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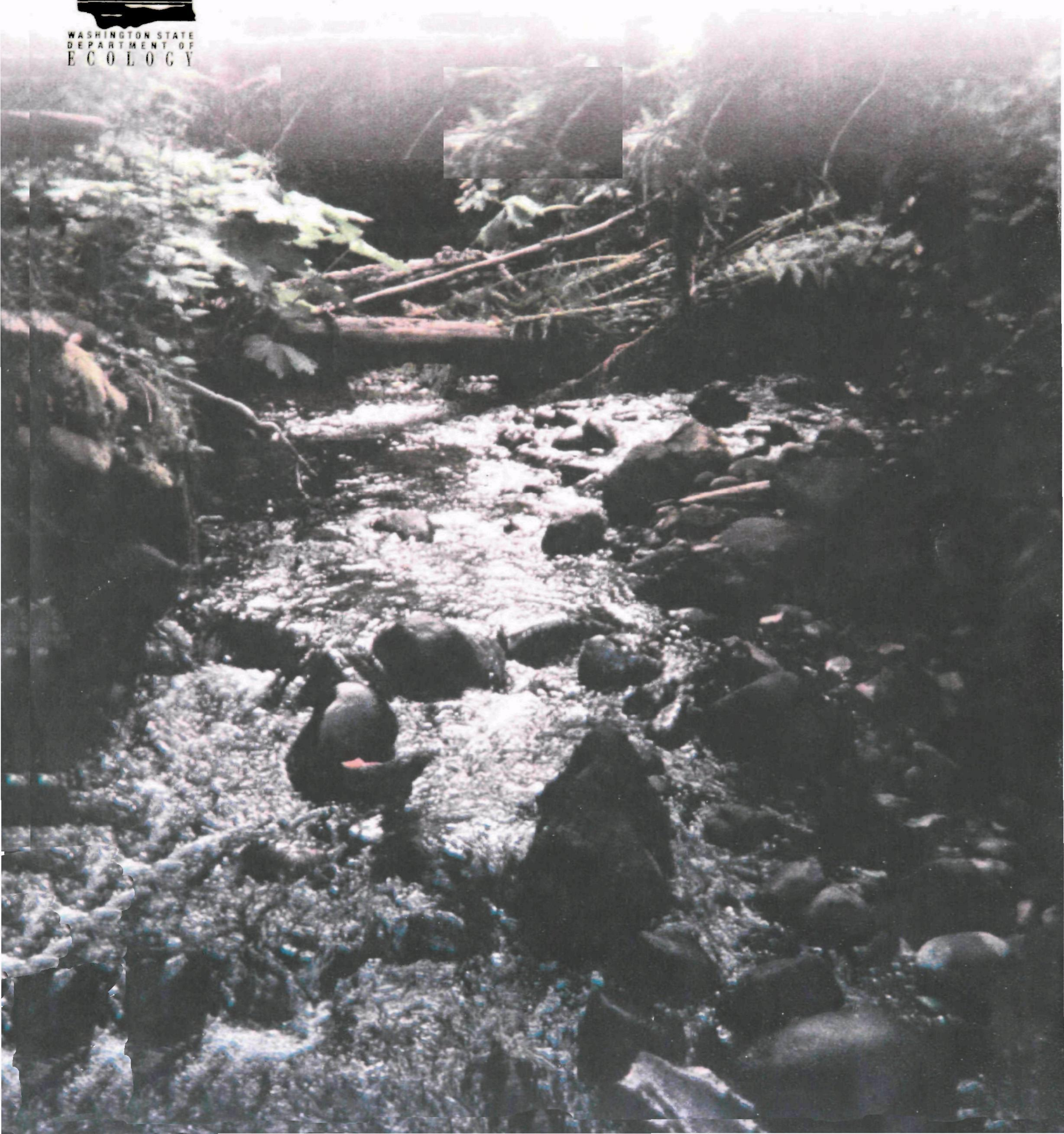
Ecological Condition of the Upper Chehalis Basin Streams



Ecological Condition of Upper Chehalis Basin Streams

an Environmental Monitoring and Assessment Program (EMAP) Report

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I. BASIN DESCRIPTION

The Chehalis River is a major basin in southwestern Washington state draining to the west into Grays Harbor. The upper portion of the Chehalis Basin is large, comprising almost 1300 square miles (see **Map 1**). The upper Chehalis lies within 2 main "ecoregions". Ecoregions are distinct geographic areas based on topography, climate, land uses, soils, geology, and naturally occurring vegetation. The upper Chehalis basin is primarily divided between the Puget Lowlands ecoregion (Omernik, 1987), in the eastern portion and the Coast Range ecoregion, in the west.

The Puget Lowland Ecoregion includes the open hills and tablelands of glacial and lacustrine deposits in the Puget Sound valley (Omernik and Gallant, 1986). The upper Chehalis basin is in the southern portion of the ecoregion where the terrain consists of hills and low mountains. In the hilly areas, relief varies from 800 to 1,000 feet with some peaks exceeding 2,500 feet. Most of the land is forested with Douglas fir as the predominant tree species. Timber harvest is an important land use in the ecoregion. Cleared areas are farmed for grains, wheat, vegetables and other crops. Urban development is concentrated along waterways and near Interstate-5, which runs through the ecoregion.

The western portion of the basin is within the Coast Range ecoregion, which is characterized by higher elevations, and the primary land use is commercial forestry. The Coast Range ecoregion includes the Pacific Coast Range mountains and coastal valley and terraces (Omernik and Gallant, 1986). The combination of maritime weather system and high local topographic relief results in large differences in local precipitation, which ranges from 55-125 inches average annual rainfall.

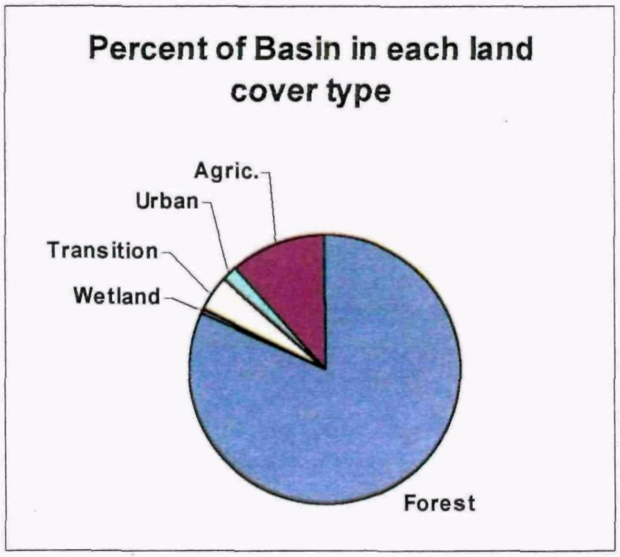
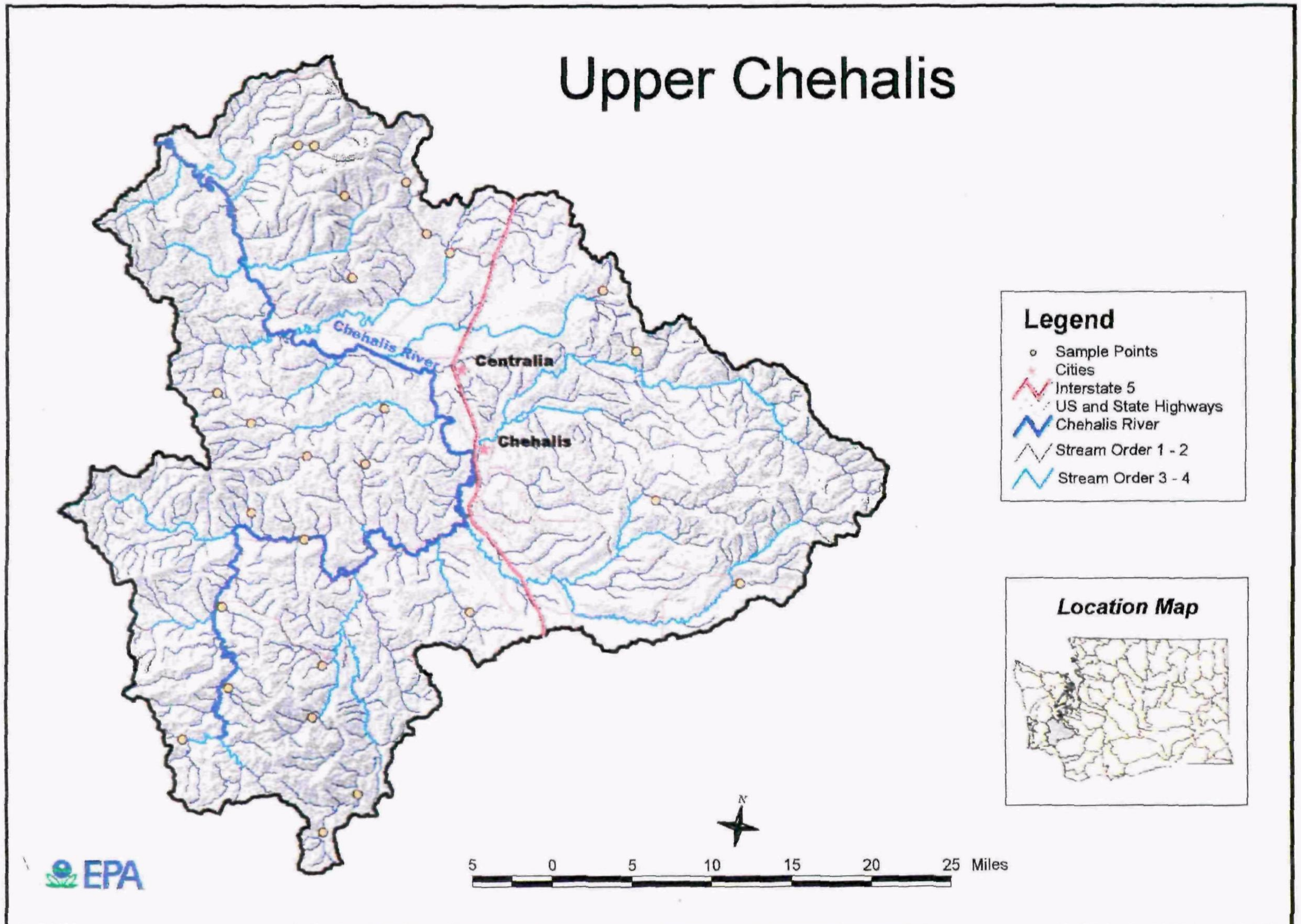


Figure 1. Percent of Landuse/Landcover in the upper Chehalis basin

The predominant land cover type in the upper Chehalis basin is forest (81%). Followed by agriculture (11%)(**Figure 1**). Urban use is concentrated in the lowlands, near the mainstem Chehalis River and the I-5 corridor. The cities of Chehalis and Centralia are the main urban centers.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II. PROJECT DESCRIPTION

This document summarizes data collected in the upper Chehalis basin of Washington as part of the Regional Environmental Monitoring and Assessment Program (R-EMAP). The project is a cooperative effort between the Environmental Protection Agency (EPA) Office of Research and Development, EPA Region 10, and the Washington Department of Ecology (Ecology). Ecology conducted all field sampling for this project in 1997.

Environmental Monitoring and Assessment Program (EMAP)

EMAP was initiated by EPA's Office of Research and Development (ORD) to estimate the current status and trends of the nation's ecological resources and to examine associations between ecological condition and natural and anthropogenic influences. The long-term goal of EMAP is to develop ecological methods and procedures that advance the science of measuring environmental resources to determine if they are in an acceptable or unacceptable condition. Two major features of EMAP are:

- the use of ecological indicators, and
- the probability-based selection of sample sites.

Regional EMAP (R-EMAP) uses EMAP's indicator concepts and statistical design, and applies them to projects of smaller geographic scale and time frames. R-EMAP provides States and EPA Regional offices opportunities to use EMAP indicators to answer questions of regional interest. The following are general descriptions of the EMAP sample design and indicators. A more in-depth description can be found in Section II.

A. DESIGN – How to Select Stream Sites to Sample?

Background

Environmental monitoring and assessments are typically based on subjectively selected stream reaches. Peterson et al. (1998; 1999) compared subjectively selected localized lake data with probability-based sample selection and showed the results for the same area to be substantially different. The primary reason for these differences was lack of regional sample representativeness of subjectively selected sites. Stream studies have been plagued by the same problem. A more objective approach is needed to assess stream quality on a regional scale.

EMAP uses a statistical sampling design that views streams as a continuous resource. This allows statements to be made in terms of length of the stream resource in various conditions (Herlihy et al., 2000). Sample sites are randomly selected from a systematic grid based on landscape maps overlaid with hydrography. The EMAP systematic grid provides uniform spatial coverage, making it possible to select stream sample locations in proportion to their occurrence (Overton et al., 1990). This design allows one to make statistically valid interpolations from the sample data to the entire length of stream in a study area, such as estimates of stream that are in "poor" condition.

Site Selection in the Upper Chehalis

Study sites were selected from a sample population of all mapped (1:100,000 scale) 2nd order streams in the upper Chehalis basin, using EMAP-Surface Water protocols (Herlihy et. al., 2000). See **Map 1** for the location of the sites.

Stream Order	Percent
0*	1
1st	58
2nd	19
3rd	14
>3rd	7

Table 1. Streams in the upper Chehalis basin by stream order. * (0 order streams are primarily unconnected reaches, side channels on large rivers or canals/ditches)

Although 1st through 3rd order streams are usually wadeable and therefore suitable for sampling using EMAP protocols, this project was limited to 2nd order streams. Due to budget limitations, the sample size was restricted to 30 sites. This is generally considered an adequate sample number in which to describe this particular stream size. There are approximately 454 km of 2nd order streams in the upper Chehalis basin.

B. INDICATORS - What to Measure at Each Selected Site?

The objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. In order to assess the nation's waters it is important to measure water quality (water column parameters), physical habitat (watershed and in-stream measurements) and biological (fish and invertebrates communities) condition. EMAP uses ecological indicators to quantify these conditions. Indicators are simply measurable characteristics of the environment, both abiotic and biotic, that can provide information on ecological resources. **Table 2** is a general list of the indicator categories used in EMAP to detect stress in stream ecosystems. The following section describes EMAP measurements in each of these indicator categories.

Indicator	Rationale
Water column chemistry	Water chemistry affects stream biota. Numeric standards are available to evaluate some water quality parameters.
Watershed condition	Disturbance related to land use affects biota and water quality.
Instream physical habitat and riparian condition	Instream and riparian alterations affect stream biota and water quality. Physical habitat in streams includes all physical attributes that influence organisms.
Biological - Benthic macro invertebrates	Benthic macroinvertebrates live on the bottom of streams and reflect the overall biological integrity of the stream. Monitoring benthic invertebrates is useful in assessing the condition of the stream.
Biological - Fish and amphibians	Fish and amphibians are meaningful indicators of biological integrity. They occupy the upper levels of the aquatic food web and are affected by chemical and physical changes in their environment.

Table 2. General EMAP Indicators

Water Column Chemistry

Water chemistry characteristics influence the organisms that reside in streams. A great deal of information is available on the effects of specific chemicals on aquatic biota. Data for 13 water quality parameters were collected at all sites. Measurements of pH, dissolved oxygen (DO), stream temperature, conductivity, dissolved organic carbon (DOC), alkalinity, total nitrogen (TPN), total phosphorus (TP), Nitrite-Nitrate (NO_2-NO_3), ammonia (NH_3), chloride (Cl^-), sulfate (SO_4) and total suspended solids. The rationale behind the selection of some of these water column measures is presented in **Table 3**.

Indicator	Importance to biota	Examples of human activities that influence this indicator
Stream Temperature	- Influences biological activity - Growth and survival of biota	- Riparian shade reduction - Altered stream morphology
Dissolved Oxygen (DO)	- Growth and survival of fish - Sustains sensitive benthic invertebrates - Organic material processing	- Erosion - Addition of organic matter - Riparian shade reduction - Industrial and municipal waste
pH	- Fish production - Benthic invertebrate survival	- Mining - Addition of organic matter
Conductivity	- Indicator of dissolved ions	- Agricultural returns, industrial input and mining.
Nutrients - Total phosphorous (TP), Total nitrogen (TPN), Nitrite-Nitrate (NO_2-NO_3), and Ammonia (NH_3)	- Stimulates primary production -Accumulation can result in nutrient enrichment	- Erosion - Recreation, septic tanks and livestock - Stormwater runoff - Fertilization from agriculture, livestock waste and sewage. - Salmon overharvest
Chloride (Cl^-)	- A surrogate for human disturbance (Herlihy et al. 1998)	- Industrial discharge, fertilizer use, livestock waste, and sewage.

Table 3. Water Column Indicators

Physical Habitat Indicators

Physical habitat in streams includes all those physical attributes that influence or provide sustenance to organisms within the stream.

Some Useful Definitions- Habitat:

Bankfull width -- The stream width measured at the average flood water mark.
Canopy -- A layer of foliage in a forest stand. This most often refers to the uppermost layer of foliage, but it can be used to describe lower layers in a multistoried stand.
Channel -- An area that contains continuously or periodically flowing water that is confined by banks and a stream bed.
Large Woody Debris -- Pieces of wood larger than 5 feet long and 4 inches in diameter, in a stream channel.
Riparian area -- An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes woodlands, vegetation, and floodplains.
Sinuosity -- The amount of bending, winding and curving in a stream or river.
Stream gradient -- A general slope or rate of change in vertical elevation per unit of horizontal distance of the water surface of a flowing stream.
Substrate -- The composition of the grain size of the sediments in the stream or river bottom, ranging from rocks to mud.
Thalweg -- The deepest part of the stream

Physical habitat varies naturally, as do biological characteristics, thus expectations differ even in the absence of human caused disturbance. Degradation of aquatic habitats by nonpoint source activities is recognized as one of the major causes for the decline of anadromous and resident fish stocks in the Pacific Northwest (Williams et al. 1989).

The following three types of habitat variables are measured or estimated:

Continuous Parameters:
Thalweg profile (a survey of depth along the stream channel), and presence/absence of fine sediments were collected at either 100 or 150 equally spaced points along the stream reach. An observation of the geomorphic channel type (e.g. riffle, glide, pool) were made at each point. Crews also tally large woody debris along the reach.

Transect Parameters:
Measures/observations of bankfull width, wetted width, depth, substrate size, canopy closure, and fish cover were taken at eleven evenly spaced transects in each reach. Gradient measurements and compass bearing between each of the 11 stations are collected to calculate reach gradient and channel sinuosity. This category also includes measures and/or visual estimates of riparian vegetation structure, human disturbance, and stream bank angle, incision and undercut.

Reach Parameters:
Channel morphology class for the entire reach is determined (Montgomery and Buffington, 1993) and instantaneous discharge is measured at one optimally chosen cross-section.

Biological Indicators

Fish/Aquatic Vertebrate Assemblage

In some regions, fish are good indicators of long-term effects and broad habitat conditions because they are relatively long-lived and mobile (Karr et al., 1986). Fish assemblages integrate various features of environmental quality, such as food abundance and habitat quality. The physical degradation of streams can cause changes in the food web and the composition and distribution of habitats (Lonzarich, 1994). These are some of the reasons that stream fish assemblages may be better indicators of land-use impacts than single salmonid species (Karr, 1981).

Some Useful Definitions - Biota

Aquatic Assemblage - an organism group of interacting populations in a given waterbody, for example, fish assemblage or a benthic macroinvertebrate assemblage.

Benthic Macroinvertebrates - animals without backbones, living in or on the sediments, and of a large enough size to be seen by the unaided eye (as captured with a 500µm mesh net). Also referred to as macroinvertebrates or benthos.

When amphibians are collected in addition to fish the more general term aquatic vertebrate will be used. The objectives of the vertebrate assemblage assessments are to:
1) collect data for estimates of relative abundance of all species present in the assemblage, and
2) collect all except the most rare species in the assemblage.

Fish were sampled with one-pass electro-fishing in all portions of the sample reach. Fish were identified, counted, and measured and voucher specimens were collected for species that were difficult to identify. Amphibians that were captured during electrofishing were identified and counted only. Although these methods were not used to estimate absolute abundance, standardized collection techniques were important for consistent measures of proportionate abundance of species.

Benthic Invertebrates Assemblage

Benthic invertebrates inhabit the sediment or surface substrates of streams. The benthic macroinvertebrate assemblages in streams reflect overall biological integrity of the benthic community. Monitoring these assemblages is useful for assessing the status of the water body and monitoring trends. Benthic communities respond to a wide array of stressors in different ways, thus it is often possible to determine the type of stress that has affected a macroinvertebrate community (Klemm et al., 1990). Because many macroinvertebrates have relatively long life cycles of a year or more and are relatively immobile, macroinvertebrate community structure is a function of past conditions.

Macroinvertebrates are sampled from the two predominant habitat types (riffles and pools) using a D-frame kick net (500μm mesh). The habitat types are described below:

Riffle - a portion of the stream with relatively fast currents and shallow depth.

Pool- a portion of a stream with reduced current velocity and greater depth.

Five kick samples are collected from each habitat type and are composited by habitat type. A subsample of each composite, representing a predetermined equivalent substrate area, is processed for macroinvertebrates. For each sample, 300 organisms are identified to the finest practical taxonomic level. The macroinvertebrate method used in the upper Chehalis is slightly different than that used in other EMAP studies (Lazorchak et al., 1998) where macroinvertebrate data is collected at each transect regardless of habitat type.

Photo: Overview of Chehalis basin from Ceres Hill Road (source: Washington Department of Ecology).

III. RESULTS

A. Introduction

Using the R-EMAP protocols described, data were collected from 26 upper Chehalis sites. In this report, we will only be presenting a portion of the indicators that were generated from the field data. This is due to the large volume of information that was collected. Additional indicators are summarized in Appendices 1-7.

Description of the Upper Chehalis River Basin

There are 455km of 2nd order streams in the upper Chehalis basin representing 19.4% of the total 2342km of streams in the basin (see **Table 1** in Section II).

Using the EMAP sampling design to select a random sample of the 2nd order streams, 46 sites were evaluated for field sampling. Of these, only 26 were selected as "target sites" (useable sample sites). Reasons for exclusion of the remaining 20 sites are shown on the next page in **Figure 2**. The estimated stream length represented by the 26 samples is 345.3km of the total 454km, as the sample is assumed to be representative of both the "target" portion as well as reaches where access was denied (76% of the total). Each of 26 sites was sampled at least once during the 1997 field season.

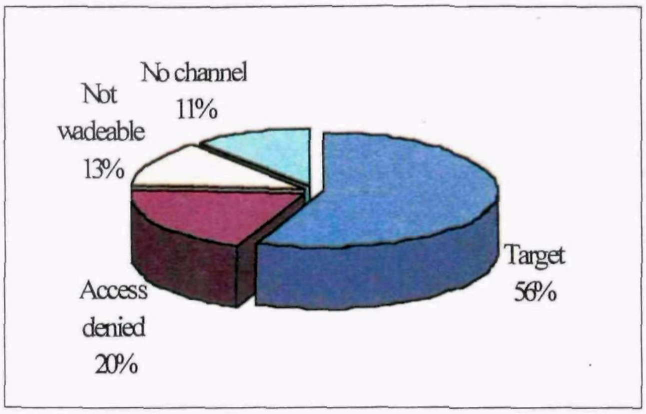

Figure 2. Stream Categories

Data Analysis and Interpretation

In this report, the primary method for evaluating indicators was cumulative distribution frequencies (CDFs). CDFs are graphs that show the complete data population above or below a particular value. The "population" in this report is the 2nd order streams of the upper Chehalis basin. For example, **Figure 3** shows that 40 percent of the 2nd order stream miles have temperatures below 14°C.

B. Water Column Chemistry

In general terms, a water quality standard defines the goals for a waterbody by designating the use or uses to be made of the water, setting criteria necessary to protect those uses, and preventing degradation of water quality through antidegradation provisions. Water quality standards apply to surface waters of the United States, including rivers, streams, lakes, oceans, estuaries and wetlands.

Under the Clean Water Act, each State establishes water quality standards which are approved by EPA. The State of Washington has established water quality standards that include water quality criteria representing maximum concentrations of pollutants that are acceptable, if State waters are to meet their designated uses.

Data for 13 water column indicators were collected from 26 sites. The data from these sites were compared to current water quality standards of Washington (**Table 4**). Water quality criteria do not exist for all of the water column variables measured during the study.

Indicator	**Standard for Washington**[1]
Water Temperature	16°C (Class AA) 18°C (Class A)
Dissolved Oxygen (DO)	>9.5 mg/L (Class AA) >8 mg/L (A)
pH	6.5 to 8.5 for both Class A and Class AA Waters

Table 4. Table of standards for freshwater (Washington State, 1992). [1]Streams in the upper Chehalis are either Class A or AA, which are state designated use classifications (Merritt et al., 1999).

The results reported below are for only those variables that have an applicable criteria and/or those that influence the biota. Sites were not continuously sampled and timing of sampling was not intended to capture the peak concentration of chemical indicators. Data interpretation reflects a single view in time at these representative locations.

Temperature

Because stream temperature is temporally variable, dependent on climatic conditions, a single measurement is of limited value in characterizing stream conditions. Temperature ranged from 10.7°C to 18.0°C. Using the Washington State criteria, no sites exceeded 18.0°C at the time of sampling. The median temperature was 14.4°C (see **Figure 3**). The sample period was from July 2nd to September 23rd.

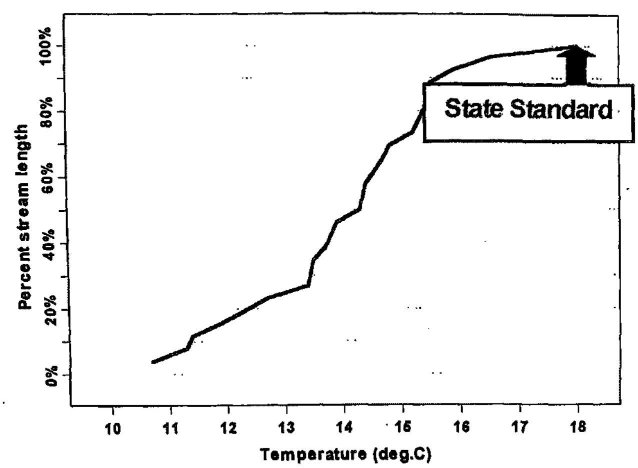

Figure 3. Stream temperature

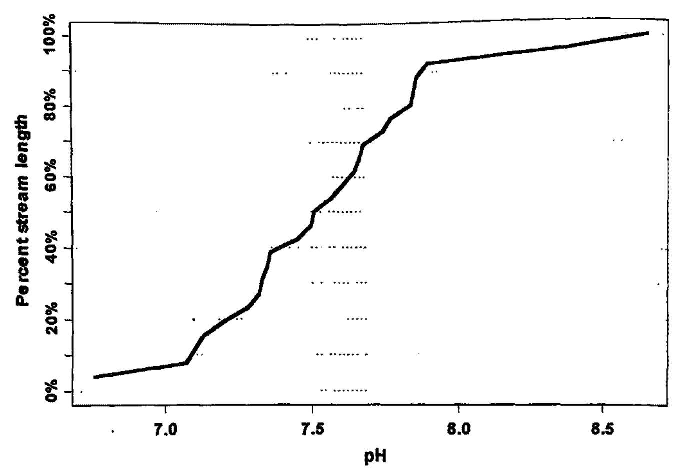

Figure 5. pH of streams.

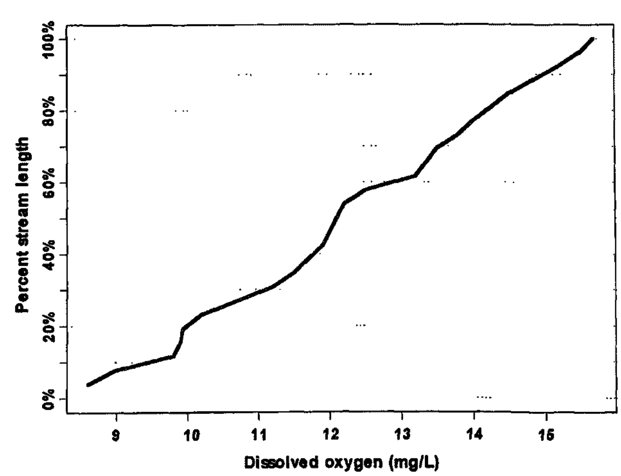

Figure 4. Stream Dissolved Oxygen (DO)

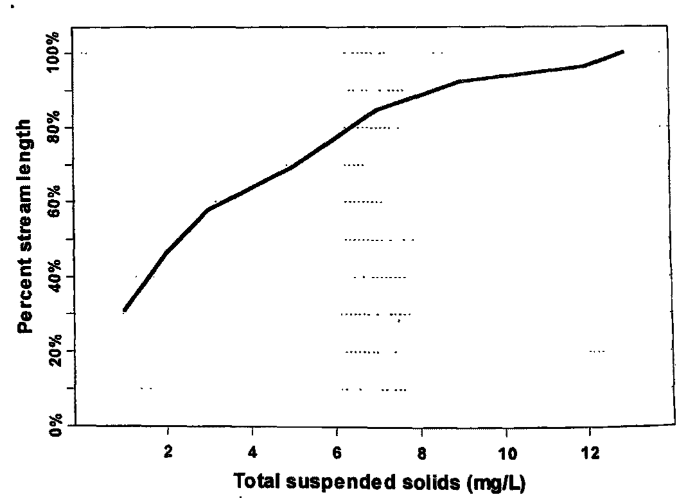

Figure 6. Total Suspended Solids (TSS) of streams.

Dissolved Oxygen (DO)

Dissolved oxygen is simply the oxygen dissolved in water that is available for organisms to use for respiration. Like temperature, DO is temporally variable and a single measurement is of limited value for characterizing stream condition. In the upper Chehalis basin, DO ranged from 8.6 mg/L to 15.7 mg/L (mean 12.2 mg/L). The State standard is >9.5 mg/L for AA and >8 for A streams. Less than 2% of the streams were below the AA standard (see **Figure 4**). Overall DO is relatively high (near saturation) based on these daytime measurements. This is an expected condition in streams with low temperature, good turbulence (relatively shallow, cobble bedded) and low primary productivity which is typical of forested streams.

pH

Another important water column variable, pH, is a numerical measure of the concentration of the constituents that determine water acidity. It is measured on a logarithmic scale of 1.0 (acidic) to 14.0 (basic) and 7.0 is neutral. The pH of the upper Chehalis basin study sites ranged from 6.8 to 8.7 with mean 7.5. Most (98%) of the stream miles were within the state criteria of 6.5 to 8.5 as shown in **Figure 5** (one site above 8.5). Measurements of pH collected during the day are typically elevated, as CO_2 is depleted due to photosynthesis which effectively shifts the pH up.

Total Suspended Solids (TSS)

Inputs of fine sediment that result in high TSS in streams occur during high winter flows as there is a strong relation between turbidity and discharge. Summer low flows provide data for 'background' TSS levels which is useful as turbidity criteria are given in terms of amount of TSS beyond background. Washington State standards allow for an increase of 5 NTU for domestic water supplies when background is less than 50 NTU and no more that a 10% increase when turbidity is above 50 NTUs. TSS of streams in the upper Chehalis basin is shown in **Figure 6**.

Nutrients

Nutrient inputs to streams are important as substantial inputs (eutrophication) from anthropogenic sources can result in increased algal growth which can upset the ecological balance of the stream. Likewise, loss of nutrients from human activities can reduce stream productivity. For sample reductions in anadromous salmonid populations has diverted large quantities of nutrients away from Washington and Oregon streams and rivers (WDFW, 2000).

Phosphorous

Although there are no State criteria for phosphorus, EPA recommends a limit of <0.05 mg/L for streams that deliver to lakes and suggested limit of 0.1 mg/L in streams that do not deliver to lakes (MacKenthun, 1973 in MacDonald et al., 1991). Because of the low phosphorous content, streams in the Pacific northwest region are considered naturally nutrient poor and sensitive to nutrient inputs (Welch et al., 1998). None of the streams exceed the 0.1 mg/L limit. Mean annual phosphorus concentrations in small forested streams of the west slope of the Cascades are typically <0.06 mg/L (see McDonald et al., 1991). The principal means of increase of phosphorous in Pacific northwest streams are increased erosion rates and organic matter inputs.

Nitrite-Nitrate (NO_2^- NO_3^-)

Inorganic nitrogen is the predominant form of nitrogen in lotic systems (Welch et al., 1998) and is readily assimilated by plants for growth. There is no national criteria for nitrate but concentrations of <0.3 mg/L (<300 eq/L) would probably prevent eutrophication (Cline 1973, in MacDonald et al., 1991).

Approximately 75% of the streams have <0.3 mg/L nitrite-nitrate. The usual range in non-enriched streams is 1 - 0.5 mg/L so all are within this normal range (Welch et al, 1998). Low nutrients in the form of nitrate are characteristic of forest streams. This is similar to stream monitoring results from other Coast Range Ecoregion areas (Herger and Hayslip, 2000). As with other water quality measures, amounts of nitrogen are highly dependent on flow.

Nutrient	Mean	Minimum	Maximum Value
Total Phosphorus	.04	.01	.09
Nitrite-Nitrate	.27	.01	1.24

Table 5. Nutrients in the upper Chehalis basin, expressed as mg/L

C. Physical Habitat Indicators

While there are currently no water quality criteria for physical habitat variables, they are very important for supporting designated uses and directly support the goal of the Clean Water Act. Watershed scale features (stream order, basin size, and gradient) describe the stream in the context of the overall landscape and provide context for the relationship of other physical habitat features.

In this section we describe the physical characteristics of streams at a broad scale using indicators such as channel form and related measures. We also describe the physical characteristics of streams at a finer reach scale using indicators such as substrate size and pool habitat. We focus on those indicators of greatest importance to the biota.

Channel Form

In the upper Chehalis basin, 2^{nd} order streams have a relatively small range of watershed area (mean 5,034 ac) and range of gradients (1.1 to 4.1%). Most of the channels of the upper Chehalis basin have a pool-riffle type channel (Montgomery and Buffington, 1998). In this channel type, flow converges and scours on alternating banks resulting in a laterally oscillating sequence of bars, pools, and riffles. Also the presence of large roughness elements (large woody debris, boulders, etc.) act to force the flow, thereby influencing the channel form and complexity.

The cross section of a stream channel (width and depth) provides information for evaluating total habitat space available for fish and other organisms. In the upper Chehalis basin, the mean thalweg depth (the depth along the deepest part of the stream) was 39.3 cm. Mean wetted stream width was 5.5m.

Substrate

Substrate describes the grain size of particles on the stream bottom, and ranges from rocks to mud. Stream substrate size is influenced by many factors including geology, gradient, flow and channel shape.

The following describes the characteristics of surface substrate particle size in the basin. Substrate particle size data were collected at five locations along each of the 11 evenly spaced transects at each sample site. Data were expanded to reflect the proportion of the stream channel area.

Overall, sand and fine (<0.06 mm) sized substrate was the most common (mean 32% and median 25% of the surface substrate) followed by coarse gravel (**Figure 7**). Although the fine sized substrate fraction was common, coarser substrate was more often the dominant substrate size (defined as > 50% of the streambed) in streams that had a dominant substrate type. In

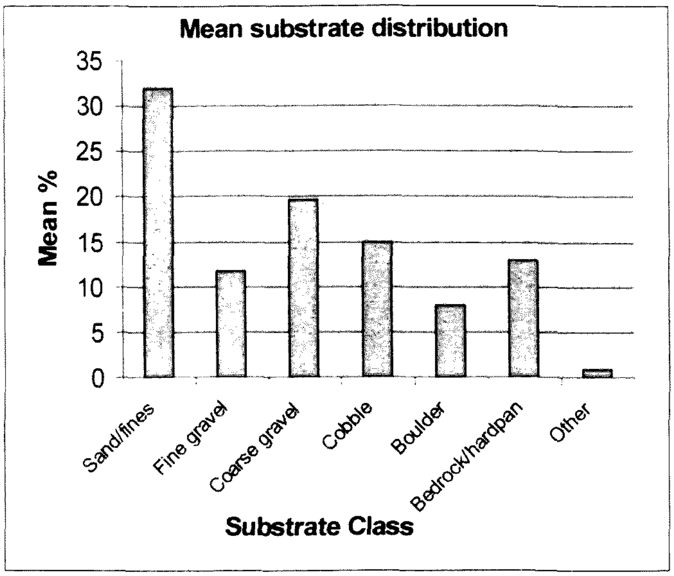

Figure 7. Bar chart of mean substrate quantity by size class in 2nd order streams.

other words fines were present in most streams, but many streams had well sorted gravel and cobble substrate. Note, many channels did not have a dominant substrate size class and no streams were boulder dominated (**Figure 8**).

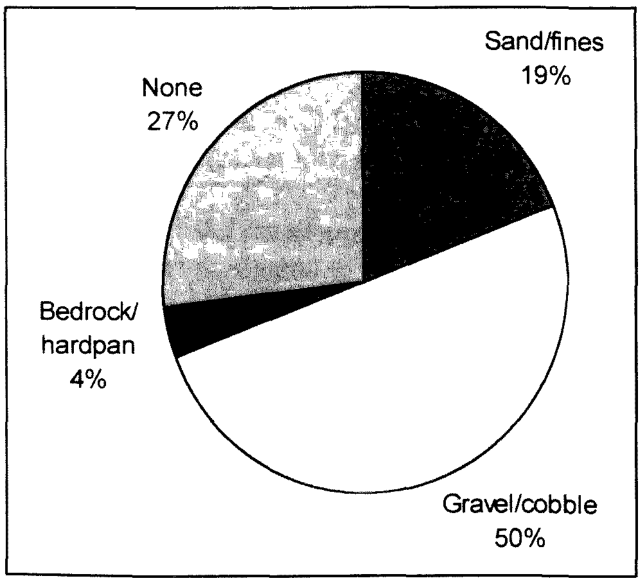

Figure 8. Pie chart of percent of streambed with dominant particle size.

Large Woody Debris (LWD)

Large woody debris (LWD), as single pieces or in accumulations (i.e. log jams), alters flow and traps sediment, thus influencing channel form and related habitat features. The quantity, type and size of LWD recruited to the channel from the riparian zone and from hillslopes is important to stream function in channels that are influenced by LWD of various sizes. Loss of LWD without a recruitment source can result in long-term alteration of channel form as well as loss of habitat complexity in the form of pools, overhead cover, flow velocity variations, and retention and sorting of spawning-sized gravels.

Field data were categorized into five size classes (very small, small, medium, large, very large) based on the following length/diameter matrix (**Table 6**).

Diameter Class (m)	Length Class (m)		
	1.5 - 5	>5 - 15	>15
0.1 - 0.3	Very Small	Small	Medium
>0.3 - 0.6	Small	Medium	Large
>0.5 - 0.8	Small	Large	Large
>0.8	Medium	Large	Very Large

Table 6. Definition of five LWD size classes based on piece length and diameter.

LWD of all sizes was generally abundant (median 22 pieces/100m and mean 32 pieces). Only 4% of the streams had no LWD. Because larger sized pieces of LWD have a greater ability to influence channel form, analyzing the medium and larger sized pieces provides a different view of the LWD content of the streams (**Figure 9**). Larger pieces, capable of influencing channel form, were rare. No very large pieces were counted and the mean large size was 3 pieces/100m, median 1 piece/100m (**Figure 10**).

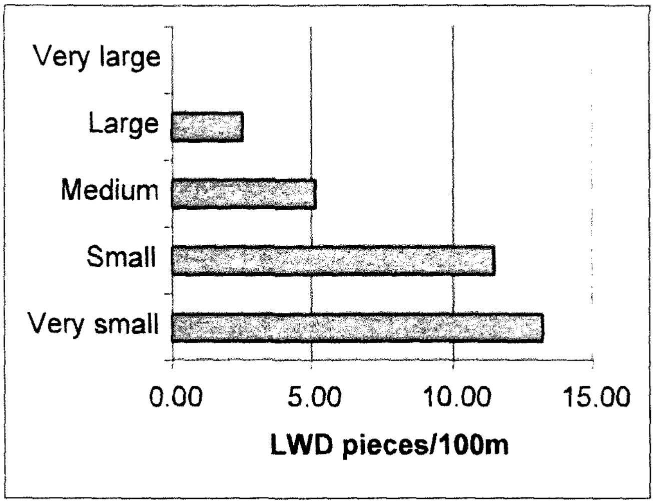

Figure 10. Mean LWD quantity (pieces per 100m) by class.

For the west side of the Cascades, the National Marine Fisheries Service (NMFS) suggests stream channels should have >80 pieces per mile (5 pieces per 100m) of LWD >24in (>60cm) diameter in order to be "properly functioning" (NMFS, 1996). Some of the streams of the basin met the NMFS criterion as the mean number of pieces in this large and very large size class averaged 2.5 pieces per 100m.

Pools

In streams, pools are areas of deeper, slower flowing water that are important habitat features for fish. The abundance of pools and their size and depth depends on the stream's power and channel complexity. Stream size, substrate size and abundance, and larger roughness element (e.g. LWD) availability all contribute to the frequency and quality of pools. Although the pool frequency is fairly high in the upper Chehalis basin (mean 1 pool per 2 channel widths of stream length), most of the pools are shallow, with mean pool depth of 24 cm (see **Figure 11**). Therefore, the deep pools useable by salmon were rare.

Fish Cover

Many structural components of streams are used by fish as concealment from predators and as hydraulic refugia (e.g. bank undercuts, LWD, boulders). Although this metric is defined by fish use, fish cover is also indicative of the overall complexity of the channel which is likely to be beneficial to other organisms. Using the metric of natural fish cover (includes overhanging vegetation, undercut banks, LWD, brush, and boulders), the mean areal cover proportion of 0.37 was estimated for the basin as shown in **Figure 12**. Using quartiles to define low, medium, high and very high, most streams are in the moderate range of natural fish cover. Few have very high amount of fish cover.

Riparian Vegetation

Riparian (stream bank) vegetation is important for several reasons:

- influences channel form and bank stability through root strength;
- source of recruitment for LWD that influences channel complexity and provide cover for fish;
- provides inputs of organic matter such as leaves, and shades the stream which influences water temperature.

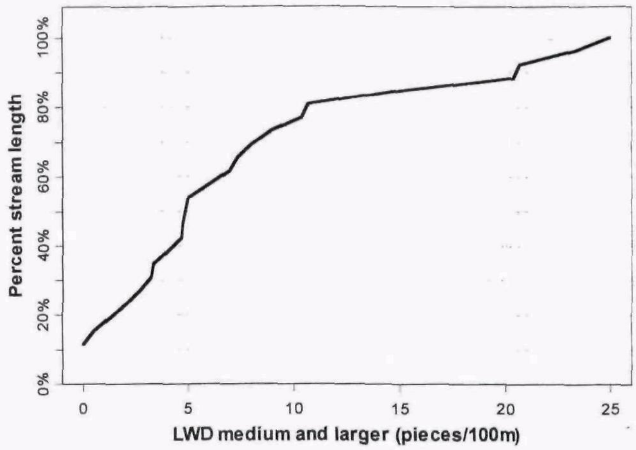

Figure 9. Large Woody Debris (LWD) quantity for The Medium and larger categories expressed as pieces per 100m.

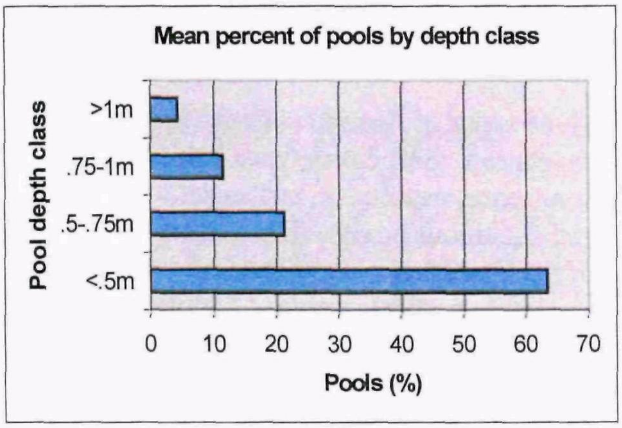

Figure 11. Frequency of pools by depth class.

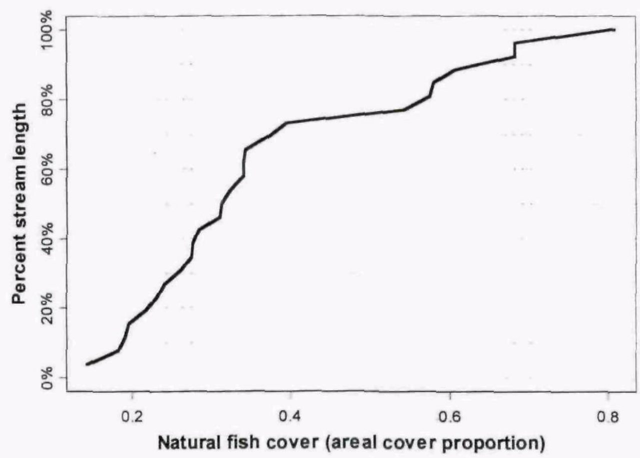

Figure 12. Natural fish cover (undercut banks, overhanging vegegation, LWD, brush and boulders)

Expressed as a proportion of the reach, riparian cover data were collected for three vegetation heights:

1. Canopy	-	>5m
2. Mid level	-	.5m to 5 m
3. Ground cover	-	<.5m

Visual estimates of cover density and general structural/species vegetation classes (e.g. coniferous, deciduous) of each layer were recorded. Overall, riparian vegetation was dense and most streams had abundant riparian vegetation (**Figure 13**). The proportion of streams with riparian coverage was approximately 100% for most streams (mean 92%).

Three types of riparian canopy (riparian vegetation >5m) cover types were considered, coniferous, deciduous, and mixed coniferous and deciduous cover. The riparian tree canopy of most streams is composed of deciduous species (e.g. alder, maple). Coniferous riparian canopy was generally rare (**Figure 14**).

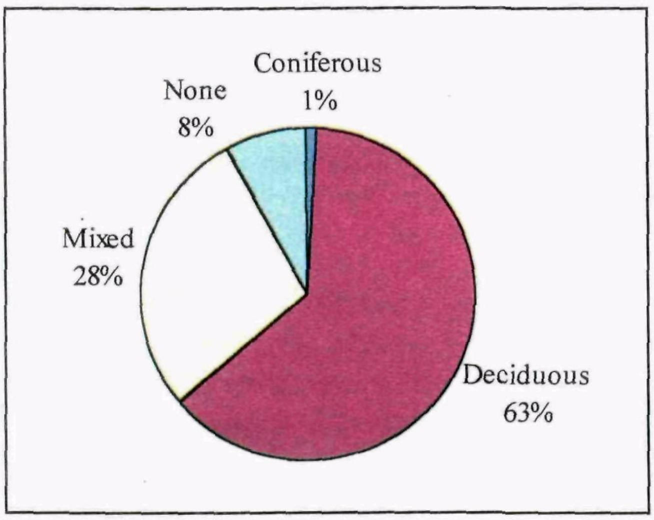

Figure 14. Pie chart of the mean percent riparian canopy cover by species types in second order streams of the upper Chehalis.

In addition to riparian vegetation presence, stream shading from riparian canopy was assessed using densiometer readings at each of the 11 transects. Separate calculations from the bank and mid-channel were made. Overall, shade was high with mean bank shading of 91% and mean mid-channel shade of 77% (see **Figure 15**).

Riparian Disturbance Indicators

Removal or alteration of riparian vegetation reduces habitat quality and can result in negative effects to the stream biota. Riparian disturbance data were collected by examining the channel, bank and riparian area on both sides of the stream at each of the 11 transects and visually estimating the presence and proximity of disturbance (Hayslip et al., 1994). Eleven different categories of disturbance were evaluated. Each disturbance category is assigned a value based on its presence and proximity to the stream (1.67, in channel or on bank; 1.0, within 10m of stream; 0.67, beyond 10m from stream;, and 0, not present).

All types of disturbance were observed in the riparian zones of the upper Chehalis streams. Some, such as row crops, mining, and pipes, were very rare both in overall mean and frequency of occurrence (number of sites). The most common form of riparian disturbance was logging (31%), followed by pasture (25%) and roads (21%) (**Figure 16**).

Data were expanded to calculate a proximity-weight disturbance index for each reach (Kaufmann et al., 1999). This index combines the extent of disturbance (based on presence or absence) as well as the proximity of the disturbance to the stream. Categories of disturbance were defined using quartile ranges of the data (**Table 7**).

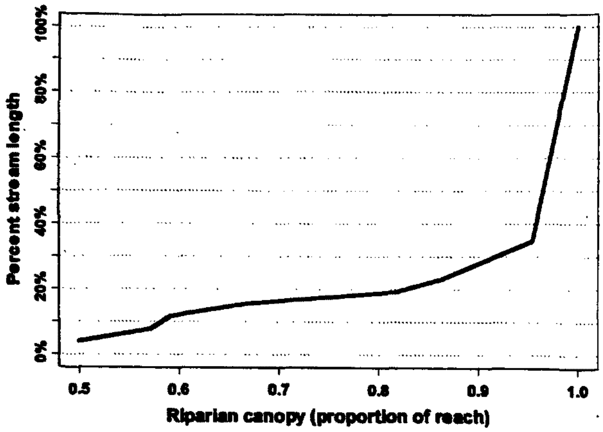

Figure 13. Riparian vegetation cover (both canopy and mid layer

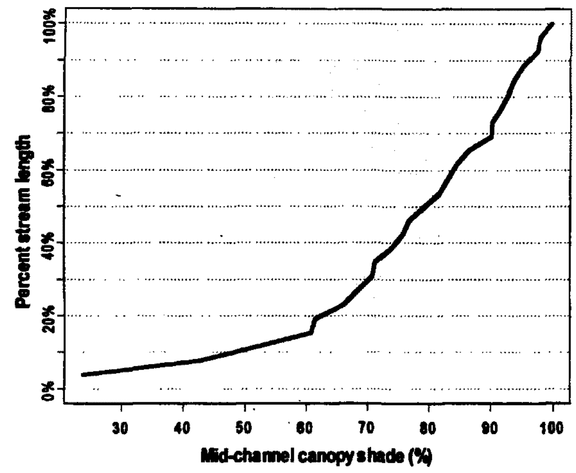

Figure 15. Mid-channel shade

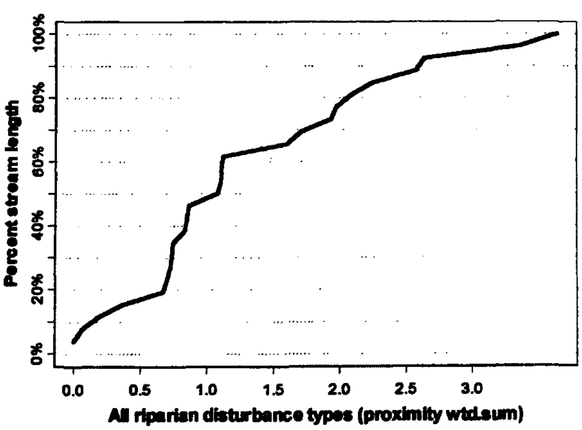

Figure 17. All riparian disturbance all types

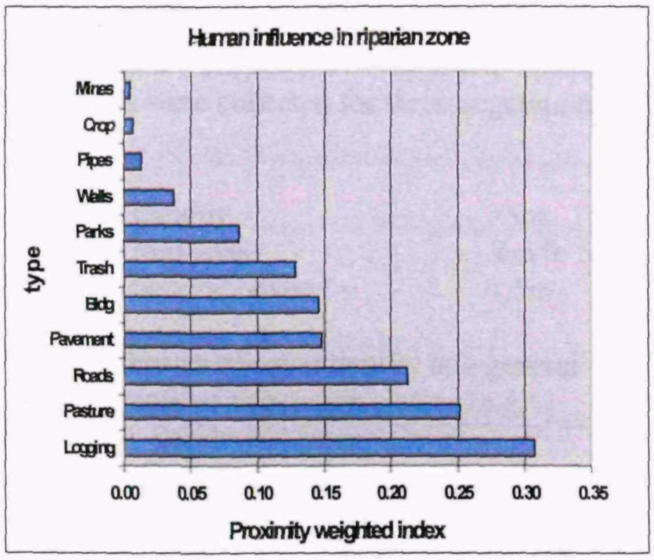

Figure 16. Mean riparian zone human influence from each of 10 disturbance categories.

Data Range	Level of Human Influence
0 - .4	Low
> .4 - .8	Medium
> .8 - 1.2	High
> 1.2	Very High

Table 7. Levels of human influence

Generally the level of human influence is low (<0.4) for the separate categories based on mean values (see Appendix 3). However, when all disturbance categories are accounted for, most sites have a high level of human influence (mean 1.34 and median 1.1) **(Figure 17)**. Approximately 40% of the stream km have very high evidence of human influence when all sources were combined.

D. Biological Indicators

Fish and Amphibian Resources

Fish were sampled at all sites and amphibians were observed in 42% of stream km. A total of 20 different species were sampled, representing 15 fish species and 5 amphibian species. Fish species are listed in **Figure 18** and the relevant statistics are in **Table 8**.

Statistic	# of Sites	% of Stream Length	Comment
Sites with Fish	26	100	15 species
Sites with salmonids	26	100	
Sites with Amphibians	11	42	5 species
Sites with non-native fish	1	4	Pumpkinseed
Sites with non-native amphibians	1	4	Bull frog
Sites with non-native vertebrates	2	8	

Table 8. Frequency of occurrence of aquatic vertebrates, upper Chehalis 2nd order streams, 1997.

Non-native species were rare in the basin's 2nd order streams. Only 1 non-native fish species (pumpkinseed) was sampled at one site, representing 4% of the stream km. In addition, only one non-native amphibian (bull frog) was sampled at one site. Although non-native species were rare, this study does not assess the presence/abundance of hatchery fish.

The Salmonidae family, which includes trout and salmon, was the most broadly distributed vertebrate family in the basin, followed by the Cottidae family (sculpins). Coho salmon and coastal cutthroat trout were the most broadly distributed salmonid species (see **Figure 18).**

Coho salmon occur along the Pacific coast from northern California to Alaska (Wydoski and Whitney, 1979). This anadromous fish spawns and juveniles rear in freshwater from 1 to 2 years before migrating to the ocean. Coho are an important commercial and popular sport fish and are one of the more commonly found salmonids in Western Washington.

Coastal cutthroat trout are the only cutthroat sub-species that is native to the west coast of North America from northern California to southeast Alaska (Wydoski and Whitney, 1979). Coastal cutthroat trout use a variety of habitats, including large and small rivers, very small, ocean-connected, streams and isolated stream reaches above migration barriers. Often, coastal cutthroat trout are the only salmonid species present in high elevation streams (Connelly and Hall, 1999). This species has a variety of life history strategies with anadromous, fluvial and resident forms as well as intermediates (Trotter, 1989). Currently, coastal cutthroat trout are proposed as a threatened species under the Endangered Species Act for Washington State.

The dominant sculpin (cottid) species are the reticulate and riffle sculpin, both of which are native to coastal streams of Washington and Oregon north to the Puget Sound with disjunct distribution in central and northern California (Lee et al., 1980). We grouped these two species together as they were often indistinguishable from one another.

Several native fish were found rarely (<5% of the estimated stream miles). These were the redside shiner, longnose dace and the northern pikeminnow.

Fish Guild descriptions:

It is useful to group fish by how sensitive they are to pollution and other human disturbances. Also, fish can be grouped by their temperature preferences. These groups are called guilds. The fish guild classification that we use in this report is based on Zaroban et al. (1999). The following classifications are used to build indices of biological integrity (IBIs) but they are also useful for providing an overview of the species within the ecoregion:

Temperature guilds - 3 classifications; warm, cool, and cold water preference.

Sensitivity guilds – tolerant, intermediate, and sensitive are classifications based on species ability to tolerate pollution and disturbance that is human induced.

Most upper Chehalis basin vertebrates are cool and coldwater species and are of intermediate sensitivity to human disturbance (see **Figures 19 and 20**, respectively).

Benthic invertebrates

Benthic macroinvertebrate assemblages reflect overall biological integrity of the stream and monitoring these assemblages is useful in assessing the current status of the water body as well as long-term changes (Plafkin et al., 1989). Benthic invertebrate data collected from riffle habitats were available from all sample reaches. The following four metrics were used in the analysis: taxa richness, EPT taxa richness, intolerant taxa richness and percent EPT. See **Table 9** for a more in depth description of each metric.

The metric "taxa richness" gives an overall indication of the variability of macroinvertebrate communities in the upper Chehalis basin (**Figure 21**). The total number of taxa ranges from 5 to 60 species.

In an assessment of Oregon Coast Range Ecoregion streams, Canale (1999) found critical levels of total taxa richness of less 30 taxa and EPT taxa richness of less than 18 taxa as indicative of impaired stream condition based on analyses developed from Oregon reference sites. In an assessment of Puget Lowland Ecoregion streams in the King County area (Karr and Chu,1999), EPT taxa richness of less

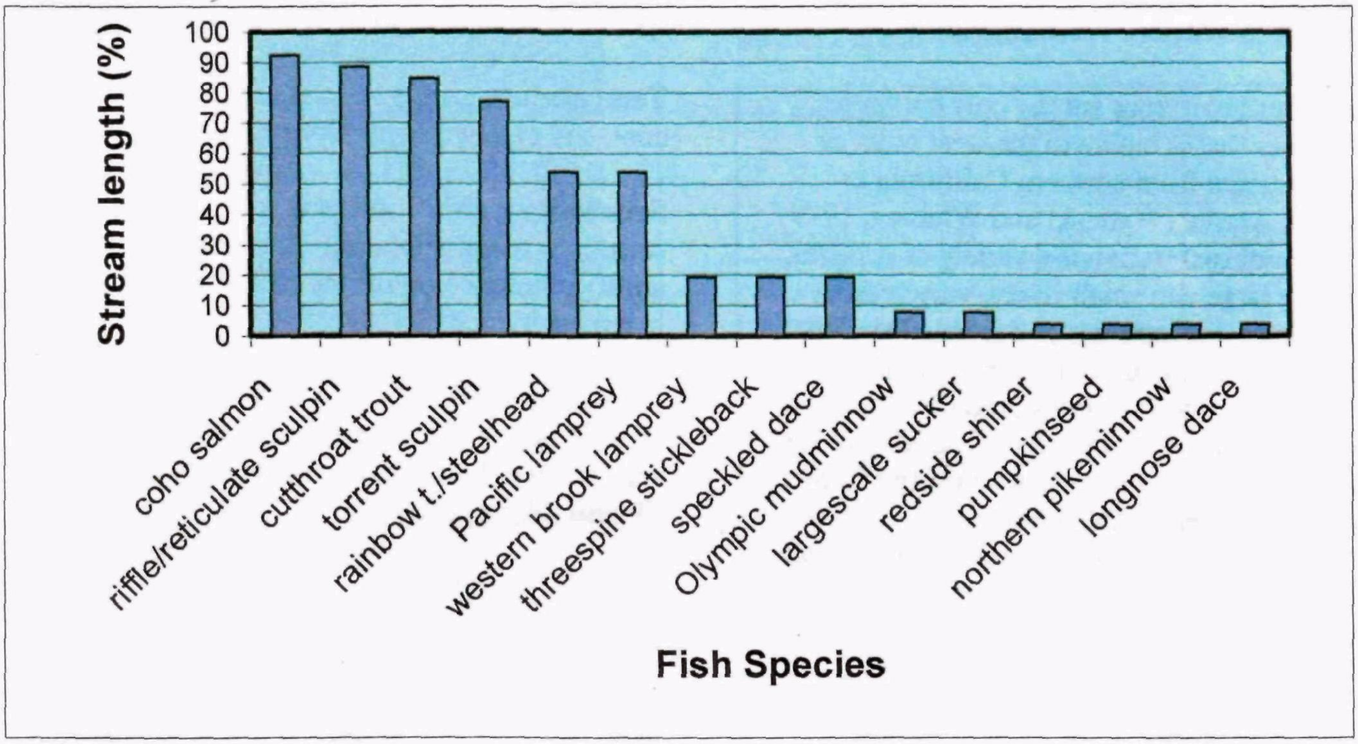

Figure 18. Fish Species found in the upper Chehalis basin, 2nd order streams, 1997.

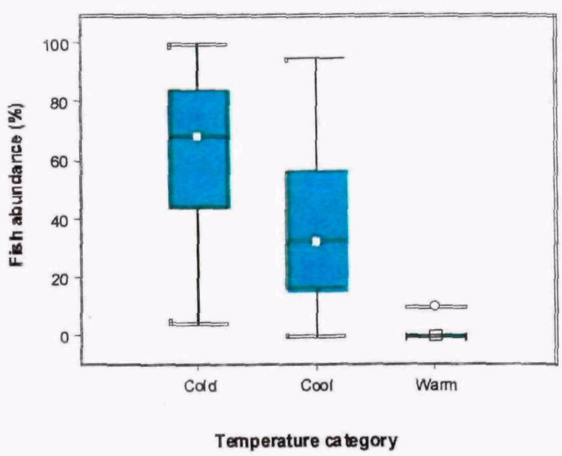

Figure 19. Percent of vertebrate species within each temperature guild. Median, 75-25% quartiles, and non-outlier min-max, shown with inner box, and bars.

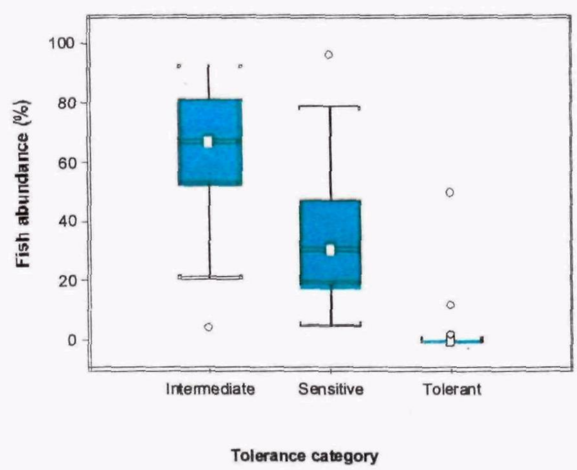

Figure 20. Percent of vertebrate species within each sensitivity guild. Median, 75-25% quartiles, and non-outlier min-max, shown with inner box, and bars

than 15 taxa was found to be indicative of an impaired condition based on reference sites from the Puget Lowlands Ecoregion.

In the upper Chehalis, approximately 90% of stream km had <30 taxa richness (**Figure 21**) and approximately 32% had <18 EPT taxa (**Figure 22**).

Metric	Description	Rationale
Taxa richness	The total number of different taxa describes the overall variety of the macroinvertebrate assemblage. Useful measure of diversity or variety of the assemblage.	Decreases with low water quality associated with increasing human influence. Sensitive to most types of human disturbance.
EPT taxa richness	Number of taxa in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddis flies).	In general, these taxa are sensitive to human disturbance.
Percent EPT	Percent of the total sample organisms that are Ephemeroptera, Plecoptera and Trichoptera.	A composite measure for identity and dominance.
Intolerant taxa richness	Taxa richness of those organisms considered to be sensitive to. perturbation	Taxa that are intolerant to pollution based on classification from Wisseman, 1996.

Table 9. Description of benthic macroinvertebrate indicator metrics (Resh and Jackson ,1993 and Resh, 1995).

As with fish, invertebrates can be grouped by their sensitivity to pollution. **Figure 23** shows the total number of taxa (taxa richness) of those organisms considered to be sensitive to pollution.

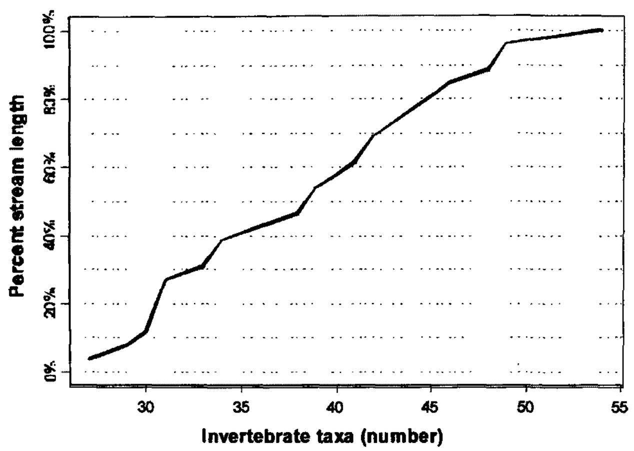

Figure 21. Total invertebrate taxa richness

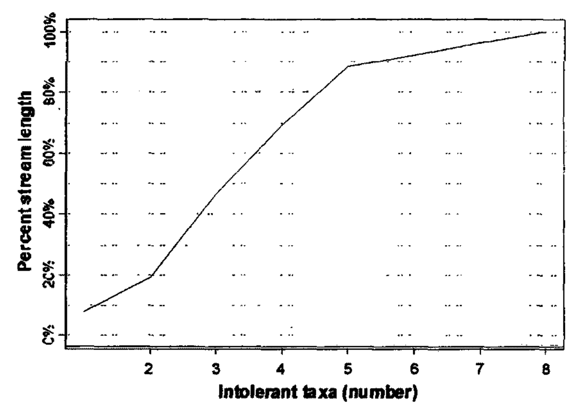

Figure 23. Intolerant taxa richness

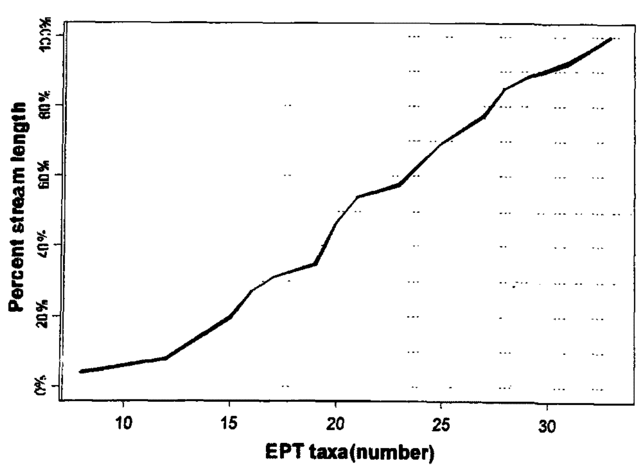

Figure 22. EPT taxa richness

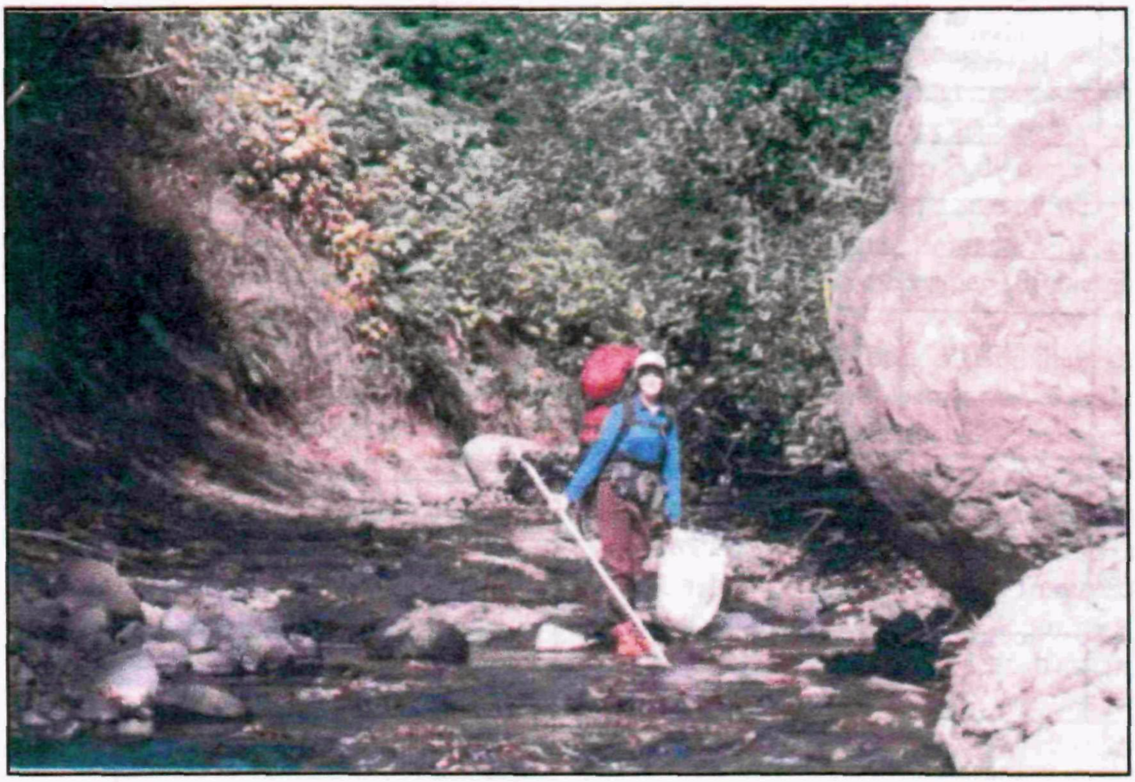

Photo: Sage Creek, Upper Chehalis basin. (Source: Washington Department of Ecology)

IV. DISCUSSION

In the upper Chehalis basin the primary land cover type is forest (81%). Much of this forested land is currently being actively managed, or has been harvested at some point in the past. The second largest land cover type in the basin is agriculture (11%). We found that 40% of the stream miles had very high evidence of human influence in the riparian area (when all sources of human influence were combined). The largest sources of human influence in the riparian areas were logging, pasture and roads.

The R-EMAP project was designed to evaluate the overall condition of the basin. The data provides a large base of information, which while not necessarily designed to investigate specific activities, can be used to assess human influence on streams in the upper Chehalis basin.

When examining the effect of human influences on aquatic ecosystems, it is often difficult to decide which indicators to examine. In the upper Chehalis basin, the major land cover type and the largest source of human influence in the riparian area is forestry. Therefore, we will evaluate some indicators that have been suggested to be sensitive to forestry in the northwest (McDonald et al., 1991). In **Table 10**, indicators are ranked according to their sensitivity to forest activities as follows:

1	=	directly affected and highly sensitive
2	=	moderately affected and somewhat sensitive
3	=	indirectly affected and not very sensitive
4	=	largely unaffected

Parameter	Forest Harvest	Road building and maintenance
pH	3	3
Nitrogen	2	3
Phosphorus	2	3
Temperature	1-2	3
Canopy opening	1-3	2
LWD	1	4
Riparian vegetation	1-3	3
Pool Parameters	2	1
Macro invertebrates	1	1

Table 10. Sensitivity of selected monitoring parameters to forest management activities, assuming average management practices (from McDonald et al., 1991).

In the following discussion and in **Table 11**, the results from the upper Chehalis basin are compared to what we would expect based on examining indicators that are sensitive to forest management activities. Note, that we are only evaluating some of the indicators measured by the R-EMAP study.

Water Column Chemistry

The available data indicates that pH is not sensitive to most forest management activities (McDonald et al., 1991). In the upper Chehalis basin, we found only 2% of the stream miles were above the Washington State pH criteria.

Forest management activities can alter many parts of the nitrogen cycle, and this makes it difficult to generalize about the effect of these activities. In the upper Chehalis basin, 75% of the streams have < .03 mg/L nitrite-nitrate (a suggested level to prevent eutrophication). All streams in the upper Chehalis basin fall within the usual range found in non-enriched streams which is 1.5 mg/L (Welch et al, 1998).

Parameter	Expected direction of response to Forest Management activities	Direction of response found in Upper Chehalis
pH	–	–
Nitrogen	–	–
Phosphorus	–	–
Temperature	↑	–
Canopy opening	↑	–
LWD	↓	↓
Deciduous Riparian Vegetation	↑	↑
Pool Depth	↓	↓
Pool Frequency	–	–
Macro invertebrate (EPT taxa richness)	↓	↓

Table 11. Expected direction of response for selected monitoring parameters to forest management activities compared to what was found in the upper Chehalis basin.

Studies in the Pacific northwest indicate that forest management activities are unlikely to substantially increase phosphate concentrations on aquatic ecosystems (McDonald et al., 1991).

In the second order streams of the upper Chehalis basin we found no streams had phosphorus above .1 mg/L (a suggested level).

Forest cover provides shade to streams and a reduction in the forest cover along streams can increase the solar radiation and hence peak summer stream temperatures. In this project, using a single measurement, we found no streams that were above the Washington State criteria of 18°C. This is not unexpected as stream temperature is variable and dependent on climatic conditions. Using a single measurement, it is unlikely to represent peak stream temperatures.

Physical Habitat

The primary influence of management activities on the riparian areas is the direct removal of vegetation. The removal of the riparian canopy, by increasing direct solar radiation to the stream, can cause marked increases in water temperature. Both coniferous and deciduous species are effective in stream shading.

In the upper Chehalis basin, the amount of shade was high, 91% of the stream miles were classified as shaded when shade was measured near the streambank. When measured in the middle of the stream, 77% of the stream miles were shaded. Therefore, decreased bank stability and increased solar radiation from riparian vegetation removal would not appear to be a widespread problem.

Although the riparian canopy provides adequate shade to these streams, these trees are mostly deciduous. Conifierous trees, which provide much greater structural function in streams due to their size, were a much less common component of the riparian vegetation.

The amount of LWD in streams of the Pacific northwest has been reduced from historical levels by forest management activities. No streams in the upper Chehalis basin had very large pieces (> 0.8 m in diameter) of LWD. The mean number of large sized LWD (.8 m - >.5 m) was 2.5 pieces per 100 meters of stream. NMFS recommends 5 pieces per 100 meters of stream.

The abundance of pools and their size and depth depends on the stream's power and channel complexity. Stream size, substrate size and abundance, and larger roughness element (e.g. LWD) availability all contribute to the frequency and quality of pools. In the upper Chehalis, while pools were frequent, they were also quite shallow (mean depth 25cm), with 63% of the pools in the less than .5m depth category.

Aquatic Biota

Benthic macroinvertebrates reflect the overall biological integrity of streams. The number of mayfly, stonefly and caddisfly taxa (EPT taxa richness) is one of the most commonly used measures of the invertebrate community. EPT taxa richness was found to decrease with increasing forest management activities in the Umpqua National Forest in Oregon (Fore et al., 1996). In an assessment of Oregon Coast Range streams, Canale (1999) found a EPT taxa richness of 18 and below as indicative of impaired stream condition based on analyses developed from Oregon reference sites. In the upper Chehalis basin, approximately 32% of the stream miles had less than 18 EPT taxa.

SUMMARY

The objective of this R-EMAP project was to evaluate the condition of 2nd order streams in the upper Chehalis basin. The primary human activity in the upper Chehalis basin is forest management. We found little evidence of acute or severe impairment, as might be expected from the relatively low level of industrial development in the basin. However, we did find evidence of nonpoint source impairment.

In general, the parameters we measured in the upper Chehalis basin R-EMAP study responded as we would have expected them to respond to forest management activities. The exception to this was temperature, which was largely due to our measurement method. However, LWD and pool depth were low and deciduous riparian vegetation was increased as would be expected to result from forest management. Sensitive macroinvertebrate taxa were also low.

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VI. APPENDICES

Appendix 1. List of sites with associated stream identification number.

Map #	Site ID	Latitude	Longitude	T_R_S	COUNTY	7.5 Quad. Map
5	WACH97-005	46.7552583333	123.096347222	T15N-R3W-S29	LEWIS	Rochester
6	WACH97-006	46.4733027778	123.171486111	T11N-R4W-S3	LEWIS	Boistfort Peak
10	WACH97-010	46.496575	123.282072222	T12N-R5W-S27	LEWIS	Elochoman Pass
14	WACH97-014	46.5690722222	123.29545	T13N-R5W-S34	LEWIS	Pe Ell
15	WACH97-015	46.7624305556	123.315294444	T15N-R5W-S28	LEWIS	Cedarville
17	WACH97-017	46.6101416667	122.619944444	T13N-R1E-S13	LEWIS	Mayfield Lake
19	WACH97-019	46.6556027778	123.263708333	T14N-R5W-S35	LEWIS	Doty
22	WACH97-022	46.9599888889	123.081538889	T17N-R3W-S17	THURSTON	Little Rock
25	WACH97-025	46.8167611111	122.769194444	T15N-R1W-S2	THURSTON	Bucoda
28	WACH97-028	46.7093527778	123.19475	T14N-R4W-S9	LEWIS	Rainbow Falls
29	WACH97-029	46.8979138889	123.018972222	T16N-R3W-S2	THURSTON	Little Rock
30	WACH97-030	46.4486111111	123.338511111	T11N-R5W-S7	LEWIS	Elochoman Pass
33	WACH97-033	46.9144055556	123.050716667	T17N-R3W-S34	THURSTON	Little Rock
37	WACH97-037	46.9890388889	123.22595	T17N-R4W-S6	GRAYS HARBOR	Capitol Peak
39	WACH97-039	46.57415	122.972430556	T13N-R2W-S31	LEWIS	Napavine
41	WACH97-041	46.6816944444	122.734955556	T14N-R1E-S19	LEWIS	Onalaska NW
42	WACH97-042	46.3705055556	123.151405556	T10N-R4W-S11	COWLITZ	Elochoman Lake
43	WACH97-043	46.9450805556	123.161516667	T17N-R4W-S22	GRAYS HARBOR	Capitol Peak
45	WACH97-045	46.870325	122.816219444	T16N-R1W-S16	THURSTON	Bucoda
58	WACH97-048	46.6334638889	123.193097222	T13N-R4W-S9	LEWIS	Rainbow Falls
50	WACH97-050	46.9890722222	123.204141667	T17N-R4W-S5	GRAYS HARBOR	Capitol Peak
53	WACH97-053	46.8717694444	123.146186111	T16N-R4W-S14	THURSTON	Oakville
54	WACH97-054	46.406475	123.108716667	T11N-R3W-S30	LEWIS	Wildwood
56	WACH97-056	46.7366638889	123.269391667	T14N-R5W-S2	LEWIS	Doty
58	WACH97-058	46.7047277778	123.117238889	T14N-R3W-S18	LEWIS	Adna
59	WACH97-059	46.5203138889	123.161822222	T12N-R4W-S15	LEWIS	Boistfort

Appendix 2. Summary statistics for water chemistry indicators.

Indicator	Units	n	Mean	95% Conf.	Median	Min.	Max.	Range	Variance	Standard Deviation	Standard Error
Alkalinity	mg/L	26	30.0	4.0	29.3	17.1	55.4	38.3	100.301	10.015	1.964
Chloride (Cl-)	mg/L	26	4.45	1.10	3.49	1.91	12.2	10.29	7.451	2.730	0.535
Conductivity	uS/cm	25	73.0	10.2	68.8	43.5	142.4	98.9	605.708	24.611	4.922
Dissolved oxygen (DO)	mg/L	26	12.4	0.8	12.2	8.6	15.7	7.1	4.339	2.083	0.409
Dissolved organic carbon (DOC)	mg/L	26	3.0	0.6	2.4	1.1	7.9	6.8	2.367	1.539	0.302
Ammonia (NH_3_N)	mg/L	26	0.01	0.00	0.01	0.01	0.02	0.01	0.000	0.003	0.001
Nitrate-nitrite (NO_{23}_N)	mg/L	26	0.27	0.10	0.20	0.01	1.24	1.23	0.063	0.250	0.049
pH	pH units	26	7.56	0.16	7.54	6.76	8.67	1.91	0.164	0.404	0.079
Total phosphorus	mg/L	26	0.04	0.01	0.04	0.01	0.09	0.08	0.001	0.025	0.005
Sulfate (SO_4)	mg/L	26	1.90	0.50	1.76	0.31	4.26	3.95	1.563	1.250	0.245
Total persulfate nitrogen	mg/L	26	0.46	0.14	0.38	0.15	1.54	1.39	0.112	0.335	0.066
Stream flow	CFS	26	4.82	2.21	3.64	0.04	21.64	21.6	29.986	5.476	1.074
Water temperature	deg C	26	14.1	0.7	14.4	10.7	18	7.3	2.831	1.683	0.330
Total suspended solids	mg/L	26	4	1	3	1	13	12	12.215	3.495	0.685

AlK, DOC, Cl each had one estimated value.
SO_4,NO_{23}_N, NH_3_N, and TSS had 3,1,20, and 4 undectable readings.

Appendix 3. Summary statistics for physical habitat metrics

type	Indicator	units	Indicator	Mean	95% Conf.	Median	Min.	Max.	Range	Variance	Standard Deviation	Standard Error
channel	reach length / mean bankfull width	count	#ch_widths	23.8	3.234	22.9	11.0	39.5	28.5	64.105	8.007	1.570
channel	mean undercut bank distance	m	XUN	0.0	0.016	0.1	0.0	0.1	0.1	0.002	0.039	0.008
channel	mean bankfull width	m	XBKF_W	9.3	1.630	9.3	3.8	19.2	15.4	16.276	4.034	0.791
channel	mean bankfull height	m	XBKF_H	0.7	0.089	0.7	0.3	1.4	1.1	0.048	0.219	0.043
channel	reach length	m	REACHLEN	200.4	28.250	150.0	150.0	360.0	210.0	4891.846	69.942	13.717
channel	mean water slope of reach	%	XSLOPE	1.5	0.533	1.1	0.0	4.1	4.1	1.743	1.320	0.259
channel	sinuosity	unitless	SINU	1.3	0.112	1.2	1.0	2.4	1.4	0.076	0.277	0.054
channel	mean thalweg depth	cm	XDEPTH	39.3	5.426	42.6	17.2	64.5	47.2	180.437	13.433	2.634
channel	std. dev. thalweg depth	cm	SDDEPTH	22.8	3.698	23.1	8.9	49.2	40.3	83.826	9.156	1.796
channel	mean wetted width	m	XWIDTH	5.5	0.929	5.2	1.5	11.6	10.1	5.290	2.300	0.451
channel	wetted width/depth	unitless	XWD_RAT	20.7	3.196	21.1	5.5	35.2	29.7	62.624	7.914	1.552
channel	% reach with glides	%	PCT_GL	53.2	9.805	46.3	20.7	100.0	79.3	589.259	24.275	4.761
channel	% reach with riffles	%	PCT_RI	29.7	6.962	31.5	0.0	64.0	64.0	297.071	17.236	3.380
channel	% reach with falls	%	PCT_FA	0.1	0.105	0.0	0.0	1.0	1.0	0.067	0.259	0.051
channel	% reach with rapids	%	PCT_RA	5.9	3.656	1.3	0.0	29.0	29.0	81.952	9.053	1.775
channel	% reach with cascades	%	PCT_CA	0.3	0.313	0.0	0.0	3.3	3.3	0.602	0.776	0.152
channel	% reach with fast water types	%	PCT_FAST	36.0	8.968	38.5	0.0	70.0	70.0	492.954	22.203	4.354
channel	% reach with slow water types	%	PCT_SLOW	64.0	8.968	61.5	30.0	100.0	70.0	492.954	22.203	4.354
channel	% reach with pools	%	PCT_POOL	10.7	4.505	8.8	0.0	40.0	40.0	124.391	11.153	2.187
channel	% reach with dry/submerged flow	%	PCT_DRS	0.0	0.000	0.0	0.0	0.0	0.0	0.000	0.000	0.000
channel	#ch widths/#residual pools	unitless	pool_freq	2.1	0.486	1.9	0.5	4.9	4.5	1.451	1.204	0.236
cover	area covered by all types but algae	frac	XFC_ALL	0.4	0.075	0.3	0.1	0.8	0.7	0.034	0.184	0.036
cover	area covered by natural. obj.	frac	XFC_NAT	0.4	0.073	0.3	0.1	0.8	0.7	0.033	0.181	0.035
cover	area covered by large obj.	frac	XFC_BIG	0.2	0.051	0.2	0.0	0.5	0.5	0.016	0.126	0.025
lwd	volume LWD class 1	m3/m2	V1W_MSQ	0.0	0.021	0.0	0.0	0.2	0.2	0.003	0.053	0.010
lwd	volume LWD class 2	m3/m2	V2W_MSQ	0.0	0.021	0.0	0.0	0.2	0.2	0.003	0.051	0.010
lwd	volume LWD class 3	m3/m2	V3W_MSQ	0.0	0.017	0.0	0.0	0.1	0.1	0.002	0.041	0.008
lwd	volume LWD class 4	m3/m2	V4W_MSQ	0.0	0.011	0.0	0.0	0.1	0.1	0.001	0.027	0.005
lwd	volume LWD class 5	m3/m2	V5W_MSQ	0.0	0.000	0.0	0.0	0.0	0.0	0.000	0.000	0.000

type	Indicator	units	Indicator	Mean	95% Conf.	Median	Min.	Max.	Range	Variance	Standard Deviation	Standard Error
lwd	count LWD class 1	#/100m	C1WM100	32.3	12.359	22.2	0.0	124.0	124.0	936.231	30.598	6.001
lwd	count LWD class 2	#/100m	C2WM100	19.1	6.944	12.7	0.0	63.3	63.3	295.604	17.193	3.372
lwd	count LWD class 3	#/100m	C3WM100	7.7	2.979	5.0	0.0	25.0	25.0	54.397	7.375	1.446
lwd	count LWD class 4	#/100m	C4WM100	2.5	1.095	1.5	0.0	10.0	10.0	7.349	2.711	0.532
lwd	count LWD class 5	#/100m	C5WM100	0.0	0.000	0.0	0.0	0.0	0.0	0.000	0.000	0.000
pool	number of residual pools	count	NRP	13.7	2.602	12.5	5.0	31.0	26.0	41.502	6.442	1.263
pool	number of pools depth> 50 cm	count	RPGT50	2.5	0.706	2.0	0.0	6.0	6.0	3.058	1.749	0.343
pool	number of pools depth> 75 cm	count	RPGT75	1.3	0.465	1.0	0.0	3.0	3.0	1.325	1.151	0.226
pool	number of pools depth> 100 cm	count	RPGT100	0.5	0.261	0.0	0.0	2.0	2.0	0.418	0.647	0.127
pool	max res. depth of deepest pool	cm	RPMDEP	100.6	25.929	89.8	37.3	360.8	323.5	4121.087	64.196	12.590
pool	vert. profile of largest res. pool	m2	RPMAREA	18.2	5.436	14.7	1.8	49.7	47.9	181.150	13.459	2.640
pool	max. pool volume	m3	RPMVOL	42.9	17.212	26.1	2.5	153.8	151.4	1815.868	42.613	8.357
pool	mean res. pool width	m	RPXWID	2.5	0.413	2.4	0.9	5.2	4.2	1.048	1.024	0.201
pool	mean res. pool depth	cm	RPXDEP	24.2	4.034	24.6	9.1	46.6	37.5	99.738	9.987	1.959
pool	mean pool length	m	RPXLEN	14.9	3.273	14.7	3.1	31.0	27.9	65.667	8.104	1.589
pool	mean res. pool area	m2	RPXAREA	4.1	1.223	3.4	0.4	9.9	9.6	9.174	3.029	0.594
pool	mean pool volume	m3	RPXVOL	8.3	3.271	5.7	0.4	33.5	33.1	65.602	8.100	1.588
human	all human dist. (prox. wtd. sum)	frac	W1_HALL	1.3	0.392	1.1	0.0	3.7	3.7	0.941	0.970	0.190
human	non-agric. human dist. (prox. wtd sum)	frac	W1_HNOAG	1.1	0.314	0.9	0.0	3.1	3.1	0.605	0.778	0.153
human	agric. human dist. (prox. wtd. sum)	frac	W1_HAG	0.3	0.174	0.0	0.0	1.5	1.5	0.186	0.431	0.085
human	channel revetment (prox. wtd. index)	frac	W1H_WALL	0.0	0.032	0.0	0.0	0.3	0.3	0.006	0.080	0.016
human	logging dist.(prox. wtd. index)	frac	W1H_LOG	0.3	0.120	0.3	0.0	0.8	0.8	0.089	0.298	0.058
human	road (prox. wtd. index)	frac	W1H_ROAD	0.2		0.3	0.0	0.6	0.6	0.031	0.177	0.035
human	pipes (prox. wtd. index)	frac	W1H_PIPE	0.0		0.0	0.0	0.2	0.2	0.001	0.036	0.007
human	landfill/trash (prox. wtd. index)	frac	W1H_LDFL	0.1		0.0	0.0	1.0	1.0	0.057	0.240	0.047
human	park (prox. wtd. index)	frac	W1H_PARK	0.1		0.0	0.0	0.7	0.7	0.047	0.216	0.042
human	row crops (prox. wtd. index)	frac	W1H_CROP	0.0		0.0	0.0	0.2	0.2	0.001	0.033	0.006
human	pasture (prox. wtd. index)	frac	W1H_PSTR	0.3		0.0	0.0	1.5	1.5	0.183	0.428	0.084
human	mines (prox. wtd. index)	frac	W1H_MINE	0.0		0.0	0.0	0.1	0.1	0.000	0.014	0.003
human	buildings (prox. wtd. index)	frac	W1H_BLDG	0.1		0.0	0.0	0.7	0.7	0.057	0.239	0.047
human	pavement (prox. wtd. index)	frac	W1H_PVMT	0.1		0.0	0.0	0.7	0.7	0.055	0.235	0.046

type	Indicator	units	Indicator	Mean	95% Conf.	Median	Min.	Max.	Range	Variance	Standard Deviation	Standard Error
Riparian	frac of reach with canopy	frac	XPCAN	0.9	0.062	1.0	0.5	1.0	0.5	0.024	0.154	0.030
Riparian	frac of reach with understory	frac	XPMID	1.0	0.005	1.0	1.0	1.0	0.0	0.000	0.013	0.002
Riparian	frac with both canopy and understory	frac	XPCM	0.9	0.062	1.0	0.5	1.0	0.5	0.024	0.154	0.030
Riparian	frac with all three veg classes	frac	XPCMG	0.9	0.062	1.0	0.5	1.0	0.5	0.024	0.155	0.030
Riparian	frac of reach covered by canopy	frac	XC	0.4	0.067	0.4	0.1	0.7	0.6	0.028	0.166	0.033
Riparian	frac of reach covered by groundcover	frac	XG	0.7	0.066	0.7	0.4	1.0	0.6	0.026	0.163	0.032
Riparian	frac of reach covered by large woody veg	frac	XCMW	0.7	0.105	0.7	0.2	1.1	0.9	0.068	0.260	0.051
Riparian	frac of reach with any veg cover	frac	XCMG	1.6	0.094	1.6	1.2	2.0	0.9	0.054	0.232	0.045
Riparian	frac of reach covered by any woody veg	frac	XCMGW	0.9	0.141	1.0	0.2	1.4	1.2	0.121	0.348	0.068
Riparian	frac of reach with coniferous dom canopy	frac	PCAN_C	0.0	0.015	0.0	0.0	0.2	0.2	0.001	0.037	0.007
Riparian	frac of reach with deciduous dom canopy	frac	PCAN_D	0.6	0.103	0.6	0.1	1.0	0.9	0.065	0.254	0.050
Riparian	frac of reach with mixed canopy	frac	PCAN_M	0.3	0.100	0.2	0.0	0.9	0.9	0.062	0.249	0.049
Riparian	frac of reach without canopy veg	frac	PCAN_N	0.1	0.061	0.0	0.0	0.5	0.5	0.023	0.151	0.030
Riparian	mean %canopy cover at LF & RT banks	%	XCDENBK	91.0	3.420	93.4	73.5	100.0	26.5	71.688	8.467	1.660
Riparian	mean % canopy cover midstream	%	XCDENMID	77.4	7.413	81.8	23.8	99.7	75.9	336.860	18.354	3.599
subst	mean substrate embeddedness	%	XEMBED	55.1	9.234	51.3	13.9	100.0	86.1	522.694	22.863	4.484
subst	log10(est geom mean substr dia. mm)	unitless	LSUB_DMM	1.2	0.452	1.5	-2.3	3.0	5.3	1.250	1.118	0.219
subst	% substrate fines class	%	PCT_FN	20.0	9.870	7.3	0.0	94.5	94.5	597.157	24.437	4.792
subst	% substrate fine gravel class	%	PCT_GF	11.7	3.865	9.1	0.0	36.4	36.4	91.565	9.569	1.877
subst	% substrate sand class	%	PCT_SA	12.0	5.839	7.3	0.0	63.6	63.6	208.971	14.456	2.835
subst	% substrate hardpan class	%	PCT_HP	4.1	3.314	0.9	0.0	36.4	36.4	67.321	8.205	1.609
subst	% substrate boulder class	%	PCT_BL	7.9	5.041	1.8	0.0	47.3	47.3	155.753	12.480	2.448
subst	% substrate cobble class	%	PCT_CB	14.9	5.704	13.6	0.0	45.5	45.5	199.410	14.121	2.769
subst	% substrate coarse gravel class	%	PCT_GC	19.6	4.641	18.2	0.0	38.2	38.2	132.048	11.491	2.254
subst	% substrate bedrock class	%	PCT_BDRK	8.8	5.729	1.8	0.0	54.5	54.5	201.175	14.184	2.782
subst	% substrate other class	%	PCT_OT	0.1	0.144	0.0	0.0	1.8	1.8	0.127	0.357	0.070

type	Indicator	units	Indicator	Mean	95% Conf.	Median	Min.	Max.	Range	Variance	Standard Deviation	Standard Error
subst	%substrate sand or fines	%	PCT_SAFN	32.0	9.133	25.5	0.0	96.4	96.4	511.252	22.611	4.434
subst	%substrate < coarse gravel	%	PCT_SFGF	43.7	10.506	39.1	3.6	100.0	96.4	676.623	26.012	5.101
subst	%substrate > fine gravel	%	PCT_BIGR	51.3	11.360	55.5	0.0	94.5	94.5	791.013	28.125	5.516
subst	%substrate wood or organic class	%	PCT_ORG	0.8	0.596	0.0	0.0	5.5	5.5	2.177	1.475	0.289

All LWD counts are for the active channel
26 samples for all physical habitat indicators

Appendix 4. List of fish and amphibians species. Extent of distribution indicated by percent of the total stream km represented by the sample.

Family	Genus	Species	Common name	# of sites	% stream km
Fishes					
Catostomidae	Catostomus	macrocheilus	largescale sucker	2	8
Centrarchidae	Lepomis	gibbosus	pumpkinseed	1	4
Cottidae	Cottus	gulosus/perplexus	riffle/reticulate sculpin	23	88
Cottidae	Cottus	rhotheus	torrent sculpin	20	77
Cyprinidae	Rhinichthys	osculus	speckled dace	5	19
Cyprinidae	Richardsonius	balteatus	redside shiner	1	4
Cyprinidae	Ptychocheilus	oregonensis	northern pikeminnow	1	4
Cyprinidae	Rhinichthys	cataractae	longnose dace	1	4
Gasterosteidae	Gasterosteus	aculeatus	threespine stickleback	5	19
Petromyzontidae	Lampetra	tridentata	Pacific lamprey	14	54
Petromyzontidae	Lampetra	richardsoni	western brook lamprey	5	19
Salmonidae	Oncorhynchus	clarki	cutthroat trout	22	85
Salmonidae	Oncorhynchus	kisutch	coho salmon	24	92
Salmonidae	Oncorhynchus	mykiss	rainbow trout/steelhead	14	54
Umbridae	Novumbra	hubbsi	Olympic mudminnow	2	8
Amphibians					
Hylidae	Pseudacris	regilla	Pacific treefrog	3	12
Leiopelmatidae	Ascaphus	truei	tailed frog	3	12
Ranidae	Rana	aurora	red-legged frog	6	23
Ranidae	Rana	catesbiana	bullfrog	1	4
Salamandridae	Taricha	granulosa	rough-skin newt	1	4

Appendix 5. Species characteristics classification for aquatic vertebrate species. Classification based on Zaroban et al. (1999).

Family/Species	Common Name	Tolerance	Habitat	Temperature	Feeding
Fish Species					
Catostomidae					
Catostomus macrocheilus	largescale sucker	tolerant	benthic	cool	omnivore
Centrarchidae					
Lepomis gibbosus[1]	pumpkinseed	tolerant	water column	cool	invert/piscivore
Cottidae					
Cottus perplexus	reticulate sculpin	intermediate	benthic	cool	invertivore
Cottus gulosus	riffle sculpin	intermediate	benthic	cool	invertivore
Cottus rhotheus	torrent sculpin	intermediate	benthic	cold	invert/piscivore
Cyprinidae					
Ptychocheilus oregonensis	northern pikeminnow	tolerant	water column	cool	invert/piscivore
Rhinichthys cataractae	longnose dace	intermediate	benthic	cool	invertivore
Rhinichthys osculus	speckled dace	intermediate	benthic	cool	invertivore
Richardsonius balteatus	redside shiner	intermediate	water column	cool	invertivore
Gasterosteidae					
Gasterosteus aculeatus	threespine stickleback	tolerant	hider	cool	invertivore
Petromyzontidae					
Lampetra tridentata	Pacific lamprey	intermediate	hider	cool	filter feeder
Lampetra richardsoni	western brook lamprey	intermediate	hider	cool	filter feeder
Salmonidae					
Oncorhynchus kisutch	coho salmon	sensitive	water column	cold	invertivore
Oncorhynchus clarki	cutthroat trout	sensitive	water column	cold	invert/piscivore
Oncorhynchus mykiss	rainbow trout	sensitive	hider	cold	invert/piscivore
Umbridae					
Novumbra hubbsi	Olympic mudminnow	tolerant	hider	warm	invertivore
Amphibians					
Leiopelmatidae					
Ascaphus truei	tailed frog	sensitive	benthic/hider	cold	invert/carnivore
Hylidae					
Pseudacris regilla	Pacific tree frog	tolerant	lentic	none	invert/carnivore
Ranidae					
Rana aurora	red-legged frog	intolerant	edge	none	invert/carnivore
Rana catesbiana[1]	bullfrog	tolerant	lentic	warm	invert/carnivore
Salamandridae					
Taricha granulosa	rough-skinned newt	tolerant	edge	none	invert/carnivore

Appendix 6. Summary Statistics for vertebrate (fish and amphibian) metrics.

Metric (% individuals)	Mean	95% Conf.	Median	Min.	Max.	Range	Variance	Standard Deviation	Standard Error
Sensitive	34.6	8.9	30.3	4.9	96.0	91.1	490.001	22.136	4.341
Intermediate	62.9	9.3	66.9	4.0	92.8	88.8	527.123	22.959	4.503
Tolerant	2.5	4.0	0.0	0.0	49.6	49.6	97.436	9.871	1.936
Benthic	61.8	9.2	65.5	4.0	92.5	88.6	517.203	22.742	4.460
Hider	14.1	9.0	5.3	0.0	92.7	92.7	491.342	22.166	4.347
Water column	24.1	6.2	20.5	3.4	63.1	59.7	233.856	15.292	2.999
Cold	61.6	12.2	67.9	4.9	100.0	95.1	916.100	30.267	5.936
Cool	38.0	12.1	32.1	0.0	95.1	95.1	892.323	29.872	5.858
Warm	0.4	0.8	0.0	0.0	10.1	10.1	3.911	1.978	0.388
Filter feeder	1.1	0.6	0.7	0.0	6.3	6.3	2.049	1.431	0.281
Omnivore	0.0	0.1	0.0	0.0	0.9	0.9	0.034	0.184	0.036
Invertivore	55.7	11.2	49.7	0.0	100.0	100.0	774.027	27.821	5.456
Invert/piscivore	43.2	11.2	48.3	0.0	100.0	100.0	771.192	27.770	5.446

Appendix 7. Summary statistics for selected invertebrate metrics.

Indicator	Mean	95% Conf.	Median	Min.	Max.	Range	Variance	Standard Deviation	Standard Error
Total invertebrate abundance	2441.3	1222.8	1444.0	278.1	15467.8	15189.7	9165890.458	3027.522	593.746
Total number of taxa	38.7	3.0	39.0	27.0	54.0	27.0	53.565	7.319	1.435
EPT abundance	878.5	232.9	793.8	36.7	2164.2	2127.5	332535.466	576.659	113.092
Number EPT taxa	21.8	2.6	21.0	8.0	33.0	25.0	42.162	6.493	1.273
No. Non-insect taxa	5.6	0.9	5.0	2.0	11.0	9.0	4.654	2.157	0.423
% Non-insects	12.3	6.5	7.1	2.0	74.1	72.2	255.263	15.977	3.133
No. Ephemeroptera taxa	7.1	1.0	7.0	3.0	12.0	9.0	5.866	2.422	0.475
% Ephemeroptera	21.5	6.2	18.3	1.8	58.7	56.8	236.987	15.394	3.019
No. Plecoptera taxa	7.2	1.1	7.0	1.0	13.0	12.0	7.145	2.673	0.524
% Plecoptera	10.1	2.0	9.1	0.2	21.4	21.2	25.568	5.056	0.992
No. Trichoptera taxa	7.5	1.3	7.0	2.0	14.0	12.0	10.338	3.215	0.631
No. Predator taxa	12.0	1.5	12.0	5.0	19.0	14.0	13.318	3.649	0.716
% Predators	12.7	3.5	12.2	1.4	45.2	43.8	74.645	8.640	1.694
No. Parasite taxa	1.9	0.2	2.0	1.0	3.0	2.0	0.266	0.516	0.101
% Parasites	3.2	1.0	2.3	0.4	9.6	9.2	6.406	2.531	0.496
No. Collector-gather taxa	11.1	0.9	11.0	8.0	16.0	8.0	4.634	2.153	0.422
% Collector-gatherers	47.1	7.1	49.2	14.2	81.3	67.2	308.087	17.552	3.442
No. Collector-filterer taxa	2.4	0.3	2.5	1.0	3.0	2.0	0.486	0.697	0.137
% Macrophyte-herbivores	0.8	0.7	0.1	0.0	6.4	6.4	2.676	1.636	0.321
% Piercer-herbivores	0.0	0.1	0.0	0.0	0.7	0.7	0.021	0.144	0.028
% Scrapers	16.4	5.4	12.4	0.8	67.6	66.7	178.056	13.344	2.617
% Shredders	4.1	1.8	2.7	0.2	19.2	19.0	19.305	4.394	0.862
% Xylophages	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000
% Omnivores	0.2	0.2	0.1	0.0	1.8	1.8	0.145	0.381	0.075
% Dominant taxa	32.5	5.9	31.6	14.6	77.3	62.7	215.048	14.665	2.876
% 5 Dominant taxa	67.9	3.9	66.9	53.4	93.3	39.8	92.246	9.604	1.884
% 10 Dominant taxa	82.2	2.7	81.5	72.0	97.5	25.5	45.024	6.710	1.316
Eveness	0.7	0.0	0.7	0.3	0.8	0.5	0.012	0.108	0.021
Tolerant species richness	4.0	0.7	4.0	1.0	8.0	7.0	3.078	1.755	0.344
% Tolerant	10.2	4.9	6.8	0.9	55.6	54.7	144.484	12.020	2.357
intolerant species richness	3.8	0.7	4.0	1.0	8.0	7.0	2.802	1.674	0.328
% Intolerant	7.2	2.5	4.3	0.2	19.9	19.8	38.962	6.242	1.224
No. Long-lived taxa	6.2	0.8	6.0	3.0	10.0	7.0	4.185	2.046	0.401
% 3 Dominant taxa	55.6	5.0	54.2	38.0	89.6	51.6	152.126	12.334	2.419