

# **PRELIMINARY ASSESSMENT OF 1996 FLOOD IMPACTS: CHANNEL MORPHOLOGY and FISH HABITAT**

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The February 1996 flood event in Oregon has been variously described as both a disaster and a benefit to stream habitat and salmonid populations. Initial anecdotal assessments have provided little resolution to this issue. Case studies highlighting detrimental effects or showing the positive effects of channel change illustrate important processes but do not provide any context for assessing overall impacts. This study undertook a more comprehensive assessment of flood impacts, designed to provide the context for understanding flood and disturbance processes and to give a statistically valid basis for the interpretation of both positive and negative channel changes. This study also develops information needed to better manage post-flood habitat and supports realistic evaluations of the interactions between habitat, disturbance processes, and land use issues.

Because the Oregon Department of Fish and Wildlife (ODFW) conducted a program of quantitative stream habitat inventories from 1990-95, we have the capacity to assess channel and habitat changes. The impact area of the February 1996 event extended from the Smith River tributary in the Umpqua basin inland to the McKenzie basin and north to include the remainder of Oregon's coast range tributaries, the Willamette Valley, and west slope of the Cascades. High precipitation and storm flows also occurred in the Hood River, Deschutes, Grande Ronde and Wallowa basins. Within this area, ODFW's Aquatic Inventory Project (AIP) has conducted stream surveys and summarized data for over 650 stream with approximately 3,800 km of stream length covered. Because of the extensive habitat information collected and analyzed by the project, we had the ability to select stream reaches for resampling, stratified by ecoregion and geology, land use, and channel gradient. Also, because the AIP program has developed many partnerships among state, county, federal, and private landowners, the assessment was able to address the flood effects across a broad range of geographic and land use criteria.

The sampling design was structured to allow analysis of the stream survey results to address the following questions:

- What is the degree and extent of habitat alteration associated with the floods?
- How did flood impacts on stream habitat vary by region, land use, and stream channel characteristics?
- What were the characteristics of stream reaches that demonstrated positive or negative habitat responses to the flooding?

- What land use and management practices were associated with positive or negative impacts on stream habitat?
- Were there different impacts relative to the habitat requirements of the different salmon species? In other words, were there net gains for coho habitat but net losses for chinook?
- Based on the observations and results of this study, what options are available for improved habitat management in streams influenced by the floods?

We obtained funding to place field crews in each of the seven major basins most affected by the storms. Some of the survey effort was directed to ensure overlap with the Oregon Department of Forestry assessment of upslope conditions, but these streams were not included with the results of the random sample.

The study basins, in priority order were:

Tillamook/Nestucca/Siletz  
McKenzie/Santiam/Upper Willamette  
Nehalem/Necanicum  
Yaquina/Alsea/Siuslaw  
Hood River/Lower Deschutes  
Grande Ronde/Wallowa

Existing staff and funding within ODFW's Research Section provided general project oversight, additional field supervision, and additional analysis and interpretation of the results.

Comprehensive post-flood habitat surveys began in June 1996, and continued through mid October 1996, the same work period as the initial surveys. The crews applied modifications to the AQI standard stream survey methodology (Moore, et al. 1995) to focus on habitat elements subject to the impacts of high flows, modified channels, debris torrents, and landslides.

## **Methods**

### Selection of Streams for Post-Flood Survey

We conducted the repeat stream habitat surveys in a stratified random sample of reaches in streams previously evaluated by the Aquatic Inventory Project.

A random selection was made for each region with the sample population stratified proportionally to land use and stream gradient. Land use was identified based on the results from the primary land use classification made at the time of the pre-flood surveys. Detailed land use classifications were generalized into the following major groups: Forestry, agriculture, Grazing, and Other. The "Other" group includes primarily rural residential, urban, and unclassified land uses.

The selection by stream gradient was made at three levels, slope classes of: Low, 0-3% gradient, Medium, 3-5% gradient, and High, greater than 5% gradient. This grouping was based on a combination of general levels of fish use and on channel classification. Coho salmon most commonly use habitats in the Low group, coho and steelhead in the Medium group, and cutthroat trout dominate in the High group. With respect to systems of channel classification (i.e. Montgomery et al. 1993), the Low group also corresponds to response channels, and the Medium and High group generally represent transport channels. Source channels (gradient > 20%) are rarely surveyed using the AQI protocols and are absent from this sample.

We proposed to resurvey an equal proportion of stream reaches in each region, resulting in a resampling rate of roughly 10 percent. We anticipated that the field effort would have the capacity to complete stream surveys in approximately 200 reaches. The selection process produced a list of 268 candidate reaches for the field crews to resurvey. The field crews, and their field supervisors, developed plans to begin surveys with final selection of reaches made to accommodate sampling logistics and efficiency.

Table 1. Selection of stream reaches for post-flood evaluation.

Stratification Factor		Total Reaches	Candidate Reaches
<u>Region</u>			
North Coast		628	90
Mid Coast		423	62
West Slope Willamette		245	38
West Cascades		244	37
Hood/Deschutes		66	12
Umatilla/Grande Ronde/Wallowa		163	29
<u>Gradient Group (% Slope)</u>			
Low	0-3.0	974	145
Medium	3.1-5.0	300	54
High	> 5.0	495	69
<u>Land Use Group</u>			
Agriculture		94	25
Forestry		1,509	209
Grazing		86	17
Other		80	17

## Flood Assessment Protocol

We made modifications to ODFW's Aquatic Inventory Project: Methods for Stream habitat Surveys to focus on the variables most sensitive to flood impacts, but the surveys also repeat all previously collected information. We were able to evaluate changes in variables associated with channel change and, in channels with little impact, assess the background variability in streams and in the methodology.

The type of additional information collected and the organization of field protocol are described below. These instructions were used in the field as a supplement the standard AQI protocols.

### **Reach Survey - Channel Impact Assessment Protocol**

The following additions to: Methods for Stream Habitat Surveys, ODFW Aquatic Inventory Project, (ODFW Research Section, Corvallis, Moore, K.M.S., K.K. Jones, and J.M. Dambacher, 1997) refer to numbered items and corresponding topics in the general field methods manual.

**Reach Form:** Carefully note starting and stopping points, care in documenting location is needed in order to link 1996 assessment to reaches identified in prior surveys. Use existing criteria for designating reach changes, areas exhibiting flood influence will naturally break out as reach changes due changes in riparian vegetation or other factors.

15. Sketch -- Include channel impacts (extent of high water, scour, deposition) in cross section sketch.

**Unit - 1 Form:** Channel Unit determination will be the same as in all other surveys. In impact areas, active channel margins may be determined by changes in bank within the scour zone as usual vegetation indicators may be absent.

10. Replace **Aspect** header with **Reach Modifier Code**

#### Low Impact Group

- NO** No perceivable impact from high-water, flood or torrent. Winter flow appear to have been contained within the active channel.
- HW** High Water impacts only. Indications of high flow such as "bird nests" in streamside vegetation, cleaning of litter from low terraces and floodplains.
- SD** Scour and Deposition patches. Localized channel, bank, and floodplain scour or deposition of fines, gravel, or cobble. Scale: Patch size generally less than typical channel units.

Moderate Impact Group

**CM** Channel **M**odified. Larger scale changes in channel characteristics with influence areas comprised of multiple channel units. Examples of changes include channel relocation, deposition of new gravel bars, scour deep pools, and development of new side channels.

High Impact Group: variations of impacts associated with debris torrents, impacts at the spatial scale of full valley floor scour or deposition and extending for more than seven channel widths.

**TS** Torrent **S**cour impacted  
**TD** Torrent **D**eposition impacted  
**TJ** Torrent **J**am  
**TI** Torrent **I**nitiation. Usually a headwall channel, if surveyed it would be as Small Stream type BD - BeDrock  
**DF** **D**ambreak **F**lood zone  
**DS** **D**ambreak torrent **S**cour combination  
**DD** **D**ambreak torrent **D**eposition combination  
**DJ** **D**ambreak torrent **J**am combination

16. Addition to **Note**, header, **Flood Impact Width** and **Flood Impact Height**. Add headers to top of column. Enter at the same interval as Active Channel Width, Height, Terrace Width, Height, and Valley Width Index (start of new reaches and every ten channel units).

**Flood Width** Total distance (meters) across the channel and valley of the area impacted by high water. If Reach Modifier Code was NO, no impact, then Flood Width is the same as active channel width.

**Flood Height** Vertical distance (meters) from the upper level of the active channel to the high point of flood impact.

**Unit - 2 Form:**

10. **Comment Codes.** Use as in any survey. Debris Jams and Mass Movement Codes will be particularly useful in later comparisons.

Example: A small unnamed tributary enters from the left hillslope, it shows evidence of a debris avalanche or “sluice-out”. Enter as **TJ/ AA/**.

**Wood Form:** All large woody debris (LWD) both within the active channel and in the areas of high flow will be counted. Method for classifying and counting is unchanged. Additional information on debris location will be collected.

5. **Debris Location.** Additional codes.

**FP** Flood Plain. LWD located between the margins of the active channel and the extent of the floodplain.

**FM** Flood Margins LWD located at the margin, and in some cases defining the margin, of the flood impact zone. Large deposits of LWD at the margins of the high water zone indicate occurrence of a dam break flood.

**Riparian Form:** No changes in information collected. In areas of flood impact, start the transect at the margin of the active channel, remembering that the active channel margin will probably be defined by changes in bank slope and scour, not subtle changes in streamside vegetation.

Analysis

During the summer of 1996, 181 randomly selected, previously surveyed stream reaches statewide were resurveyed using the 1996 flood impact assessment methods developed by the Oregon Department of Fish and Wildlife Aquatic Inventories Project. The purpose of this effort was to characterize and quantify the effects of the flood event of the winter and spring of 1996 upon watersheds and fish habitat in stream reaches for which baseline habitat data already existed. Raw data from these resurveys were analyzed at stream and basin spatial scales, and the resulting derived metrics were compiled into a database containing data from both the initial habitat surveys and the flood assessment resurveys. Beginning and ending points of the resurveys were chosen to correspond with known points in the initial surveys, in order to facilitate analyses of the same samples. In this study a single sample consists of a section of stream (reach) which was surveyed initially between 1991 and 1996, and was then resurveyed during 1996. The research question being addressed in this study is whether there are statistically significant differences in sample variables before vs. after the flood event.

ANALYTICAL APPROACH

The analysis focused on the following issues:

- 1.) Geographic scope of channel changes
  - Tabular summary
  - GIS view
- 2.) Instream habitat characteristics - changes pre vs. post flood
  - Fequency histograms
  - Statistical analysis - MANOVA, ANOVA

### 3.) Relationships between variables and channel morphology

- Descriptive multivariate analysis
- GIS view

### 4.) Causal relationships

The spatial scale chosen for the regional analyses in this study was the “geographic area”, of which there are six in the database: North Coast, Mid-Coast, West Cascades, West slope Willamette Basin, Northeast, and Hood/Deschutes. This scale was chosen to take maximum advantage of the Central Limit Theorem (q.v.) by maximizing the sample number  $n$  in each regional analysis, while retaining enough resolution to obtain results which are interpretable and inferentially useful. We did not perform statistical analyses of the Hood/Deschutes geographic area data because the number of samples was too small to obtain useful results.

Table 1 shows the 11 variables that were chosen for statistical analysis in this study. These variables were chosen based upon their direct importance to salmonid habitat, as well as our confidence in our ability to measure them with an appropriate degree of accuracy and repeatability.

Table 1. Names and descriptions of variables used in statistical analysis.

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- 1) Percentage of total channel area as secondary channels
  - 2) Percentage of total channel area as pools
  - 3) Percentage of riffle substrate as fine sediments
  - 4) Percentage of riffle substrate as gravel
  - 5) Pool frequency as active channel widths per pool
  - 6) Percentage of reach length containing actively eroding banks
  - 7) Average width to depth ratio of riffles
  - 8) Average residual pool depth (m)
  - 9) Density of large boulders (dia. > 0.5m)
  - 10) Density of pieces of large woody debris (>15 cm x 3m)
  - 11) Volume density of large woody debris (>15 cm x 3m)
- 

Two types of approaches were chosen to characterize the data: exploratory and analytical. In the exploratory approach, distributions of habitat variables pre and post flood are generated and depicted as distributions of change; for example, we explored the change in pool frequency between the initial survey and the flood resurvey. Distributions were categorized whenever appropriate in order to explore potential systematic relationships between variables; for example, variable distributions were categorized by valley type, gradient, and predominant flood impact.

The analytical approach consisted of testing assumptions, followed by group difference testing. Assumptions about the distributions of individual variables were tested in order to assess the appropriateness of the normal distribution-based tests of statistical significance. Two main assumptions are relevant: normality and variance homogeneity. The normality assumption holds that the sampling distribution of a variable follows the so-called normal distribution. This assumption was tested on each analyzed variable with two different tests. The Kolmogorov-Smirnov (K-S) with its associated “Lillefors probabilities” and the Shapiro-Wilks’  $W$  test. Both of these normality tests use means and standard deviations which are computed from the data, and do not require that they be known *a priori*. Results are reported as p-values, which are probabilities of error associated with rejecting the null hypothesis, which in this case would state that the sampling distribution is drawn from a normal distribution. P-values  $<.05$  are generally considered to be significant, which in this case would cause us to reject the null hypothesis and conclude that the samples are not normally distributed. Normality can also be assessed by examining the descriptive statistics computed for each variable. If the mean and median are divergent, or if the skewness or kurtosis are substantially different from 0, then the distribution is less likely to be normal. Normality can also be assessed by examining the frequency histograms for the variables, where non-normal shapes can more easily be identified.

Variance homogeneity is an assumption in the normal-distribution based tests of group differences. These tests assume that the variance between groups is similar, or homogeneous. Variance homogeneity can be assessed by examining the descriptive statistics for the variables, and also by box-and-whisker plots of means and standard deviations of the variables.

The Central Limit Theorem, which states that as the sample size increases, the sampling distribution approaches the Normal distribution, is able in this study to obviate much of the concern over the aforementioned assumptions. The Central Limit Theorem is generally thought to apply when the sample size  $n > 100$ , and serious biases are even unlikely at  $n=50$ .

## GROUP DIFFERENCE TESTS

Two classes of group difference tests were used in order to test for the presence of statistically significant differences between the values of variables sampled before and after the flood. These two classes are the parametric, or normal distribution-based tests, and the non-parametric, or “distribution-free” tests. The parametric tests are most appropriate when the aforementioned assumptions of normality and variance homogeneity are met by the sample data. The parametric group difference test that was used was the “*t-test* for dependent samples”. This test is typically used for comparing two repeated measures of the same sample. In this case the repeated measures are the values of the variables measured in the initial surveys, and then repeated in the flood resurveys. The samples are the reaches that were surveyed. The advantage of the *t-test* for dependent variables is that it is able to account for and exclude from the analysis that part of the within-group variability that is attributable to the initial individual differences between samples (reaches). In other words, it analyzes only the before vs. after differences between samples, and excludes the base level variability between samples. This property makes the *t-test* for dependent samples a sensitive test of group differences.

In cases where the assumptions of normality and variance homogeneity are not met, and especially if sample sizes are small ( $n < 50$ ), non-parametric alternatives to the *t-test* for dependent samples should be considered as tests of group differences. The non-parametric tests that were used were the Sign Test and the Wilcoxon Matched Pairs Test. Both of these tests are applicable to situations in which we have two measures for each sample and we wish to test whether the two pooled measurements are significantly different from one another. The only assumption required by the Sign Test is that the distribution of the variables being tested are continuous; no assumptions about the nature or shape of the underlying distributions are required. The test simply computes the number of times that the value of the first variable (A) is larger than that of the second variable (B). Under the null hypothesis, stating that the values of the two variables are not different from each other, we expect  $A > B$  about 50% of the time. Based upon the binomial distribution, we can compute a standardized z value for the observed number of cases where  $A > B$ , and compute the associated tail probability (p-level) for that z value. In contrast to the Sign Test, the Wilcoxon Matched Pairs Test assumes that the variables under consideration were measured on a scale that allows the rank-ordering of both the variables and the differences between variables (ordinal scale). Thus, the required assumptions for this test are more rigorous than those for the Sign Test. However, if the magnitudes of differences contain meaningful information, then this test is more powerful than the Sign Test. In fact, if the variables are measured on an interval scale, where the differences between measures can be not only rank-ordered but also quantified, then this test is almost as powerful as the parametric *t-test* for dependent samples.

## MULTIPLE ANALYSIS OF VARIANCE (MANOVA)

In general, analysis of variance (ANOVA) techniques are used to test for significant differences between means; indeed, ANOVA will yield the same results as *t-tests* if we are comparing only two means. ANOVA compares means by analyzing the variances of our samples, partitioning the variances into 2 categories: Within-group variability, or error variance, and between-group variability, or effect variance. The error variance represents the fraction of the total variability that we are unable to account for, while the effect variance represents that part of the total variability that can be accounted for or “explained” by group membership, i.e., the effect variance is explained by the difference in means. ANOVA tests statistical significance by comparing the effect and error variances, that is by computing the ratio of explained to unexplained variability. Under the null hypothesis, that there is no difference between group means in the population, the effect and error variances should be about the same in our sample data. We compare these two measures of variance with the *F-test*, which tests the degree to which the ratio of the effect to error variances is greater than 1.0. Larger values of the F-statistic represent greater proportions of effect variance as a fraction of the total variability, leading to greater significance in differences between means. The significances of differences are expressed as p-values, or probabilities of error in rejecting the null hypothesis of no differences between means. If  $p < .05$ , then we generally reject the null hypothesis, and accept the alternative hypothesis of statistically significant differences between means.

The purpose of the first series of MANOVA analyses was to test for the existence of significant differences in the habitat variables PRE vs. POST flood, within each set of reaches defined by the six aforementioned GEO-AREAs in the database. We analyze the overall effects, and the contribution of each variable to the overall effect. In this design, we analyze the same 11 dependent variables that we used in the *t-tests* (Table 1). We have no between-groups factor, and our within-groups factor consists of the 2 repeated measures, PRE and POST.

The results of each analysis is in four parts. First, we show a summary of all effects for the variables which represent combined PRE and POST flood scenarios. The statistic which embodies this result is Wilks' Lambda, which is essentially a multivariate *F-test*, in that it represents the pooled ratio of effect variance to error variance, with the associated p-values. Second we show a table of Main Effects, which shows the variance partitioning into effect and error, and also shows the F-statistic, and its associated p-value, for each dependent variable (repeated measures). Third, we show a table of sample means for each dependent variable. Finally, we display plots of means for each habitat variable, PRE and POST flood.

### Detrended Correspondence Analysis

Detrended correspondence analysis (Hill 1979; Gauch 1982) was used to identify the principle patterns of variation in the habitat of stream reaches as a result of the flood. The technique arrays similar reaches closely and separates dissimilar reaches

based on multiple attributes of stream habitat. Detrended correspondence analysis maximizes the correlation between the habitat variables (the value of differences before and after the flood) and reaches, while maximizing the difference among reaches. It arrays the habitat variables along each axis in a direction similar to the individual reaches, and prevents undesired systematic relations between successive axes. Each reach is treated as an individual sample unit. As a result, the reaches are laid out along a continuum that represents the variability of habitat parameters among the reaches.

## RESULTS

### Channel modifications

The field crews completed post-flood stream and riparian habitat surveys in 196 reaches across geographic regions. The first level of analysis was to simply characterize the proportional amount of stream channels in each of the flood impact levels. This was done by totaling the stream channel length within each of the impact groups as identified in the Reach Modifier Codes. Impact levels were groups as follows: None=NO perceivable impact, Low=High Water and Scour and Deposition impacts, Moderate=Channel Modified impacts, and High=any of the levels associated with debris torrents or dam break floods. Results of flood at the channel impact level are summarized in Table 2.

Table 2. Percent of stream length in each flood impact group.

<u>Region</u>	<u>No Impact</u>	<u>Low</u>	<u>Moderate</u>	<u>High</u>
North Coast (n=60)	9.2	60.8	25.6	3.1
Mid Coast (n=45)	4.1	90.9	4.8	0.4
West Cascades (n=25)	11.9	61.9	14.7	11.6
Hood /Sandy (n=7)	0.0	59.8	39.3	1.2
West Slope/Willamette (n=22)	15.5	69.1	12.0	0.8
Umatilla/Grande Ronde (n=15)	66.5	31.9	1.6	0.0

The West Cascade and North Coast geographic areas experienced larger effects on the channel with some debris torrents influencing channel structure and morphology. Moderate changes in the channel such as channel relocation, deposition of new gravel bars, and development of side channels occurred in 14-40% of the channel in the North Coast, West Cascades, and Hood/Sandy geographic areas. The Mid-Coast, West Slope/Willamette, and Umatila/Grande Ronde geographic areas showed very low responses to the February 1996 flood.

Concurrent with overall influences on channel morphology were changes in attributes at the habitat unit level. As described earlier, we used a combination of graphical and statistical techniques to examine changes in habitat characteristics. Below, we provide examples of the analysis using information for the North Coast geographic area.

Example results of analyses: North coast reaches

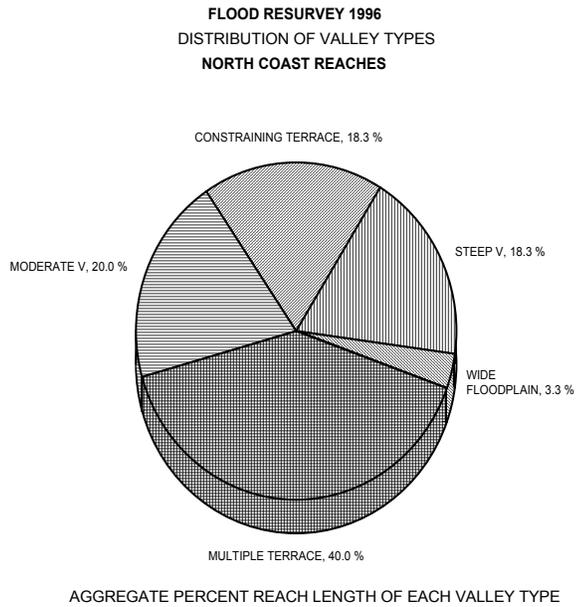
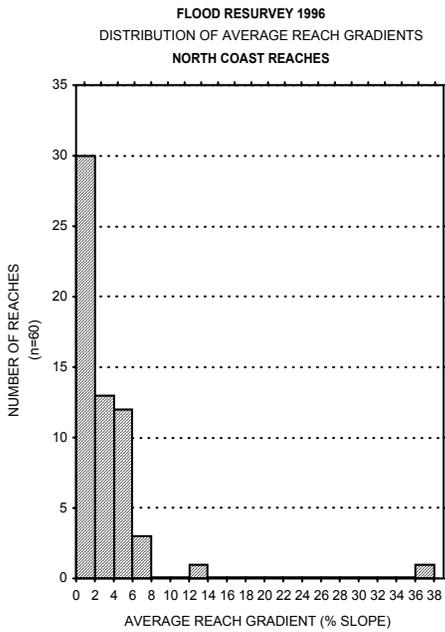
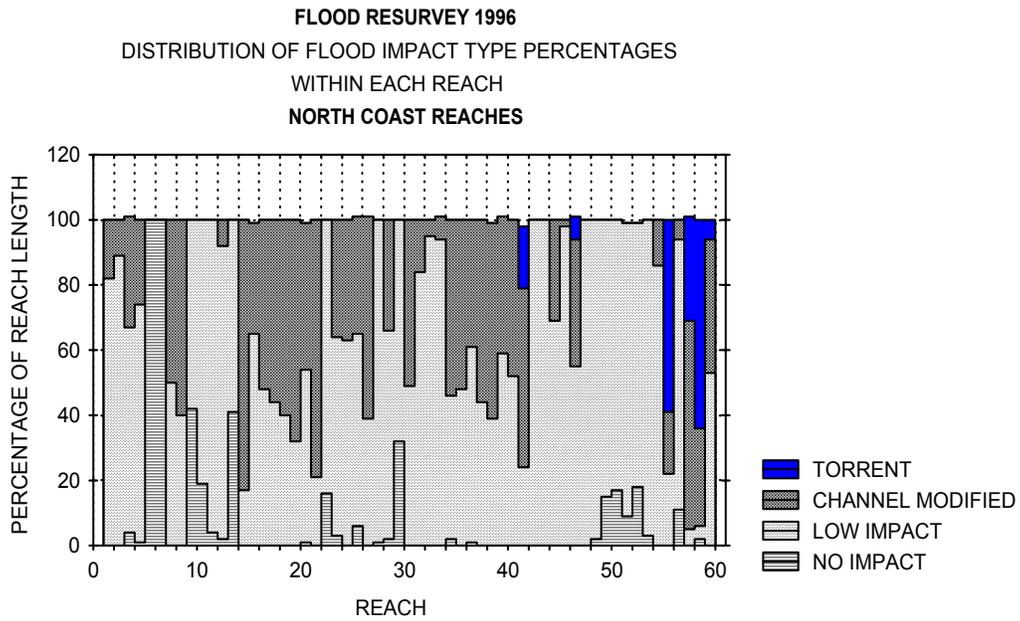


Figure 1. Description of flood impacts on channel morphology, average gradient of surveyed reaches, and reach type in the North Coast geographic region.

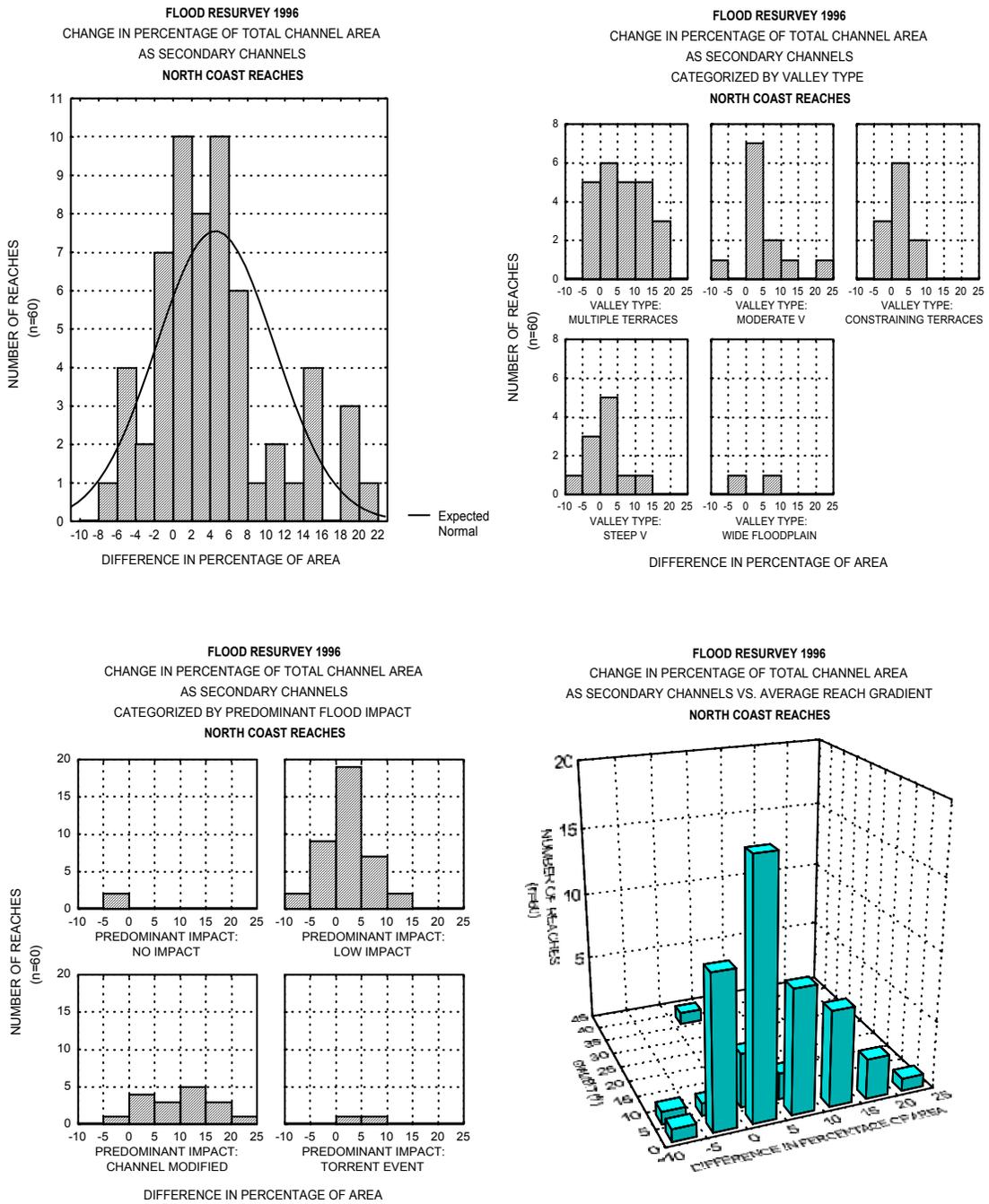
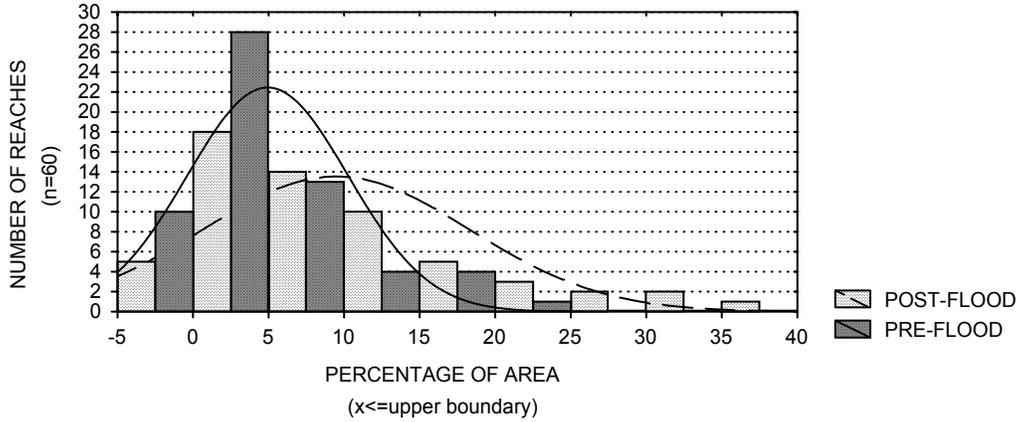


Figure 2. Change in amount of secondary channel habitat relative to reach type, channel impacts, and gradient.

**FLOOD RESURVEY 1996**  
 DISTRIBUTION OF PERCENTAGE OF TOTAL CHANNEL AREA  
 AS SECONDARY CHANNELS, PRE AND POST FLOOD,  
 WITH SUPERIMPOSED FITTED NORMAL CURVES  
**NORTH COAST REACHES**



**FLOOD RESURVEY 1996**  
 LOCATION OF MEANS AND DISPERSION OF DATA,  
 PERCENTAGE OF TOTAL CHANNEL AREAS AS SECONDARY CHANNELS,  
 PRE AND POST FLOOD  
**NORTH COAST REACHES**

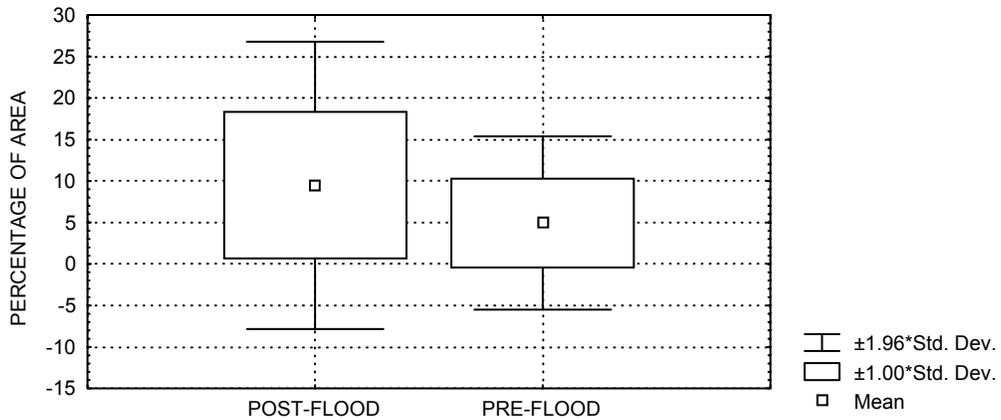


Figure 3. comparison of amount of secondary channel in the North Coast before and after the flood.

**TABLE 3. MANOVA Statistical summary of North Coast reaches.**

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DESIGN: 1 - way MANOVA, fixed effects. NORTH COAST REACHES  
 DEPENDENT: 11 variables (Repeated Measures)  
 BETWEEN: none  
 WITHIN: 1-PRE-POST (2)  
 SAMPLE SIZE: n = 60

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STAT. GENERAL MANOVA      **SUMMARY OF ALL EFFECTS, NORTH COAST REACHES**  
 1-PRE-POST

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
1	.373763*	7.463568*	11*	49*	.000000*

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STAT. GENERAL MANOVA      **MAIN EFFECT: NORTH COAST REACHES**  
 1-PRE-POST

Dependent variable	Mean sqr Effect	Mean sqr Error	F (df1,2) 1,59	p-level
PCTSCCHN	615.85	20.0351	30.73880	.000001
PCTPOOL	2936.34	210.4378	13.95349	.000425
RIFSNDOR	213.33	128.3503	1.66212	.202349
RIFGRAV	95.41	137.4083	.69434	.408052
CWPOOL	2556.25	824.3331	3.10099	.083427
BANKEROS	14344.53	469.0762	30.58039	.000001
WDRATIO	22.62	134.2469	.16850	.682939
RESIDPD	.07	.0367	1.79406	.185570
LRGBLDR1	380.49	405.5862	.93813	.336713
LWDPIECE	85.51	82.6415	1.03476	.313197
LWDVOL1	129.58	390.9037	.33150	.566968

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STAT. GENERAL MANOVA      **MEANS: NORTH COAST REACHES**

	DEPENDENT VARIABLES						
<u>PRE-POST</u>	PCTSCCHN	PCTPOOL	RIFSNDOR	RIFGRAV	CWPOOL	BANKEROS	WDRATIO
PRE	4.941000	27.58667	22.35000	41.63334	17.53417	13.40333	28.49500
POST	9.471833	37.48000	25.01667	39.85000	8.30333	35.27000	29.36333
<u>PRE-POST</u>	RESIDPD	LRGBLDR1	LWDPIECE	LWDVOL1			
PRE	.581500	23.21750	16.62333	29.99500			
POST	.628333	19.65617	18.31167	27.91667			

**FLOOD RESURVEY 1996**  
**MANOVA RESULTS: PLOT OF MEANS**  
**NORTH COAST REACHES**

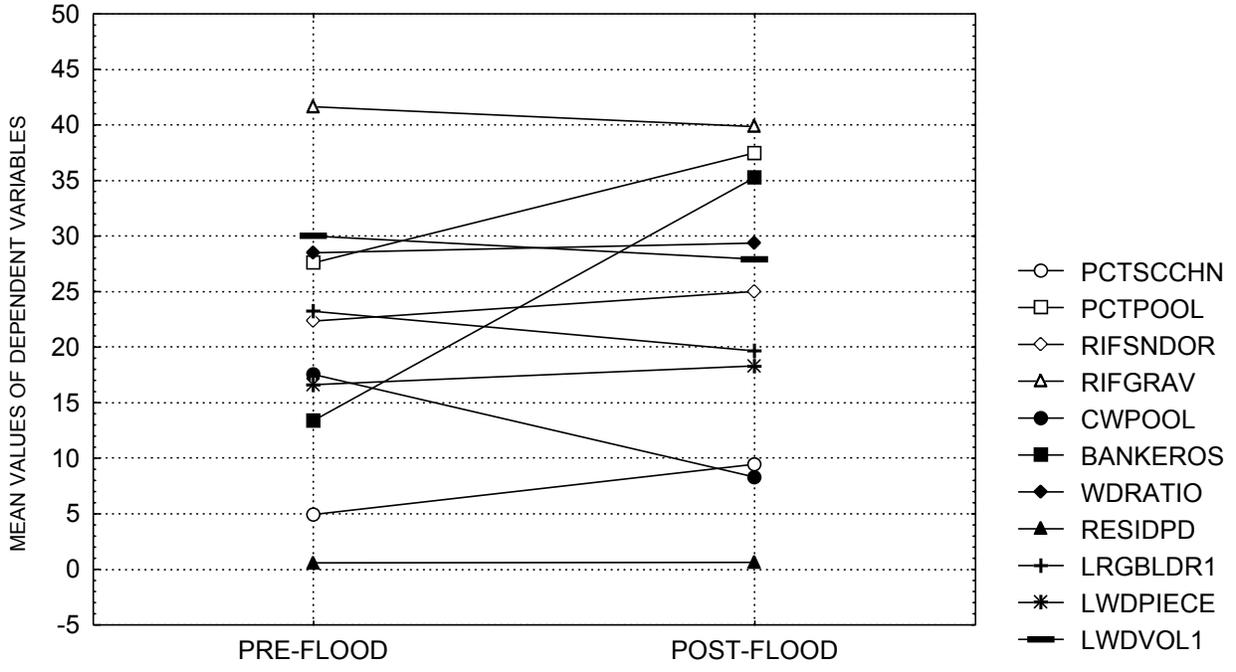


Figure 3. Display of means of variables for the North Coast area.

## Analysis of Variance Results

### North coast reaches ( $n= 60$ )

The North Coast reaches received the most intense precipitation inputs during the flood event, and thus experienced the greatest overall impacts, both in terms of the number of reaches displaying moderate to high levels of flood effects as defined by our survey protocol, as well as by the magnitude of changes within those watersheds. Statistical analysis shows that 3 variables experienced significant increases after the flood event in the North Coast reaches:

- Percentage of total channel area as secondary channels
- Percentage of total channel area as pools
- Percentage of reach length containing actively eroding banks

### Mid-coast reaches ( $n=45$ )

The Mid-Coast reaches experienced a more diverse response to the flood event in terms of the variables that are analyzed herein; responses are sometimes in opposition to those experienced in the North Coast reaches. Statistical analysis shows that 4 variables experienced significant increases after the flood event:

- Percentage of total channel area as pools
- Percentage of riffle substrate as fine sediments
- Average width to depth ratio of riffles
- Density of pieces of large woody debris

In contrast, 2 variables experienced significant decreases after the flood event:

- Pool frequency as active channel widths per pool
- Percentage of reach length containing actively eroding banks

### West Cascades reaches ( $n=32$ )

Statistical analysis shows that 2 variables experienced significant increases in the West Cascades reaches:

- Percentage of reach length containing actively eroding banks
- Density of pieces of large woody debris

### West Willamette Reaches ( $n=22$ )

Statistical analysis shows that 1 variable experienced a significant increase in the West Willamette reaches:

- Percentage of total channel area as secondary channels

In contrast, 1 variable experienced a significant decrease after the flood event:

- Pool frequency as channel widths per pool

### Northeast Reaches ( $n=15$ )

Statistical analysis shows that 1 variable experienced a significant increase in the Northeast reaches:

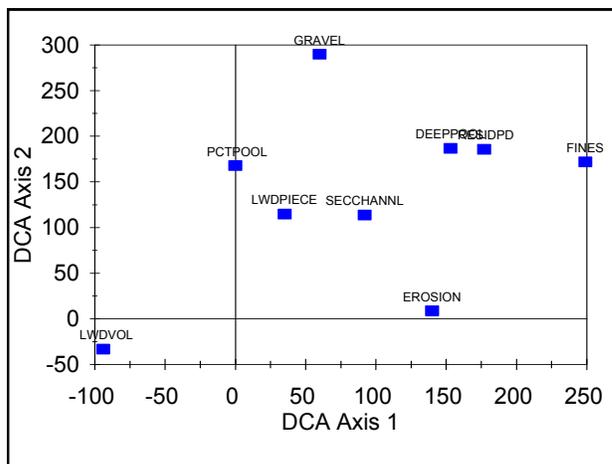
- Average residual pool depth

In contrast, 2 variables experienced significant decreases after the flood event:

- Density of large boulders
- Volume density of large woody debris

### Relationship of habitat variables to site attributes

The changes in individual stream characteristics did not appear to be correlated with reach type, flood impact level, or stream gradient (see Figure 2 for example). We used a detrended correspondence analysis (DCA) to examine the multiple variables simultaneously. Figure 4 displays the results of the DCA. The axes for the variables correspond to the axes for the sites. That is, the sites in the bottom left corner had increases in the volume of large wood following the flood, and the sites to the far right experienced increases in the amount of fine sediment in the riffles. The flood impact level at each sites is displayed in this example. There is no consistent pattern of sites relative to the axes. This suggests that the effect of flood impacts (as described by the channel modification) is not clearly related to specific site changes in habitat characteristics.



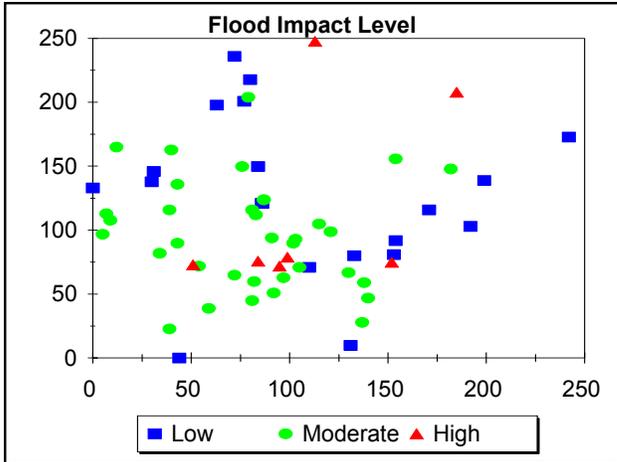


Figure 4. Detrended correspondence analysis ordination of habitat variables and 60 reaches in the North Coast region. The upper figure depicts habitat variables along two axes and the lower figure depicts a scatter plot of stream reaches.

Stream reaches were displayed on a GIS to compare against precipitation levels during the storm (Figure 5). Precipitation coverages were provided by George Taylor (Oregon Climate Service, Oregon State University). The stream reaches in the North Coast geographic region that had a high impact from debris torrents were within or immediately downstream of heavy precipitation zones.

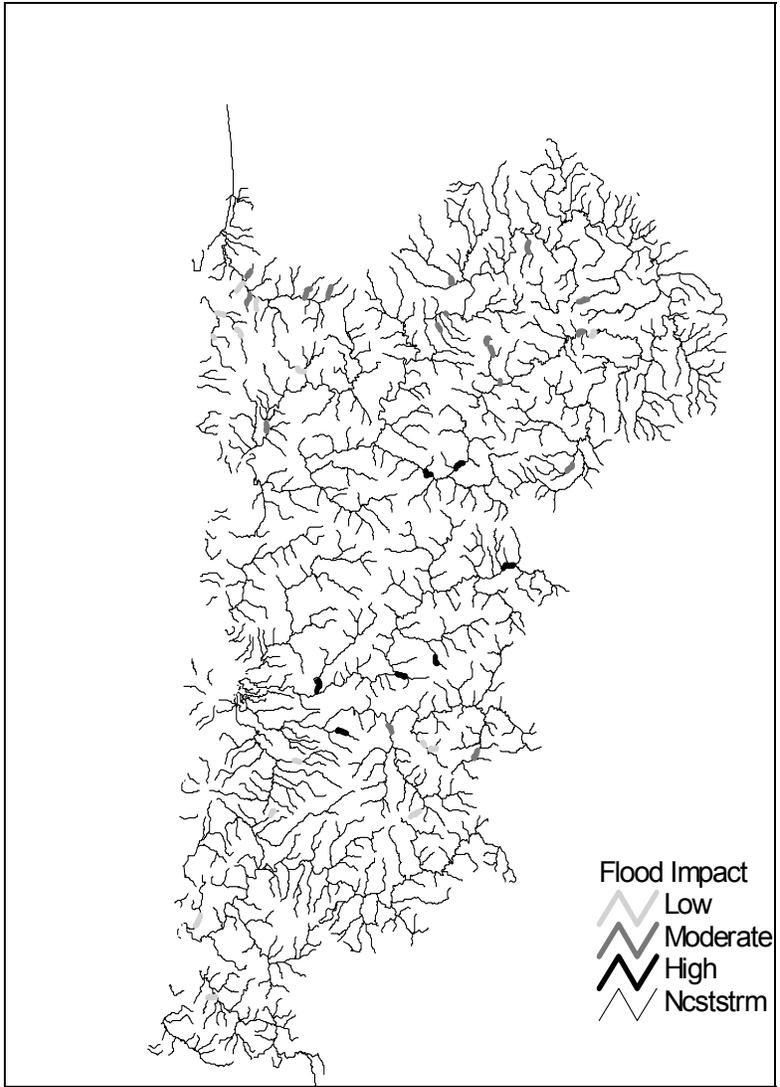


Figure 5. Display of stream reach surveyed in the North Coast geographic region and the level of flood impact each experienced base on channel modification observations.

### Discussion

Levels of flood impact varied by geographic region, but the greatest degree of channel modification occurred in the North Coast, West Cascades, and Hood/Sandy regions. The predominant impacts were low to moderate changes at the habitat unit or multiple unit level. Few streams experienced debris torrents. The flood impact level appears closely related to the level of precipitation, but the changes in inchannel characteristics were not predictable based on the level of channel modification.

Habitat features changed significantly following the flood event, although not in relation to flood impact level, channel type, or gradient. The characteristics that changed varied with geographic region, but some general conclusions can be drawn.

Secondary channels represent very important areas of “off-channel” habitat, especially for coho salmon, which utilize this habitat in winter as well as in summer. In the North Coast reaches, analysis of the data shows significant increases in the formation of secondary channels, and this result was borne out in routine field observations during the resurvey process. Secondary channel formation was often occurring in stream segments which experienced “channel modified” flood effects as described in the methods. A typical channel modified area would have a section of stream longer than the prevailing habitat unit length modified by the flood event. This modification often consisted of the movement of bedload in the form of gravel, cobbles and boulders from upstream regions into downstream regions, where lower gradients and wider active channels allowed a transition from transport to deposition.

The movement of bedload described previously had significant effects upon pool habitat. Often, pools were simply filled in. Yet, as the channel is reestablished, the physics of the scouring process will create new pools adjacent to boulders or large woody debris that may have been moved by the flood event. In some areas, large cedars, buried since the salvage logging after the Tillamook Burn, were unearthed, transported, and redeposited by the flood event. Hopefully, deep, stable pools can form around these impressive pieces of wood, creating sheltered, cool-water habitat.

In some areas, beaver ponds were blown out by the flood event, creating riffles and glides in their places. This resulted in changes in pool frequency in beaver-dominated reaches.

Our statistical analysis of LWD considered only the wood in or touching the active channel. However, as pointed out in the modified methods, we did tally all wood in the flood margin and floodplain created by the flood event. This wood, while not contributing to habitat complexity at the time of the resurvey, is available to the stream should its channel wander within its valley.

Most of the reaches experiencing “torrent scour” or “torrent deposition” flood effects did so due to the sluicing of high-gradient tributaries. These tributaries were often sluiced down to bare bedrock, resulting in the transport of massive amounts of bedload, as well as many riparian trees, especially alders. This bedload and wood melange often created massive debris jams at the tributary confluences. Such areas were often the sites of secondary channel formation.

“Channel modified” and “torrent scour” or “torrent deposition” areas confounded our ability to accurately assess the dimensions of the stream channel, particularly the following metrics:

- Active channel width (ACW)
- Active channel height (ACH)
- Terrace width (TW)
- Terrace height (TH)
- Valley width index (VWI)

Often, the entire old active channel would be filled with bedload, with the stream finding its new channel within, making it difficult to distinguish between active channel margin, low terrace, and high terrace. Our uncertainty in measuring these variables prevented us from confidently subjecting them to statistical analysis.

Overall, dramatic changes in channel morphology and habitat characteristics were limited in scope. Moderate influences of the flood on habitat characteristics, such as increases in secondary channels and percent of surface areas in pools, has the potential to improve salmon habitat if the channel has enough structural elements to maintain and improve the complexity of the stream.

We need to further explore the influence of watershed characteristics and pre-flood conditions on the post flood effects. Total precipitation played a role in the level of channel modification, but not in the resulting inchannel characteristics such as amounts of large wood. The DCA ordination analysis also indicated that the stream variables did not vary in a consistent pattern with flood impact levels, channel type, or gradient.

## CONCLUSIONS

1. Effects of flood varied by geographic region.
2. Overall occurrence of debris torrents was low.
3. Significant changes in channel morphology occurred in the north coast and Cascades geographic regions.
4. Changes in channel morphology showed a relationship to amount of precipitation.
5. Instream characteristics showed changes, but varied by region.
6. Changes in instream characteristics were not directly related to level of impact, gradient, or channel type.
7. Effects on fish habitat across a region suggested potential for positive influences.

## References

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