. Source tracking log of institutions (continued).

Institution	Contact Complete?	Individual Contact?	Internet Address?	Topics Covered	Information on Eastern Washington? (Y/N)	Is Information Quantitative? (Y/N)	Information from Analogous Regions? (Y/N)	Is Information Quantitative? (Y/N)
Jackson County, Oregon	Obtained Watershed Analysis	No		Watershed data				
Okanogon County	N			Unknown				
Kittitas County	Obtained Watershed Analysis	No		Watershed data				
Klickitat County	N			Unknown				
Lincoln County	N			Unknown				
Pend Oreille County	N			Unknown				
Spokane County	Obtained Watershed Analysis	No		Watershed data				
Stevens County	Obtained Watershed Analysis	No		Watershed data				
Walla Walla County	N			Unknown				
Whitman County	N			Unknown				
Yakima County	Obtained Watershed Analysis	No		Watershed data				
Bonneville Power Administration	N			Unknown				
DNR	Y	Contacted SAGE Members		Variety of wood and stream related information	Y	Y	Y	Y

Table B2. Source tracking log of institutions (continued).

Institution	Contact Complete?	Individual Contact?	Internet Address?	Topics Covered	Information on Eastern Washington? (Y/N)	Is Information Quantitative? (Y/N)	Information from Analogous Regions? (Y/N)	Is Information Quantitative? (Y/N)
DFW	Y	Contacted through individuals						
Washington DOE publications list	Y	Contacted through database search	http://www.ecy.wa.gov/biblio/wr1976.html		T	Unknown	N	
National Council for Air and Stream Improvement Inc.	Y	Contacted through database search	http://www.ncasi.org/forestry/secure/headwater/lwd_hab.pdf	Bibliography of LWD-relevant papers, including annotations on contents as they relate to LWD stocking and in-stream characteristics	Y	Unknown	Possibly	Unknown

Table B3. Source tracking log of individuals.

Individual	Address of Individual Contacted	Email of Individual	Topics Covered	Information on Eastern Washington (if so where?)	Quantitative? (Y/N)	Information from Analogous Regions? (if so, where?)	Is Information Quantitative? (Y/N)
Domini Glass	SAGE 15208 Goodrich Drive NW Gig Harbor, WA 98329	dglass@centurytel.net	Various wood debris sources, watershed plans	Y - Watershed assessments cover several watersheds throughout E WA	Y	Y- data for pine forests of Idaho, northeastern Oregon	Y, some of it
Jim Agee	Division of Ecosystem Sciences College of Forest Resources Box 352100 University of Washington Seattle, WA 98195	jagee@u.washington.edu	Fire research				
Al Wald	Washington Department of Fish and Wildlife	waldarw@dfw.wa.gov	In-stream manipulation	No	Y	N	
James Thomas	Yakima Tribe	jthomas@yakama.com					
Rick Williams	Boise Cascade or Plum Creek		Historical changes in Eastern WA rivers: Teanaway, maybe others				
Jim Mathews, SAGE	Yakima Tribe	jmatthews@yakima.com	Woody debris-recruitment and instream volumes	Possibly - he needs to look around his office and compile information. Also suggested exploring the ICEBMP program (?)	Y, probably	N	
Charles Chesney, SAGE	SAGE	alnusrubra@aimcomm.com	Wood recruitment and loading information for E Cascades streams	Y - eastern Cascades	Y	N	N/A
Pierre Dawson,	USFS Okenagen/Wenatchee Forest Supervisor's Office		Unknown	Possibly	Unknown	Unknown	
Mark Harmon	Oregon State University	mark.harmon@orst.edu	None	No		No	

Table B3. Source tracking log of individuals (continued).

Individual	Address of Individual Contacted	Email of Individual	Topics Covered	Information on Eastern Washington (if so where?)	Quantitative? (Y/N)	Information from Analogous Regions? (if so, where?)	Is Information Quantitative? (Y/N)
Dan McMeekan, SAGE	SAGE	danm@spokanetribe.com	None	No		No	
Stan Gregory	Oregon State University	stan.gregory@orst.edu	None	Unknown		Unknown	
Peter Bisson	Pacific Northwest Research Station 333 SW First Avenue Portland, WA 97204	pbisson@fs.fed.us	None	No		No	
Doug Weidemeyer, SAGE	SAGE	wiededjw@dfw.wa.gov	None	No		No	
Todd Baldwin, SAGE	SAGE	ebaldwin@knrd.org	Large woody debris in Pend Oreille county	Y - Pend Oreille County	Y	N	
Tim Beechie	Northwest Fisheries Science Center 2725 Montlake Blvd East Seattle, WA 98112	Tim.Beechie@noaa.gov	Valley, stream geomorphology, wood recruitment, historic conditions				
Richard Wood-Smith	Aquatic and Land Interactions Program PNW Research Station USDA Forest Service 1133 N. Western Avenue Wenatchee, WA 98801	rwoodsmith@fs.fed.us	Stream geomorphology				
John Buffington	University of Idaho	jbuff@uidaho.edu	Stream geomorphology				
Josh Latterell	University of Washington						
Dave Montgomery	University of Washington	dave@geology.washington.edu	Extensive wood in streams literature		Y		

Table B3. Source tracking log of individuals (continued).

Individual	Address of Individual Contacted	Email of Individual	Topics Covered	Information on Eastern Washington (if so where?)	Quantitative? (Y/N)	Information from Analogous Regions? (if so, where?)	Is Information Quantitative? (Y/N)
Dr. Andrew Brooks	Senior Research Fellow Centre for Riverine Landscapes Griffith University Nathan Qld 4111 Australia	Andrew.Brooks@griffith.edu.au	Wood distribution and loading	No	Y	Australia?	Y
Nancy Sturhan	WDNR	nancy.sturhan@wadnr.gov	Possibly - watershed analyses for eastern Washington, not sure of geographic location	Unknown			
Lynda Hofmann, SAGE	Washington Department of Fish and Wildlife	hofmalah@dfw.wa.gov	Yes - Loomis Watershed, and database of assorted EW-relevant fire studies	Y - Loomis Watershed, and general EW fire database	Possibly- some Oregon and Idaho studies are listed in fire database	Possibly- have not yet reviewed	Electronic files - excel and pdf documents
Todd Baldwin, SAGE	Kalispel Tribe	ebaldwin@knrd.org	Yes - Kalispel tribal lands (NE corner of WA)	Y	No		Word document
Bruce Thomson	Canadian Cataloguing in Publication Data Victoria, B.C.		Wood literature on a variety of topics	no	N/A	Yes, possibly	N/A
Andrew Wilcox	Colorado State University	awilcox@cnr.colostate.edu					
Ellen Wohl	Colorado State University	ellenw@cnr.colostate.edu	Wood in streams	Y - Cascades			
John Potyondy	USDA Forest Service Rocky Mountain Research Station Natural Resources Research Center 2150 Centre Ave. Building A Fort Collins, CO 80526	jpotyondy@fs.fed.us					
Terry Lilybridge	Wenatchee National Forest Service	tlillybridge@fs.fed.us					

Table B3. Source tracking log of individuals (continued).

Individual	Address of Individual Contacted	Email of Individual	Topics Covered	Information on Eastern Washington (if so where?)	Quantitative? (Y/N)	Information from Analogous Regions? (if so, where?)	Is Information Quantitative? (Y/N)
Michael Pollock	Northwest Fisheries Science Center 2725 Montlake Blvd East Seattle, WA 98112		Article on beaver dams	N	NA	Y	Y
Janet Curran	USGS Alaska Science Center 4230 University Dr. Suite 201 Anchorage, AK 99508-4664	jcurran@usgs.gov		Yes - for several streams in the western and eastern Cascades	Yes, probably	N	N/A
Lee MacDonald	University of Colorado Fort Collins, CO 80523	leemac@env.colostate.edu	Forest ecology of dry land forests			Possible	Unknown at this time
Chad Oliver	University of Washington Management and Engineering Division Forest Resources Box 352100 Seattle, WA 98195	oliver@silvae.cfr.washington.edu	Silvicultural applications, riparian growth and functions	Possibly	Unknown	Unknown	Unknown at this time
Paul Hessberg	USDA Forest Service Pacific Northwest Research Station 1133 N. Western Avenue Wenatchee, WA 98801		Variety of forestry-related topics	Yes	Unknown	Unknown	Unknown at this time
Ann Camp	USDA Forest Service Pacific Northwest Research Station 1133 N. Western Avenue Wenatchee, WA 98801		Variety of forestry-related topics	Yes	Unknown	Unknown	Unknown at this time
John Lehmkuhl	USDA Forest Service Pacific Northwest Research Station 1133 N. Western Avenue Wenatchee, WA 98801		Variety of forestry-related topics	Yes	Unknown	Unknown	Unknown at this time
Bud Kovolchik	Need information	Need information	Riparian ecosystems, classification in E. Washington	Yes - have not obtained data	Unknown	Unknown	Unknown at this time
Pete Peterson, SAGE	Need information	lpetz@aimcomm.com	NE/ Blue Mountain information	Unknown	Unknown	Unknown	Unknown at this time

Table B3. Source tracking log of individuals (continued).

Individual	Address of Individual Contacted	Email of Individual	Topics Covered	Information on Eastern Washington (if so where?)	Quantitative? (Y/N)	Information from Analogous Regions? (if so, where?)	Is Information Quantitative? (Y/N)
Kris Ray, SAGE	Need information	kris.ray@colvilletribes.com	North Central	Unknown	Unknown	Unknown	Unknown at this time
Joe Weeks, SAGE	Need information	joe.weeks@wadnr.gov	All of Eastside	Unknown	Unknown	Unknown	Unknown at this time

APPENDIX C

List of Watershed Analyses for Eastern and Western Washington

Table C1. Summary of watershed analyses currently procured by Herrera Team.

Title and Date	Watershed Location	Scientific Credibility	No. LWD CMR [c]	Questions to Which Assessment is Relevant and Examples of Quantitative Data Available			Notes on Contents
				Riparian Function Assessment	Stream Channel Assessment	Fish Habitat Assessment	
Teanaway Watershed Analysis [a] July 1996	E. Cascades, Kittitas County	Unclear methods for RFA; SCA refers reader to version 2.1 of WA manual	4	6 Riparian composition and density; % shade per study segment;	NONE Ranks of LWD abundance only, per tributary	Same as for SCA	RFA: Data quantified by "segments" determined by aerial photos, so hard to quantify LWD or pool frequency, amt, etc, though there is a map of LWD levels over the watershed
Big Sheep Creek Watershed Analysis [a] February 1995	Stevens County	RFA used aerial photography with ground-truthing of indeterminate sections	7	2, 5, 9 Riparian composition and density (subset of transects only); % shade per study segment	2 Segment summaries of BFW[d], wetted channel W and D, and LWD counts	2, 21, 22 Pool frequency, volume, area, shading (but inconsistent and largely qualitative)	RFA "codes" LWD in a way that is hard to understand or quantify - large-scale verbal summaries only
West Branch of the Little Spokane River [a, b] May 9, 1996	Spokane County	RFA: LWD>12"DBH; "most LWD comes from relatively near bank"?? SCA uses V 3.0 of the WA manual	3	2, 25 Quantifies number of LWD pieces per BFW, % pools formed by LWD as a function of riparian forest type	NONE Only ranks LWD load categorically, (low, med ,high)	2 (#), 21, 23 Quantified pool area, residual depths, and LWD frequency per survey transect	Missing pages F:23-24, relevant to LWD; FHA ranks LWD availability to fish (categorical)
South Fork Touchet Watershed Analysis [b] Feb 96	Blue Mountains; Columbia County	Fair for riparian. Channel assessment: "LWD were recorded "at regular intervals" – unclear. Fish section used TFW methods, including quantifying LWD levels	2	32, 33 Shade levels per channel segment; dominant riparian composition per transect (narrative categories only)	9, 21, 22 Narrative summaries only	Too difficult to understand tables, data to tell if could be used. Possibly Sections 2, 21, 22.	Draft? Doesn't appear to be complete, no date or authors. LWD is not quantified by volume or type (no. pieces only); tables are hard to understand. Mostly summaries given for stream reaches – e.g. "LWD appears to play a dominant role in pool creation in this section"
Gold Fork Watershed: Watershed Assessment Report [a]				% canopy cover per creek studied	Not much quantitative data	LWD count, W/D ratio, pool area per reach	Located in western central Idaho: However, frequent historic fire regime, Ponderosa/Douglas-fir forests, and snowmelt streams suggest aspects of this ecosystem are similar to watersheds in E WA.

Table C1. Summary of watershed analyses currently procured by Herrera Team (continued).

Title and Date	Watershed Location	Scientific Credibility	No. LWD CMR [c]	Questions to Which Assessment is Relevant and Examples of Quantitative Data Available			Notes on Contents
				Riparian Function Assessment	Stream Channel Assessment	Fish Habitat Assessment	
Huckleberry Watershed Analysis Unclear [b]	Stevens County, part of the Colville River drainage system that feeds the Columbia R.	Defines LWD as >12" DBH, coniferous. Recruitment width = 66 ft from stream	3	NONE Summaries of recruitment potential only	2 (but hard to quantify)	NONE No discussion of LWD	This may be a draft? Data quantified by "segments" determined by aerial photos, so hard to quantify LWD or pool frequency, amount, etc.
Thompson Creek Watershed Analysis [b]	Slightly east and north of Spokane – Spokane County	Unclear methods for riparian function	4	1, 2, 32 LWD/Channel width; dominant riparian canopy, canopy closure% by transect	2, 25 Qualitative LWD, pool formation factors per geomorphic channel type (no numbers)	2, 21 Pool volume, area, LWD per channel width, some residual pool depths for 2 transects on Thompson creek	Verbal summaries only in SC, no original data.
Elk Creek Watershed Analysis [a] Mar 1997	Watershed is located in Jackson County, Oregon (near Medford).						Outside of E WA area of interest.
Grossman Creek Watershed Analysis [a] June 1996	NE Oregon Border, in the Blue Mountains	Only a summary, with minimal methods, available in this WA		NONE Categorical ranking (low, med, high) of LWD volume only	NONE	NONE Categorical ranking (low, med, high) of LWD volume only	This WA does not have the detailed appendices of the others; summary of WA only.
Upper Little Klickitat Watershed Analysis [a] July 1999	Goldendale area, south-central Washington	RFA fairly complete methods. This WA uses version 4.0 of the WA Manual.	3 (3 reports for 3 size classes: >8,>12, >24	NONE Verbal/categorical summaries only	9, 21 % pool area, , % pools LWD formed, LWD/cw per study transect	Combined with CA	Appears to be a final report. Several maps in RFA code riparian conditions and LWD recruitment potential. CA/FHA would be hard to quantify, as values are given per segment and segment lengths unclear/short.

Table C1. Summary of watershed analyses currently procured by Herrera Team (continued).

Title and Date	Watershed Location	Scientific Credibility	No. LWD CMR [c]	Questions to Which Assessment is Relevant and Examples of Quantitative Data Available			Notes on Contents
				Riparian Function Assessment	Stream Channel Assessment	Fish Habitat Assessment	
Onion Creek Watershed Analysis [a] March 1997	Drains to the Columbia River Stevens County	RFA, CA, and FHA refers to WA Manual for methods, Level II anal.	NONE- segs. with low LWD loading on map	2, 5, 3, 4 % land use adj. to stream; riparian densities and sizes; canopy closure %	2, 21, 22 LWD/CW, % pools; pool depth (but units aren't defined)	Combined with CA	Draft: Front material is not complete, but some appendices are complete, including RFA.
Ahtanum Watershed Analysis Aug 1997/ some parts Dec 96	Drains to the Yakima River Yakima County	Focus on aerial photography for LWD quantification in RFA. Qualitative and quantitative data are presented in CA.	2, CRSN and WISSP	NONE Focus on LWD recruitment potential- outside scope of our study	2 Piece enumerations: total number, per unit channel length, per 500 feet channel length, and per bankfull width	2, 21, 22 (but see notes)	FHA has quantifications of LWD and pools, but cannot determine length of reaches quantified. The channel networks data include numerous channel measurements.

[a] Boise Cascade.
[b] WDNR.
[c] CMR= Causal Mechanism Reports. These reports are included in several WAs. They are a way for the authors to target specific problem areas in the watershed, and form the basis for Prescription Reports to address these problems. Problems include erosion hazard to lack of stream shading, etc. This column identifies the number of CMRs in the WA that are relevant to LWD; most describe lack of LWD due to past land use practices as trigging the CMR. The DNR Manual describes the prescription processes as, "Based on the findings of the resource assessment, a field managers team made up of managers and analysts determines the required and voluntary forest practices for each identified area of resource assessment…" The specific methods for quantifying problems are not identified by DNR. The methodologies are developed by the prescription team for most WAs.
[d] BFW=Bankfull channel width.

Table C2. Summary of locations of additional watershed analyses available, but not obtained or reviewed.
Information provided by Nancy Sturhan, WDNR Forest Practices.

Watershed Analysis	Date [a]	Sponsor	Region
Chehalis Headwaters	Nov. 1994	Weyerhaeuser	Central Washington
Connelly Creek	Sep. 1993	Murray Pacific	Central Washington
East Fork Tilton	Nov. 1994	Murray Pacific	Central Washington
Fall River	Oct. 1997	Weyerhaeuser	Central Washington
Kennedy Creek	Sep. 1995	DNR Regulatory	Central Washington
Kiona Creek	Nov. 1995	Murray Pacific	Central Washington
Kosmos	Aug. 1997	Murray Pacific	Central Washington
Little North/Vesta	Feb. 1996	Weyerhaeuser	Central Washington
Lower North River	incomplete	Weyerhaeuser	Central Washington
Mineral Creek	Oct. 1998	Murray Pacific	Central Washington
Nineteen Creek	Oct. 1998	Murray Pacific	Central Washington
North Fork Mineral	Oct. 1998	Murray Pacific	Central Washington
North Fork Newaukum	incomplete	Weyerhaeuser	Central Washington
Palix	Mar. 1998	Rayonier	Central Washington
Silver Creek	1999	Murray Pacific	Central Washington
South Fork Newaukum	incomplete	Weyerhaeuser	Central Washington
Stillman Creek	Oct. 1994	Weyerhaeuser	Central Washington
Upper Skookumchuck	Oct. 1998	Weyerhaeuser	Central Washington
West Fork Satsop	Nov. 1996	Weyerhaeuser /Simpson	Central Washington
West Fork Tilton	Oct. 1998	Murray Pacific	Central Washington
Willapa Headwaters	Dec. 1994	Weyerhaeuser	Central Washington
LeClerc Creek	1998	Plum Creek/Stimson	Northeast Washington
West Branch	incomplete	Boise Cascade	Northeast Washington
Acme	incomplete	Crown	Northwest Washington
Deer Creek	incomplete	DNR State Lands	Northwest Washington
Hansen	Apr. 1995	DNR Regulatory	Northwest Washington
Hazel	Feb. 1998	DNR Regulatory	Northwest Washington
Hutchinson Creek	Mar. 1998	DNR Regulatory	Northwest Washington
Jordan/Boulder	Apr. 1997	DNR State Lands	Northwest Washington
Lake Whatcom	Jan. 1998	DNR State Lands	Northwest Washington
Skookum Creek	Apr. 1995	MRGC	Northwest Washington
Warnick	Jan. 1996	DePaul/Trillium	Northwest Washington
Woods Creek	Aug. 1993	DNR Regulatory	Northwest Washington
Big Quilcene	Aug. 1996	DNR Regulatory/USFS	Olympic Region
East Fork Dickey	incomplete	Rayonier	Olympic Region
East Humptulips	incomplete	Rayonier	Olympic Region
Hoko	1997	Rayonier/Crown Pacific	Olympic Region
Middle Hoh	incomplete	DNR Regulatory	Olympic Region
North Fork Calawah	Jan. 1998	Rayonier	Olympic Region
North Fork Sol Duc	Aug. 1996	DNR Regulatory/USFS	Olympic Region
Rainforest	incomplete	DNR Regulatory	Olympic Region

Table C2. Summary of locations of additional watershed analyses available, but not obtained or reviewed (continued).

Watershed Analysis	Date [a]	Sponsor	Region
Sekiu	incomplete	DNR Regulatory	Olympic Region
Sol Duc Lowlands	Aug. 1996	DNR Regulatory/USFS	Olympic Region
Sol Duc Valley	Aug. 1996	DNR Regulatory/USFS	Olympic Region
Upper Sol Duc	Aug. 1996	DNR Regulatory/USFS	Olympic Region
West Fork Dickey	incomplete	Rayonier	Olympic Region
West Humptulips	incomplete	Rayonier	Olympic Region
Watershed Analysis	Date[a]	Sponsor	Regional Location
Brush Creek	incomplete	Weyerhaeuser/DNR Regulatory	South Puget Sound
Busy Wild	incomplete	DNR Reg/Weyco/Champion	South Puget Sound
Clearwater River	incomplete	Weyerhaeuser/DNR Regulatory	South Puget Sound
Green	incomplete	Plum Creek	South Puget Sound
Griffin	Sep. 1996	Weyerhaeuser	South Puget Sound
Howard Hansen	incomplete	DNR/Plum Creek	South Puget Sound
Lester	Apr. 1998	Plum Creek	South Puget Sound
Middle White River	incomplete	Weyerhaeuser/DNR Regulatory	South Puget Sound
Ohop Creek	incomplete	DNR Regulatory/Nisqually Tribe	South Puget Sound
Powell Creek	incomplete	DNR Regulatory/Nisqually Tribe	South Puget Sound
Raging	incomplete	DNR Regulatory	South Puget Sound
S. Fk. Skokomish	Nov. 1997	Simpson	South Puget Sound
Smay Creek	incomplete	DNR/Plum Creek	South Puget Sound
Sunday	incomplete	Plum Creek	South Puget Sound
Tanwax Creek	incomplete	DNR Regulatory/Nisqually Tribe	South Puget Sound
Tokul	Sep. 1996	Weyerhaeuser	South Puget Sound
Tolt	Aug. 1993	Weyerhaeuser	South Puget Sound
West Kitsap	Mar. 1998	DNR Regulatory	South Puget Sound
Alps	1994	Plum Creek	Southeast Washington
Big Creek	Incomplete	Plum Creek	Southeast Washington
Brooks	unknown	Boise	Southeast Washington
Butler	unknown	Boise	Southeast Washington
Cabin Creek	incomplete	Plum Creek	Southeast Washington
Keechelus	incomplete	Plum Creek	Southeast Washington
Mosquito Creek	incomplete	Plum Creek	Southeast Washington
Naches Pass	1997	Plum Creek	Southeast Washington
Naneum	Dec. 1994	DNR Regulatory	Southeast Washington
Panakanic	Sep. 1997	Champion	Southeast Washington
Quartz Mountain	Nov. 1994	Plum Creek	Southeast Washington
W. Fk. Teanaway	incomplete	Plum Creek	Southeast Washington
West Prong	unknown	Boise	Southeast Washington
North Elochoman	May 1995	DNR Regulatory	Southwest Washington
Upper Coweeman	Feb. 1998	Weyerhaeuser	Southwest Washington

[a] Date of study is a best guess by N. Sturhan. Some completion dates are unknown, and some analyses have not yet been completed.

Summary of SRC Review Comments on
"Review of the Available Literature Related to Wood Loading Dynamics in and around Streams in Eastern Washington Forests"
(SRC # 04-05-04)

June 7, 2005

Three anonymous reviews were solicited from experts in the field to review the above-mentioned document. The following is a summary of the comments and suggestions included in the two reviews that were received. The charge for the SRC reviewers was to address four questions, the responses to which are summarized in detail following the general comments.

General Comments:

Overall the report is thorough and well documented. The principal comment of the SRC reviewers was to include a broader selection of literature from other regions that is pertinent to addressing the questions of interest in eastern Washington. The general themes that ran through the SRC reviewers' comments are below:

A. The literature review could be better integrated in relating the topics covered in the 41 questions. Answers to some questions were pertinent to other questions as well, but were not mentioned in both places. The recommendations by the authors for future field and lab studies are scattered throughout the document in response to individual questions, and could be summarized to facilitate the design and prioritization of such studies. Pulling the document into a more integrated format, summarizing recommendations, and cross-referencing or relating topics to one another would help address this concern.

B. The SRC reviewers agreed that there is a paucity of studies of channel wood conducted in eastern Washington. Because of this, the SRC reviewers emphasized that this literature review must rely heavily on analogous studies from other areas. The reviewers cited several additional useful studies from other locations that should be added to the document, some of which were mentioned by both reviewers. Marcus et al (2002) is cited on the first page of Review #1, all others are in the reference list at the end of Review #2. Reviewer #1 mentioned that a list of the criteria by which the authors judged the appropriateness of the analogous studies from other regions would be useful.

C. A prioritization of research needs in eastern Washington would be a useful addition to the authors' summary.

D. Additional existing literature on this topic from other regions could provide greater insight and depth of understanding to the problems discussed in the report; however the SRC reviewers concurred that its inclusion would not alter the general recommendations made by the authors of the report. In some cases the literature from other regions may provide information or data that indicate particular trends that are not quantifiable from existing data in eastern Washington. The authors of the report were conservative in their interpretation of conclusions in the literature that were not specifically obtained in eastern Washington.

E. Both reviewers had some useful and creative ideas for addressing several of the specific topics in the 41 questions within the report, by relying on literature from other regions or areas of study. Examples include using streams in unharvested basins from analogous regions as a surrogate for historical conditions (question 6) (Overton et al., 1995); impact of railroad tie drives as an analog for harvesting firewood from streams (question 11) (Young et al., 1994); forest fuel studies from Pacific Northwest (question 7 and others); as well as many direct references to the same topic in studies from different regions.

F. Reviewer # 1 had a good suggestion of variables that should be considered when assessing whether another region or system is an appropriate analog for the system in question in eastern Washington: 1) geology, 2) forest characteristics, 3) hydroclimatology, and 4) aquatic ecology.

Comments on Questions posed to SRC Reviewers:

1. Did the literature review include all relevant research pertinent to the key questions? Were there any major omissions of literature that would significantly change the answer to any key questions?

As mentioned in the General Comments, the SRC reviewers recommended that the addition of literature from other areas that would add depth and insight to the findings. However, its inclusion would not significantly change the answers to key questions or alter the general recommendations of the report. Additional citations are included in the text of Review #1, and Reviewer #2 includes a comprehensive list of additional references, many of which are keyed to specific points in the 41 questions covered in the report. These should be given careful consideration for inclusion in the revised report. Two recent conferences focusing on channel wood should definitely be reviewed and included (Laudenslayer et al., 2002 and Gregory et al, 2003).

2. Given the literature cited, did the authors respond to the key questions using all available literature on eastern Washington? Does other literature not included in the review change the level of qualification or certainty for the key questions?

The SRC reviewers agreed that the report covers most of the literature that they are aware of from eastern Washington. They concur with the authors of the report that there is not much existing literature on channel wood from this specific region. Again, discussion of additional appropriate studies from outside the eastern Washington region would add to the understanding of processes within this region and strengthen the report. However, as Reviewer #2 states "the data necessary to quantify patterns and relations with respect to wood in eastern Washington are absent and specific recommendations are unwise." Additional literature that would change the level of qualification or certainty is currently not available for eastern Washington. The authors have chosen to be conservative in their application of data trends from other regions. A compromise position might be to cite the data, examples and patterns from other regions, but clearly state the qualification that those results have yet to be tested and assessed in eastern Washington.

3.Was enough information and analysis provided from the outlined literature to clearly corroborate the recommendations and conclusions that were reached?

The authors adequately substantiated and documented their conclusions with evidence from their cited literature through inclusion of figures, tables and summaries. In the revised report, they should continue to thoroughly document their findings from the additional literature suggested by the SRC reviewers.

4. In cases where little pertinent literature was found concerning a key question, do the authors recognize these limitations? Do the authors overextend or draw conclusions without supporting literature?

The SRC reviews agreed that the authors recognized and acknowledged the limitations of the literature. Their conclusions were carefully based on their cited data and did not result in any unjustified extrapolations.

Comments on Specific Questions:

The SRC reviews include numerous comments addressing many of the 41 questions in the report. Many of these are suggestions of additional literature on specific relevant topics. Major comments are summarized below, and some have already been touched upon in the general comments above. Refer to the individual SRC reviews for the full range of specific comments.

Question 1: Variations in the size and transport capability of the channel, as well as the delivery mechanisms must be taken into account when estimating the source of channel wood and determining whether there is a correlation with the adjacent riparian community. These variables are critical to assessing the answer to Question 1 in the report, and were not adequately considered and discussed.

Question 2: There is a high spatial variability in wood loads within streams, which makes it difficult to accurately assess the range of current wood loads in eastside forested streams (Question 2). In addition, the length of the stream reach sampled in many studies may be inadequate to characterize the wood load. Emphasis in the report on the findings from Fox (2001) that wood loads increase with stream width is inconsistent with other studies.

Question 3: The question of how wood loads in streams adjacent to unlogged or recently logged forest stands is more complex than implied by the authors' conclusions that wood loads are greater in unmanaged systems. Wood loads may be more variable in managed systems; "a key point is appreciating the time since disturbance in either type of system because wood loads are predicted to vary dramatically as succession proceeds." Reviewer #2 provides some references that may provide a more comprehensive answer to this question.

Questions 7, 8, 9, 33: All of these questions touch on piece size, and the report would be better integrated with some cross-referencing and discussion. The responses to questions 7 and 8 could be expanded per suggestions by Reviewer #2.

Questions 20 and 23: Distribution of sizes and characteristics of pools in eastside streams. The question was not fully answered, although it is a broad one. Reviewer #2 suggested that Overton et al. (1995) provide information from comparable forest types in Idaho. However, before extending this interpretation to eastern Washington the authors should assess the criteria laid out by Reviewer #1 for judging the appropriateness of utilizing analogs from other regions. The geology and hydroclimatology exert a major control on pool morphology and may be significantly different between the eastern Cascades and Idaho.

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Central Washington University
Ellensburg, WA
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