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A STRATEGY FOR IMPLEMENTATION, EFFECTIVENESS, AND VALIDATION MONITORING OF HABITAT RESTORATION PROJECTS, WITH TWO EXAMPLES FROM THE SKAGIT RIVER BASIN, WASHINGTON.

Report to:

Mount Baker - Snoqualmie National Forest, Mount Baker Ranger District,
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ABSTRACT

This report describes an approach to monitoring the outcome of restoration actions conducted under the Aquatic Conservation Strategy of Northwest Forest Plan, and gives two examples of its application. As outlined in the Aquatic Conservation Strategy, this approach includes implementation, effectiveness, and validation monitoring, each of which is driven by hypotheses about the expected outcome of a project. *Implementation monitoring* checks to see if the project was completed as designed, *effectiveness monitoring* checks to see that the project had the desired effect on a landscape process, and *validation monitoring* checks to see that the project ultimately had the desired effect on a stream habitat condition or fish production. Analyses of past and current conditions in a watershed help us to understand how habitat-forming processes have changed and how each restoration project should help restore them. This guides the development of hypotheses about the expected outcome of each project. Based on these hypotheses, we identify monitoring tasks and methods that are suitable for testing the hypotheses. For each project we identify parameters that are sensitive measures of the changes expected, locations in the watershed where changes are most likely to be detected, and specific tasks and timelines required to complete the monitoring effort.

The first application of this approach is to the monitoring of projects designed to reduce sediment production from forest roads. For a watershed where road sediment reduction projects are planned, we must first ask whether roads or other land uses have significantly altered sediment supply in a watershed, and whether any such changes have affected habitat conditions. The answers to these questions define whether projects are considered protection projects (i.e., intended to prevent future degradation where conditions are currently "good") or restoration projects (i.e., designed to restore degraded conditions where they are currently "bad"). For each case, implementation monitoring simply determines whether each project is carried out as designed. Effectiveness monitoring evaluates whether the project prevents future increases in sediment production or reduces sediment production as intended. This is accomplished through construction of a partial sediment budget, which quantifies sediment inputs through time and by associated land use. Validation monitoring focuses on changes to channel widths and residual pool depths as a way of measuring the effect of changing sediment supply on channel morphology and fish habitat. Measurements from aerial photographs and in the field are required for the validation monitoring.

Applied to the Illabot Creek drainage, this approach to monitoring sediment reduction from forest roads found that road related mass wasting has significantly influenced sediment supply during the last several years, but also that the total supply is not presently high for Illabot Creek. In other words, mass wasting has significantly increased

due to roads in the last decade, but land use overall has caused relatively little mass wasting compared to that from mature forests and naturally unvegetated areas. Between 1994 and 1996, residual pool depths downstream of the alluvial fan (reaches 2, 2.1, 2.2) increased from 10% to 30% whereas residual depths upstream of the fan (reaches 3, 4, and 6) decreased by 10% to 30%. While past road-related sediment supply is one possible cause of decreasing residual depths in these reaches, subsequent mass wasting inventories are required to rule out other potential causes. Our monitoring has also documented significant short-term variation in pool formation by LWD (presumably a result of a >10-year flood), and provided further evidence that a process-based channel typing system is responsive to such variability.

The second application of this monitoring approach is to a fish passage improvement project on Little Park Creek in the Baker River drainage. For fish passage improvement projects, our hypotheses are developed from our understanding of the extent of habitat (types and quality) upstream of the project, the fish species and life stages in the project area that are expected to utilize the reconnected habitat, and other factors that may affect production of these species at the site. Implementation monitoring evaluates whether the project was constructed as specified in the design. Effectiveness monitoring evaluates whether the project has achieved the desired fish passage. Validation monitoring evaluates whether the observed fish production is consistent with the expected production from the site. Effectiveness monitoring includes measurement of water depths and velocities in the passage structure, observations of fish passage at the site, and spawner surveys upstream of the project. Validation monitoring consists primarily of smolt trapping at the site.

Measurements at the Little Park Creek site showed that depths and velocities were generally within the specified passage criteria over the range of flows for which measurements were taken. However, measured velocities were always higher than the design velocities for a specified flow, indicating that velocity will exceed the maximum velocity criteria at flows less than the maximum design flow of 60 cfs. Spawners surveys documented the site's effectiveness for adult coho migration. However, seeding levels have been lower than expected in two of three years, suggesting that short term smolt production will also be less than expected. For validation monitoring, we predicted coho salmon smolt production as a function of escapement to the site using a Beverton-Holt stock recruitment relationship. We estimated carrying capacity based on habitat surveys and density independent survival based on literature values. We predicted that coho smolt production from the site would be limited by the availability of summer rearing habitat, and our first year smolt trapping results support this prediction.

1. INTRODUCTION AND BACKGROUND

In 1994 the Mt. Baker-Snoqualmie National Forest (MBSNF) undertook an expanded watershed restoration program¹. The mandate for this program was included in the Aquatic Conservation Strategy as part of the Northwest Forest Plan (USDA and USDI 1994). The MBSNF program followed guidelines developed by an interagency task group (Interagency Task Group 1993). Under these guidelines, the Task Group identified examples of restoration actions that could be taken within each of several major restoration treatment categories (Appendix 1). The guidelines also facilitated the formation of interagency river basin teams comprised of members from the MBSNF, Indian tribes, and other federal, state or county agencies to participate in selecting watershed restoration projects.

Lacking completed watershed analyses, the Skagit River Basin Local Interagency Team authored Preliminary Watershed Assessments (Appendix 2) and prioritized 19 proposed projects (Appendix 3). These efforts resulted in the completion of nine restoration projects on federal lands within the Skagit River Basin (Table 1-1, Figure 1-1). Only projects related to the treatment categories of road related erosion and stream channels were considered. The nine projects upgraded 47.6 miles of forest road, decommissioned 17.16 miles of forest road, revegetated one landslide, and provided fish passage through two blocking culverts. The total contract cost was \$801,400.

The monitoring component of the Aquatic Conservation Strategy outlines the following objectives: (1) determine if best management practices have been implemented, (2) determine the effectiveness of management practices at multiple scales ranging from individual sites to watersheds, and (3) validate whether ecosystem functions and processes have been maintained as predicted (USDA and USDI 1994, page B-32). Based on these objectives, the Mt. Baker Ranger District developed a monitoring strategy for the MBSNF 1994 Skagit Watershed Restoration effort (Appendix 4). In August of 1994 the Skagit System Cooperative and the MBSNF entered into a Challenge-Cost-Share Agreement (CCS-94-04-05-01-050) entitled: 1994 Skagit Watershed Restoration Monitoring. The purpose of the agreement was to implement the coordinated approach to monitoring outlined in the Mount Baker District's monitoring strategy. This initial monitoring effort was intended to serve as a framework which could accommodate future restoration projects and could incorporate or coordinate with monitoring by other entities throughout the river basin at a broader scale (e.g., the Skagit Wild & Scenic River Water Resource Monitoring Plan [Ralph et. al. 1994]).

¹ This program was outlined in the Forest Ecosystem Management Report (1993) which has since been finalized as USDA and USDI (1994), commonly referred to as the Northwest Forest Plan.

Table 1-1. Restoration Project descriptions and contract costs for 1994 projects completed on federal lands in the Skagit River Basin.

| Project Name | Description | Contract Price |
|--------------------------------------|----------------------------------------------------|------------------------|
| Lime Creek Roads/Reveg. ² | decommission 1.06 miles / 1 landslide revegetation | \$64,200 |
| Illabot Creek Roads | 23.9 miles - upgrade/ 0.6 miles - decommission | \$394,000 |
| Conrad Creek Roads | 10.7 miles - upgrade/ 4.9 miles - decommission | \$36,300 |
| Finney Creek B Roads ³ | 0.9 miles - upgrade/ 6.2 miles - decommission | \$54,000 |
| Little Park Creek Fish Passage | 1 site: fish passage improvement | \$121,000 ⁴ |
| Falls Creek Roads | 2.9 miles - upgrade/ 2.4 miles - decommission | \$50,000 |
| Dan Creek Roads | 9.2 miles - upgrade/ 2 miles - decommission | \$24,900 |
| Boundary Creek Fish Passage | 1 site: fish passage improvement | \$57,000 ⁵ |

This report describes our approach and rationale for monitoring two restoration treatment types: (1) reduction of erosion from forest roads and (2) fish passage improvement. We also present the monitoring hypotheses, current results, and recommendations from two projects (Illabot Creek Roads and Little Park Creek Fish Passage) completed as part of the MBSNF 1994 Skagit Watershed Restoration Program (Table 1-1, Figure 1-1).

² In 1993, the Forest decommissioned and storm proofed another 4 miles and 2.4 miles of forest road respectively, for a total of \$57,000.

³ We note that additional forest road decommissioning and upgrade has recently taken place in the Finney watershed (25.65 miles on USFS land and 11.26 miles on private land) -- see Beechie et. al. (1997).

⁴ The total cost for the Little Park Creek fish passage project was \$165,000 (includes design cost and WDFW's cost share).

⁵ The total cost for the Boundary Creek fish passage project was \$117,200 (includes design cost and WDFW's cost share).

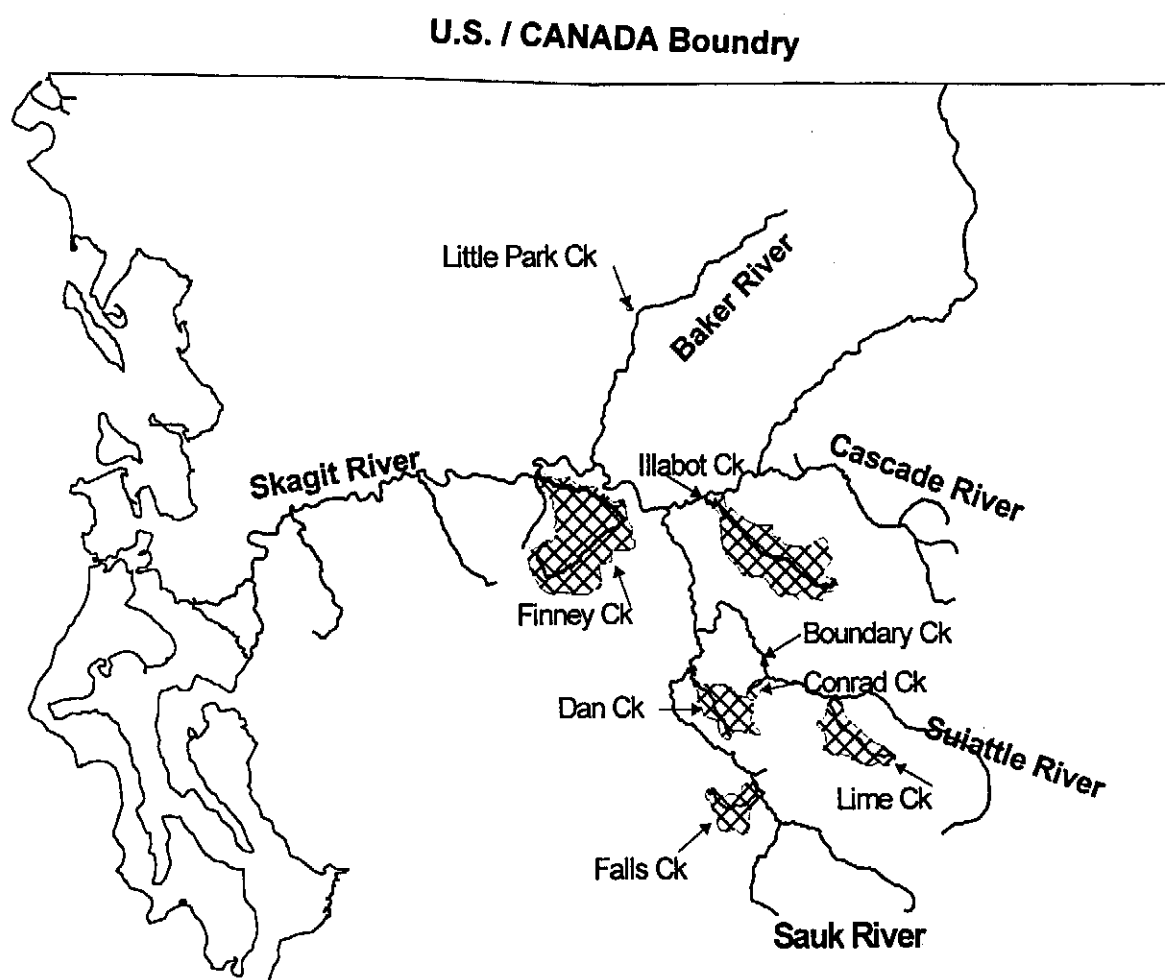


Figure 1-1. Location of watersheds in which restoration projects were implemented by MBSNF in 1994.

2. GENERAL MONITORING APPROACH

The first step in our monitoring approach is to identify the intent of proposed watershed restoration projects (i.e., protection or restoration). In cases where projects have been identified from a watershed analysis⁶, distinguishing between protection and restoration projects usually follows logically from the results of the analysis. In cases where watershed analysis has not been completed, we develop hypotheses about how land-use has altered watershed processes and fish habitat. The second step is to develop hypotheses about the expected results of the proposed protection or restoration actions. Finally, we identify the monitoring methods and tasks that allow us to test our hypotheses.

2.1 DEFINITIONS OF PROTECTION AND RESTORATION

When planning to monitor the effectiveness of watershed projects that target improvement or maintenance of stream habitat, it is important to understand the objectives of the projects and the expected outcomes for stream habitat. The objectives of watershed projects may be broadly classified as either protection or restoration.

Protection actions are those that are intended to protect existing good quality habitat by preventing or minimizing future impacts, whereas *restoration* actions are those that are intended to help restore habitats in poor condition.

For watershed/habitat *protection* projects, we know (or perceive) that stream habitat is generally in good condition, but that past land-use actions have put this habitat at risk (e.g. roads that have the potential to cause landslides in the future). In these cases, actions are intended to protect habitat that is currently in good condition by preventing or minimizing land-use related impacts.

For watershed/habitat *restoration* projects, we know (or perceive) that stream habitat is generally in poor condition, and that past land-use actions have caused the degraded condition. These actions are intended to help restore habitat that is currently in poor condition by reducing future impacts or accelerating the recovery of fish habitat. That is, these actions are designed to help restore habitat to pre-management conditions. Similarly, where access to habitat has been limited or eliminated, restoration is designed to restore connectivity of existing habitat.

⁶ In this paper, We refer to “watershed analysis” as a scientific framework where the analyst identifies:

- the natural processes active in a watershed,
- the effects of land use on natural processes, and
- the causal relationships between land use and habitat conditions.

We are not necessarily referring to the formal Washington State Watershed Analysis or Federal Ecosystem Analysis methodologies.

2.2 DEVELOPMENT OF HYPOTHESES AND IDENTIFICATION OF MONITORING METHODS.

The next step in our rationale for developing monitoring plans is to describe past and current conditions in a watershed, and to develop hypotheses about the expected outcome of a restoration or protection project. Ideally, a watershed analysis will describe past and current habitat conditions, and will also clearly indicate which landscape processes and land-use impacts have caused changes in habitat conditions. In such cases, it is unnecessary to develop hypotheses regarding changes to habitat and linkages to land-use, because causes and effects are already understood. In this case, the objectives of watershed projects stem from relatively straight-forward results of watershed analysis.

Without a watershed analysis, we generate hypotheses of past and current conditions based on available data, and test these hypotheses early in the monitoring effort. These hypotheses may be based on limited data, or on the professional judgments of local managers and scientists. Typically, there are some data available to help describe current conditions, but assessing changes from past conditions are usually based on a series of assumptions about historical conditions and on the processes that cause changes to habitat. From these hypotheses, we can then develop hypotheses concerning the expected outcome of protection or restoration projects.

With this series of hypotheses, the monitoring objectives should be relatively clear. That is, the hypotheses identify specific processes or habitat characteristics that projects are expected to restore or protect, and they further identify the expected trend for each process or habitat characteristic. We then identify monitoring tasks and methods that are suitable for testing the hypotheses. The steps involved include identifying parameters that are sensitive measures of the changes expected, identifying locations in the watershed where changes are most likely to be detected and where changes will be most pronounced, and identifying specific tasks and timelines required to complete the monitoring effort. Finally, additional monitoring variables and tasks may be identified based on existing knowledge of processes or inputs that may affect or confound interpretations of the results.

3. APPROACH TO MONITORING AND EVALUATION OF SEDIMENT REDUCTION FROM FOREST ROADS

This section describes the rationale for our approach to monitoring sediment reduction from forest roads, how we selected parameters for monitoring, and monitoring methods.

3.1 BACKGROUND

3.1.1 Sediment supply and routing in a watershed

Most of the supply of sediment to stream channels in a mountainous watershed is generated by three types of processes: mass wasting (landsliding), surface erosion, and soil creep (see Paulson 1997 for review). Mass wasting and surface erosion can be significantly affected by forest management activities, whereas forest management effects on soil creep have not been measured. Forest management effects on mass wasting have the greatest effect on the supply of coarse sediment to stream channels because much of the sediment produced by mass wasting is greater than 2 mm diameter (Paulson, unpublished data). This coarse sediment tends to travel as bed load, and can have relatively large effects on channel morphology as it moves through the network at the rate of a few hundred to a few thousand meters per year (Madej and Ozaki 1996). By contrast, surface erosion tends to produce fine sediment (Paulson, unpublished data), which is transported through the stream network as wash load, suspended load, or more rapidly moving bed load (Beschta 1987).

Forest management effects on mass wasting are most commonly noted as one of two types: loss of root strength due to logging, and failure of road side cast or fills (Sidle et al. 1985). Increases in soil moisture due to rain-on-snow events in clearcut or immature (< 20 year) forest areas or misdirected ditch drainage may also be factors in increasing mass wasting (Sidle et al. 1985). The relative influence of the two primary factors (lost root strength and road failures) are typically documented through a mass wasting inventory in which landslides are documented along with the associated land use. From these data, annually averaged rates of mass wasting (# slides/area/year) or sediment production (sediment volume/area/year) are calculated so that the relative influence of each cause can be compared to the mass wasting rates from mature forest areas.

Sediment that is supplied to stream channels by mass wasting is either stored in the channel/floodplain or transported through the stream network. An understanding of how sediment is routed through the network is important for determining where sediment will have the greatest effect on salmonid habitat, and for determining which areas of potential mass wasting have the greatest likelihood of affecting habitat. From field data, one can gain an understanding of how sediment is stored or routed through different parts of the

stream network in a watershed. In general, field data for this type of assessment include estimating the volumes (based on field measurements) and timing (based on aerial photo interpretation) of sediment storage, as well as the particle sizes of stored sediment in different types of storage sites (e.g. channel bed, bars, flood plain). These data can then be used to interpret where sediment is stored in the channel network, and what sizes of sediment are transported through various stream segments.

3.1.2 Effects of increased sediment supply

Changes in sediment supply to stream reaches have their most obvious effects in “response” reaches, which are low gradient segments of the stream network where sediment tends to deposit more readily or travel more slowly (Montgomery and Buffington 1993). Response reaches are generally identifiable on USGS 7.5' topographic maps, but should be verified using aerial photography and field observations.

Changes in the sediment supply to stream channels have several effects on salmonid habitat characteristics, including changes in habitat capacity and in salmonid survival (e.g., Collins et al. 1994, Chapter 6). Large increases in coarse sediment supply fill pools and aggrade the channel (e.g., Lisle 1982), resulting in reduced habitat complexity and reduced rearing capacity for some salmonids (e.g., Collins et al. 1994). Large increases in total sediment supply to a channel also increase the proportion of fine sediments in the bed (Dietrich et al. 1989), which may reduce the survival of incubating eggs in the gravel.

The effects of changes in supply of coarse sediment to a stream are reflected in the channel by several indicators, including residual pool depth, scour depth, and the proportion of fines in the surface (armor) layer of the bed (Dietrich et al. 1989). However, each of these indicators can be misleading if data are collected at only one point in time. Evaluating the indicators over time is the most useful method of assessing changes in habitat conditions that result from changes in sediment supply. Reductions in residual pool depths as a result of increased sediment supply have been documented in the region (Collins et al. 1994), and habitat-based salmonid production models have been used to estimate the degree to which rearing capacity has been reduced by loss of pools (Collins et al. 1994). Increases in scour depth as a function of sediment supply have also been documented locally (G. Pess, Tulalip Tribes, personal communication). Increased fines in the armor layer of the bed have been documented in the literature (Dietrich et al. 1989).

3.2 APPROACH

3.2.1 Identification of Hypotheses

With the preceding background in mind, we generate hypotheses of how sediment supply and routing have affected fish habitat in a watershed. Each hypothesis can then be “tested” to the extent that we can analyze whether field and aerial photo data clearly

support or refute the hypothesis. Ideally, some of the hypotheses would be unnecessary because our understanding of the habitat and sediment supply problems would have been generated from a watershed analysis. However, in watersheds where we do not have completed watershed analyses, hypotheses about the mass wasting history and linkages to current habitat conditions can be stated and subsequently tested during the initial phase of monitoring.

For coarse sediment impacts, the description of watershed conditions (or hypotheses about watershed conditions) must include a response to each of the following questions.

- What are the land-use related changes in coarse sediment supply?
- What has been the influence of roads on mass wasting?
- How have changes in sediment supply affected habitat conditions?

These responses describe the situation to which managers respond when selecting sediment reduction actions, and establish whether the action is one of protection or restoration. If the responses are not based on relatively complete data, the first phase of monitoring should provide data to answer these questions. This step is important for understanding current conditions, creating a hypothesis of how watershed/habitat conditions will respond to sediment reduction efforts, and providing baseline data for future monitoring.

3.2.2 Identification of monitoring tasks.

Three types of monitoring can be used to monitor protection or restoration projects: implementation, effectiveness, and validation (USDA Forest Service et al. 1994).

Implementation monitoring simply evaluates whether protection or restoration projects were carried out as designed. *Effectiveness monitoring* evaluates whether projects achieved the desired effect (in this case reduced sediment supply). *Validation monitoring* evaluates whether hypotheses about the cause and effect relationship between the management action and habitat conditions (or fish production) were correct. For each road sediment reduction project, the identification of monitoring tasks should: (1) be based on the hypotheses describing the disrupted (or altered) watershed process and the expected outcome of the protection or restoration action, and (2) consider each of the three types of monitoring.

Increases in sediment supply due to mass-wasting may be due to poorly constructed or aging roads, or other land uses such as logging. For the watersheds targeted in this monitoring agreement, sediment reduction efforts focus on roads, and will consist of either decommissioning or reconstructing portions of the road system that present a hazard to fish habitat. Our first task is to determine how much of the change in sediment supply is due to roads. We do this by constructing a partial sediment budget, which

describes the amounts of sediment generated by various sediment supply processes and how different land uses have influenced those processes. If most of the increase is due to roads, we can expect road restoration efforts to have a large effect on reducing sediment supply. If there is little increase in sediment supply, we expect road sediment reduction efforts to prevent roads from causing an increased sediment supply in the future.

The second task is to determine which aspects of existing roads are causing mass wasting. Failures are typically of two types: failure of stream-crossing fills and failure of side-cast material. Road work (the sediment reduction project) will focus on reducing the likelihood of these failures occurring, which means that fills and side-cast are removed or reconstructed so they will not fail where they have the potential to enter streams. This helps to focus sediment reduction work on the causes of increased mass wasting. The initial landslide inventory, which is completed as part of the sediment budget, documents the types of road failures that cause increased sediment supply. Future *effectiveness monitoring* (repeating the landslide inventory with each new aerial photo series) will determine whether these types of road failures have been successfully reduced by the sediment reduction project.

Next we create hypotheses about the types of habitat responses we expect to see when sediment supply is increased or decreased. In these watersheds, we anticipate that the most likely effect of increased sediment supply is a change in residual pool depth similar to that found by Collins et al. (1994). We expect that under increased sediment supplies, residual pool depth will decrease. Therefore, we expect residual pool depths in watersheds with relatively intact habitat (those in need of protection type actions) to be relatively high, and to remain high if road reconstruction work is successful. In watersheds with degraded habitat (those in need of restorative type actions), we expect residual pool depths to increase over time as sediment reduction efforts decrease sediment supply. Therefore, *validation monitoring* will consist of habitat surveys that focus on pool formation and residual depths.

Finally, we identify locations in the stream which are most sensitive to changes in sediment supply. Increases in sediment supply are more likely to affect habitat conditions in response reaches than in source or transport reaches (Montgomery and Buffington 1993). We therefore focus validation monitoring efforts on response reaches, which are typically low-gradient reaches of stream where sediment tends to deposit most easily.

Once the monitoring reaches are identified, we can select monitoring parameters and methods (see sections 3.2.3 and 3.3). For sediment reduction projects, we can summarize the monitoring objectives as:

- Use a partial sediment budget to confirm that changes in sediment supply due to roads are significant, and to estimate the magnitude of the “natural” sediment supply

(*watershed analysis* substitute).

- Check to see whether road decommissioning or reconstruction were carried out as planned (*implementation monitoring*).
- Use aerial photo landslide inventories and field surveys of landslide sites in future years to determine if the work reduces sediment supply as expected (*effectiveness monitoring*).
- Monitor habitat conditions to determine whether residual pool depths respond as expected (*validation monitoring*).

We do not carry validation monitoring of sediment reduction projects to a measured fish population response due to the numerous other variables also influencing fish populations. However, we can use habitat-based fish production models to illustrate the expected effects of a project on a variety of fish species at a variety of life stages.

3.2.3 Selection of monitoring parameters

The selection of monitoring parameters in streams should consider the relevance of the parameter to the anticipated effect of reducing sediment supply, and the accuracy and precision with which measurements can be made under changing environmental conditions. For validation monitoring of sediment reduction efforts, we want to determine whether or not existing habitat conditions are maintained in watersheds with good quality habitat (protection watersheds) or restored in the future (restoration watersheds). The most pronounced habitat effect of increased sediment supply is expected to be a reduction of pool depths (e.g., Collins et al 1994). Increased fine sediment in the armor layer of the bed (measured as Q^* , Dietrich et al. 1989), channel widening, and increased scour depth are also potential effects. Of these possibilities, residual depth and channel width are the most repeatable measurements because they are independent of the flows at which measurements are taken. Scour depth is a function of the flood discharges preceding scour chain recovery, and current Q^* methods appear to result in measurements that are confounded by flood-caused changes in channel width. We therefore selected the RAPID method of monitoring changes in channel width (Grant 1988), and the measurement of residual pool depths (e.g., Lisle 1982) as the most reliable methods of monitoring changes in habitat conditions that are due to changes in sediment supply.

3.3 METHODS

3.3.1 Partial sediment budget (initial conditions and effectiveness monitoring)

A partial sediment budget (e.g., Paulson 1995) consists of a mass wasting inventory, an estimate of sediment volume produced by mass wasting, an estimate of sediment volume delivered by soil creep, and an estimate of sediment volume contributed by surface erosion. (It does not include estimates of storage or routing in the channel network.)

Methods for each component of the partial sediment budget are described in Paulson (1995). The estimates of sediment supply from different sources are used to determine which sediment producing processes are most important in a basin, and to estimate the magnitude of the effect of land-use on sediment supply. These data can also be used to identify which landforms are prone to mass wasting, which land-use activities affect mass wasting rates, the average annual sediment supply, and the temporal variation in mass wasting and surface erosion over the last 40-50 years.

The sediment budget constructed at the beginning of the monitoring effort provides a historical overview of sediment supply in a watershed, and provides baseline data for the effectiveness monitoring in subsequent years. The landslide inventory is repeated in future years by reviewing each new set of aerial photos as they become available, and by field surveying the volumes and causes of individual landslides. By monitoring the volumes of sediment produced in each photo period and the causes of mass wasting, one can determine whether the sediment reduction efforts were effective in preventing or reducing the road-related component of mass wasting.

The sediment budget is simply a quantification of sediment supply, storage, and routing in a watershed. For our monitoring, we incorporated quantification of sediment supply to the channel network over the time period of historical air photos (approximately the last 50 years) in order to describe the history of sediment supply to the channel network and to evaluate the effect of land use on sediment supply. Specific methods for constructing the sediment supply portion of a sediment budget are discussed in detail in Paulson (1995).

3.3.2 Identification of response reaches

In watersheds where sediment reduction efforts are planned, response reaches (stream reaches that respond most dramatically to changes in sediment supply) are identified so that validation monitoring efforts can be limited to areas where responses to changes in sediment supply will be most pronounced. Response reaches generally have channel gradients less than 3% to 4% (Montgomery and Buffington 1993) and can be initially identified using topographic maps. Measurements of changes in channel width over time, which can be measured from aerial photographs, are also a useful tool for locating response reaches. Reaches that have widened significantly are usually low-slope response reaches where bed aggradation has led to erosion of the stream banks. Bed aggradation and channel widening tend to be most obvious in response reaches because of their low sediment transport capacity, and because they often have relatively wide flood plains that are susceptible to erosion. When sediment supply exceeds sediment transport capacity, the channel bed must aggrade to accommodate the increased storage of sediment, which subsequently leads to bank erosion as flood flows are forced overbank. However, it is important to recognize that channel widening measured in aerial photography can also be

caused by large floods and logging of riparian forests, and therefore should not be considered a definitive indication that sediment supply has increased.

Once the suite of response reaches has been identified, a sub-set of these reaches may be selected for monitoring. When several response reaches are in sequence, or when several response reaches are difficult to access, it may be desirable to focus monitoring effort on those reaches where responses have been or are expected to be greatest. By targeting fewer reaches, monitoring effort can be more cost effective when a large area must be covered.

Sediment routing and storage in the channel network are evaluated separately, using a variation of the RAPID technique (Grant 1988) on aerial photos and collecting field measurements of depths of sediment stored in the channel. Channel widths were measured to the nearest tenth of a millimeter on individually scaled 1:12,000 or 1:24,000 aerial photos covering the time period of historical aerial photography. From the RAPID data we estimate the change in surface area of sediment stored in different sediment storage features (e.g., bed, bars and floodplain). Field measurements of the depths of these features with a hand level (or clinometer) and stadia rod allows the estimation of volume of sediment stored.

3.3.3 *In-channel habitat surveys*

This section describes the methods used in habitat surveys to characterize in-channel habitat conditions for each monitored stream reach. The following parameters are useful for evaluating our monitoring hypotheses because stream flow variation during the measurement season does not bias results⁷.

Stream reaches selected for monitoring (previous section) are numbered and classified by channel type based on Montgomery and Buffington (1997). The length of each reach is measured by hip chain to the nearest 1 m. Channel width (bankfull) is measured to the nearest 0.1 m at approximately every 5 to 10 channel widths and averaged for a reach. The basic channel types are pool-riffle, forced pool-riffle, plane-bed, and step-pool channels. We also distinguish sub-types based on the dominant pool forming mechanisms as follows:

- *Pool-riffle channels (PR)*: Pool-riffle channels are commonly found at channel slopes between ~0.5% and ~2%, and have pool spacing > 4 channel widths per pool. They typically exhibit regularly spaced alternate bars and pools that are formed without in-

⁷ The results are expected to change as a function of the peak flows experienced by the stream reach between monitoring surveys. Our surveys are conducted during the low flow period of the water year when sediment and LWD are not typically supplied or transported in a channel network.

channel obstructions. Pool-riffle channels where some of the pools in the reach are formed by woody debris (but not > 50%) are classed as sub-type *PRw*.

- *Plane bed channels (PB)*: Plane bed channels are usually found at channel slopes between ~2% and ~4%, and have pool spacing > 4 bankfull channel widths per pool. They consist primarily of riffle area, lack the free-forming bars and pools common in PR channels, and require in-channel obstructions to create pools.
- *Forced pool-riffle channels (fPR)*: Forced pool-riffle channels are found at slopes from ~0.5%~4% (covering the range of both pool-riffle and plane bed channels), and have pool spacing < 4 bankfull channel widths per pool. More than half of the pools are formed as a consequence of in-channel obstructions such as woody debris (*fPRw*), bedrock (*fPRbdrk*), or boulders (*fPRblr*).
- *Step-pool channels (SP)*: Step-pool channels are found at higher channel slopes, generally ranging from ~4% to ~8%. These channels exhibit channel spanning steps visible in the low-flow water surface profile. The steps are generally formed by boulders organized into small dams.

Large woody debris (LWD) within the bankfull channel is tallied in each reach for the purpose of quantifying relationships between LWD frequency and the number of pools in a reach. LWD was tallied in three size classes: 10-20 cm diameter and > 2 m in length (small), 20-50 cm diameter and > 3 m in length (medium), and >50 cm diameter and > 5 m in length (large).

Pools are identified in a manner similar to that of Bisson et al. (1982), except that some categories were grouped in order to increase consistency among observers. In general, pools are areas of deeper and slower water with little surface turbulence. For the purpose of our monitoring, we define pools as topographic depressions that occupy more than half the wetted channel width. Maximum and tail water pool depths are measured to the nearest centimeter with a measuring rod. Residual depth is the maximum depth minus the tail water depth.

The primary pool forming mechanism is recorded for each pool in monitored PR, fPR, and PB reaches. Pool forming mechanisms are listed in Appendix 6. The height (nearest 0.1m), volume (nearest 0.1m³), and type (individual logs or jams) of pool-forming LWD accumulations were also measured in order to identify relationships between size of an obstruction and residual depth of a pool. These relationships are used to assure that any changes in pool characteristics resulting from changes in amount or size of LWD will not be wrongly attributed to changes in sediment supply.

3.3.4 Use of habitat-based fish production models

Models that estimate fish production potential based on stream habitat conditions are useful in understanding the probable impact of a project on fish. First, these models help

us identify the relative importance of different areas within the stream network for fish production potential. These areas can then be spatially related to disturbances (past, present or future) within the watershed. Secondly, as habitat conditions change (i.e., improve or degrade) over the monitoring period, the model results can illustrate the corresponding change in fish production potential.

The habitat-based models that we suggest using for this purpose should have habitat inputs that are sensitive to change as a result of the stream habitat recovering or degrading. We selected two models for use in this assessment: Reeves et. al. (1989) for juvenile coho, and Marshall et. al. (1980) for juvenile steelhead. Both models are based on the area of different habitat unit types (e.g., pools, glides, riffles etc.). For each unit type, there is a corresponding average density of juvenile fish (number of fish per unit area), and an estimated survival to a life stage (e.g., smolt, parr) . The estimated production for each unit is $density \times area \times survival$. Stream habitat area data are aggregated based on the stream reaches identified for each watershed, and fish production potential for each reach is the sum of production from all individual units.

Changes in pool depth may be seen in habitat surveys as (1) changes in the identification of units (i.e., where very shallow pools are identified as glides or flats rather than pools), or (2) as changes in residual pool depth for some pools that remain identifiable as pools. Changes of the first type are reflected in fish production values for each of the two models that we use in this monitoring program, whereas changes of the second type are not. This suggests that only extreme changes in residual depth can actually be reflected in estimates of fish production (e.g., Collins et al. 1994).

There are some differences between the two models, the most important of which is in the unit types used for analysis. Juvenile steelhead production is related to the percentage of riffle area in boulders (Marshall et. al. 1980), because boulders > 0.3 m diameter protruding above the substrate create "pockets" of suitable rearing area for steelhead. This phenomenon has not been observed for coho salmon. However, in both models, production is also related to other unit types including pools, flats (or glides), and runs. Despite a different suite of unit names used by Reeves et al. (1989), there is significant overlap in unit definitions for the two models. Hence, with the addition of percent boulder in riffles to our data collection, we are able to use the habitat model for steelhead as well as the model for coho salmon.

3.3.5 Integration of results

As in a watershed analysis, the trend of a single effectiveness or validation monitoring parameter should not be interpreted in isolation from other monitoring results. For sediment reduction projects, effectiveness monitoring will look for expected trends in road-related landslide rates and sediment volume delivered to streams (Table 3-1). Where

sediment reduction projects have been completed (and confirmed by implementation monitoring), landslide rates and delivered sediment volume should remain low in protection watersheds and should decrease in restoration watersheds. Either result can be monitored by updating the landslide inventory and sediment budget in future years.

For the selected channel monitoring parameters (channel width and residual pool depth) it is important to recognize that the supply of sediment is not the only factor that causes changes. Channel width can be affected by flooding and riparian logging (e.g., Collins et al. 1994), and residual pool depth can be affected by the size of woody debris that forms pools (e.g., Hansen Watershed Analysis 1994, see also Figure 4-8 in this report). Therefore, it is important to monitor other parameters that will provide the data required to sort out the causes of changes in the validation monitoring parameters. For residual depth, we monitor the amounts and sizes of woody debris in channels so that we can distinguish between changes in residual depth that are caused by changes in sediment supply from those that are caused by changes in the size of woody debris that forms pools. For channel width, we use the landslide inventory and our understanding of sediment routing to determine whether or not changes in channel widths are consistent with changes in sediment supply.

Because changes in channel widths and residual pool depths are affected by a number of watershed processes, all monitoring parameters must be evaluated together. For example, even if both channel width and residual depths follow the expected trends (Table 3-1), we cannot conclude that sediment reduction efforts were responsible for those changes in the absence of other data. For monitoring efforts conducted under this agreement, additional data will include amounts and sizes of woody debris, landslide rates, and sediment supply.

Table 3-1. Expected trends in monitoring parameters for response reaches of each watershed type assuming no significant change in LWD loading or effect of large floods.

| Parameter | Protection watershed | Restoration watershed |
|------------------------------------------------|----------------------|-----------------------|
| Road-related landslide rate | Remain low | Decrease |
| Road-related sediment supply | Remain low | Decrease |
| Overall sediment supply | Remain low | Decrease |
| Proportion of watershed in immature vegetation | Assume no change | Assume no change |
| Channel width | No change | Decrease |
| Residual pool depth | No change | Increase |

Storm and flood records in the Skagit basin are also critical in interpreting the results of monitoring efforts. If both channel widths and residual pool depths follow the expected trends, we should only conclude that these changes were the result of sediment reduction efforts if each of the expected trends in Table 3-1 are confirmed.

Due to natural variations in storm intensities and floods, a variety of possible outcomes exist for these restoration projects. Hence, trends in residual depths or channel width that contradict the expectations in Table 3-1 do not necessarily indicate that the initial hypotheses of habitat response were incorrect. For example, residual pool depth may not increase or may even decrease in a watershed where road-related landslide rates and road-related sediment supply has decreased as a result of restoration projects. This can occur if (1) the overall sediment supply increases (from landslide sites other than roads) and sediment continues to fill pools even though road-sediment reduction efforts were effective, or (2) sediment stored in the channel upstream of monitored reaches is transported into the reach and fills pools. Because there is a large number of possible outcomes, we did not feel that it was necessary to sort through all possible combinations of monitoring results in generating hypotheses to guide this monitoring effort. However, we recognize that in any analysis of validation monitoring results, all of the monitoring data (including implementation and effectiveness) must be consistent with any interpretation of validation monitoring results.

4. SEDIMENT REDUCTION FROM ROADS IN ILLABOT CREEK

This section of the report describes the Illabot Creek sediment reduction project, its monitoring hypotheses, monitoring results through 1996, and recommendations for monitoring tasks to be conducted in future years.

4.1 ILLABOT CREEK PROJECT DESCRIPTION

The Illabot Creek sediment reduction project addressed road erosion and sedimentation using storm proofing and decommissioning treatments. Storm proofing on forest road 16 included sidecast pullback, installing additional and larger culverts, adding road dips, lowering and reconstructing fills and riprap protection. Road decommissioning on roads 1600012 and 1600012a spur included removing fills and culverts in stream channels, removing cross culverts and installing dips, pulling back sidecast material, and outsloping the road. All disturbed areas were seeded and mulched with a minimum of 4 inches of straw. Approximately 24 miles of road were treated (Figure 4-1).

Because there appeared to be little road-related increase in sediment supply to Illabot Creek over the past few decades, this project was considered a “protection” project. Road storm proofing was expected to reduce the existing risk of catastrophic failures into Illabot Creek and its tributaries. Road decommissioning was expected to have the same effect as road storm proofing, but since the road fills in the drainages are removed, the risk of future failure was expected to be lower.

4.2 ILLABOT CREEK MONITORING HYPOTHESES

Monitoring hypotheses for Illabot Creek include three statements that describe the current conditions of the watershed as perceived by USFS and SSC, and two statements of the anticipated outcome of sediment reduction projects.

Hypotheses of current condition:

1. Sediment supply has not been significantly increased by land-use in Illabot Creek watershed.
2. Mass wasting has not increased significantly due to road failures in Illabot Creek watershed.
3. Residual pool depths have not been significantly affected by changes in sediment supply in Illabot Creek watershed.

Hypotheses of anticipated future condition:

4. Road-related mass-wasting rates and sediment supply are not expected to increase in the future (assuming road sediment reduction projects are completed).
5. Residual pool depths are expected to remain high in Illabot Creek watershed as road sediment reduction efforts prevent future increases in sediment supply.

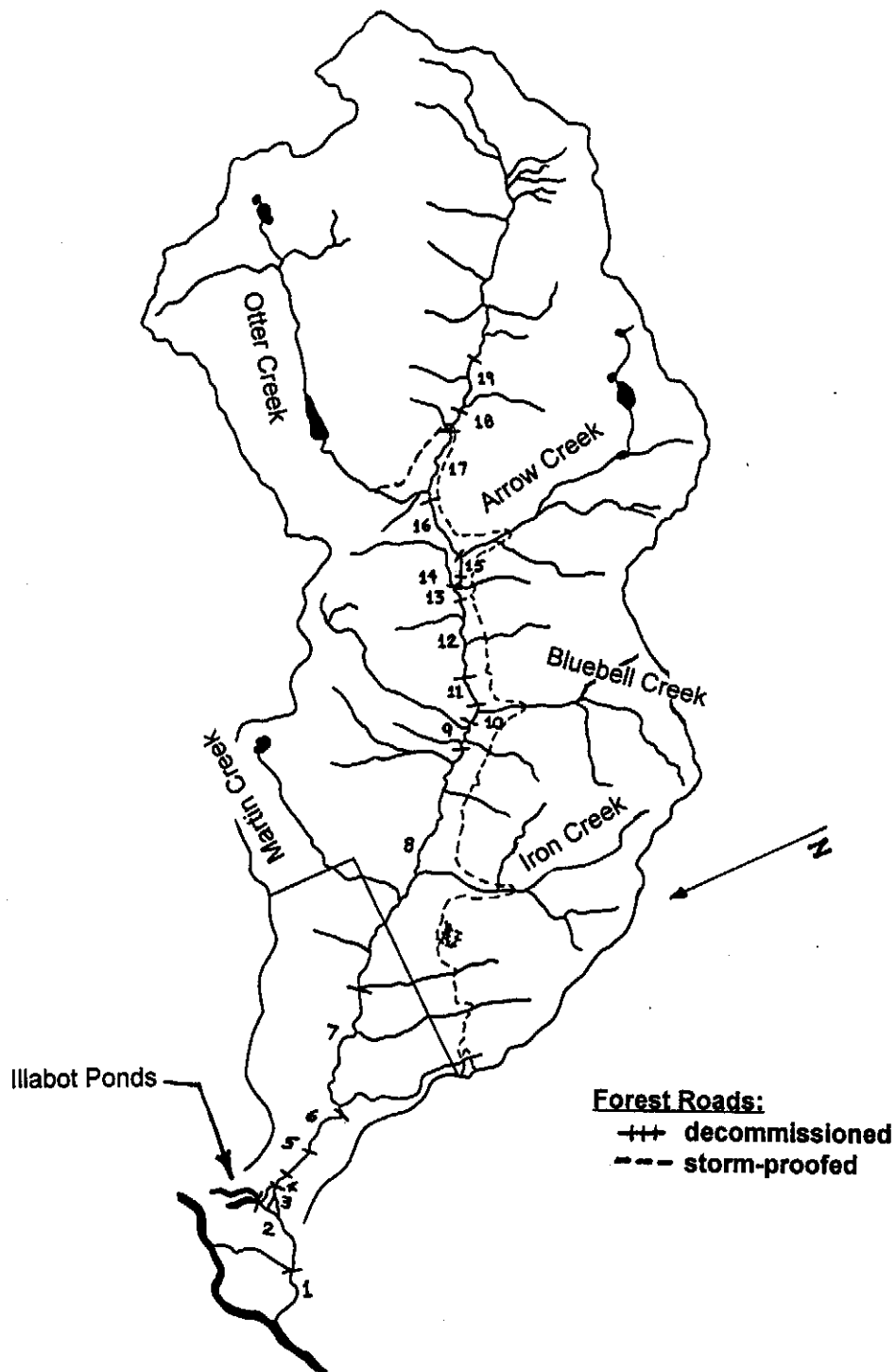


Figure 4-1. Map of Illabot Creek watershed with stream reaches and sections of road decommissioned or storm-proofed.

The first three hypotheses are those that describe our present understanding of sediment supply and habitat conditions in Illabot Creek watershed. Each hypothesis will be tested in the early stages of monitoring as data describing past and current conditions are collected. These initial monitoring data are used to confirm our initial hypotheses of watershed and habitat conditions (1 through 3 above), as well as to document the current conditions to which subsequent monitoring data will be compared. The fourth and fifth hypotheses describe the anticipated outcome of sediment reduction efforts in Illabot Creek watershed. These hypotheses will be tested in future years by comparing future monitoring data to those collected in the first year.

If the hypotheses of current conditions are shown to be incorrect (hypotheses 1 through 3), then hypotheses 4 and 5 may change. For example, if initial monitoring results show that residual pool depths are low and sediment supply has been significantly increased, then hypotheses 4 and 5 would read as follows:

4. Road-related mass-wasting rates and sediment supply are expected to decrease in the future as road sediment reduction projects are completed.
5. Residual pool depths are expected to increase in Illabot Creek watershed as road sediment reduction efforts reduce sediment supply in the future.

In the event that initial data change the hypotheses of future trends, all monitoring methods will remain the same because the same data are required to evaluate either set of hypothesized outcomes for sediment reduction efforts.

4.3 RESULTS OF ILLABOT CREEK MONITORING THROUGH 1996

4.3.1 Peak Flows

Beechie (1992) delineated hydrologic regions within the Skagit River basin on the basis of flow, elevation, and precipitation characteristics. Because there is no active stream flow gage in Illabot Creek, we used two active USGS stream flow stations to estimate the magnitude of peak flows experienced by Illabot Creek (Table 4-1). As discussed earlier, peak flow information is important for properly interpreting monitoring results (see discussion in section 3.3.5, Table 3-1).

The Sauk River above Whitechuck River gage (USGS station number 12186000, basin area = 394 km²) and Newhalem Creek gage (USGS station number 12178100, basin area = 72 km²) measure flow from unregulated basins (i.e., no dams) like Illabot Creek (basin area = 115 km²) and have long periods of record thus enabling the development of flow

frequency analysis⁸.

Table 4-1. Relationship between peak flow and flood recurrence interval from USGS (1997) for two basins within the same hydro-region as Illabot Creek. 95% confidence limits in brackets.

| Flood Recurrence Interval (year) | Sauk R. above Whitechuck R. peak flow in cfs | Newhalem Creek peak flow in cfs |
|----------------------------------|----------------------------------------------|---------------------------------|
| 2 | 9,217 (8,302 - 10,220) | 1,962 (1,665 - 2,307) |
| 5 | 14,790 (13,220 - 16,810) | 3,254 (2,742 - 4,014) |
| 10 | 19,360 (17,010 - 22,640) | 4,298 (3,538 - 5,551) |
| 25 | 26,260 (22,470 - 31,890) | 5,845 (4,646 - 8,012) |
| 50 | 32,280 (27,080 - 40,320) | 7,170 (5,552 - 10,260) |
| 100 | 39,130 (32,190 - 50,220) | 8,652 (6,530 - 12,890) |

In water years 1995 and 1996, Newhalem Creek experienced peak flows of 1400 cfs (< 2 yr. event) and 4500 cfs (~ 10 year event) respectively. The Sauk River above Whitechuck River, experienced peak flows of 8,390 cfs (within the 95 % confidence limit of a 2 yr. event) and 24,100 cfs (~ 25 year event) respectively. Peak flow in Illabot Creek was probably ≤2 year flood event in 1995 and between a 10 and 25 year event in 1996. Therefore, for water years 1995 and 1996, we conclude floods were “normal” and “greater than normal”, respectively.

We also estimated flood magnitude in Illabot Creek for the periods corresponding to intervals used in the partial sediment budget (Table 4-2).

Table 4-2. Estimated number of flood events in Illabot Creek for the periods corresponding to intervals used in the partial sediment budget, 1950 - 1991.

| Time Period | Number of events: recurrence interval |
|-------------|-------------------------------------------|
| 1950 - 1956 | 1: >25 yr., 1: 10 yr., 2: 5 yr., 3: 2 yr. |
| 1957 - 1964 | 2: 5 yr., 6: 2 yr. |
| 1965 - 1972 | 1: 5 yr., 2: 2 yr. |
| 1973 - 1985 | 1: 100 yr., 3: 10 yr., 4: 5 yr., 6: 2 yr. |
| 1986 - 1991 | 1: 25 yr., 1: 10 yr., 2: 5 yr., 4: 2 yr. |

4.3.2 Sediment supply

The assessment of historical sediment supply provides two important pieces of data. First it confirms or refutes the initial hypotheses that USFS roads in the Illabot Creek watershed have not contributed significantly to an increase in sediment supply, but that future failures may increase sediment supply to Illabot Creek. Second, if the initial hypothesis is correct, it provides baseline sediment supply data that will be used in subsequent years to estimate whether the road treatments were successful in preventing

⁸ The Sauk River flood frequency analysis used annual peaks from 1918 through 1996. The Newhalem Creek flood frequency analysis used annual peaks from 1961 through 1996.

increased sediment supply to Illabot Creek.

Results of the sediment supply assessment are in the report entitled "Estimates of land-use effects on sediment supply in the Illabot Creek watershed, Skagit County, Washington" (Paulson 1995), which was completed under sub-contract to Skagit System Cooperative as part of this cost-share monitoring agreement (#CCS-94-04-05-01-050), and submitted to USFS in April 1995. The report concludes that total sediment supply to streams is about 50% above the estimated "background" or natural rate, but that sediment supply in Illabot Creek remains low compared to other basins managed for timber harvest in the North Cascades. The increase in sediment supply due to mass wasting from roads was largest during the 1985-1991 photo period, when road-related failures accounted for about 40% of the total sediment produced by mass wasting. However, total sediment from mass wasting during the 1985-1991 photo period remained lower than total mass wasting during the period prior to 1964 (16,762 yd³ compared to 144,955 yd³; Table 4-3), when road-related mass wasting accounted for only 2% of the total sediment volume. The increase in road-related mass wasting during the 1985-1991 photo period may reflect the age of roads, the large storm event of November 1990, or both.

All of the confirmed anadromous fish production occurs in channels downstream of Illabot Lake, as are the majority of road miles in the basin. Additionally, the Illabot Lake reach (reach 17) stores virtually all sediment larger than sand, which means that coarse sediment delivered to channels above reach 17 is not transported to reaches with confirmed anadromous fish production. Therefore, it is also important to consider only sediment delivered to channels downstream of the lake, which represents that part of the sediment that can affect anadromous fish production. For those reaches downstream of Illabot Lake, the total volume of sediment delivered decreases over the inventory period (Figure 4-2). However, the proportion that was associated with roads was much higher in the 1985-1991 period (40%) than in either the pre-1956 period (0%) or the 1957-1964 period (7%).

Soil creep and surface erosion from roads were not considered to be significant contributors to the supply of coarse sediment (particles > 2 mm diameter) to Illabot Creek. Most sediment from surface erosion of roads is < 2 mm diameter, and increases in creep rate due to land use have not been documented.

Table 4-3. Mass wasting sediment supplied to reaches in Illabot Creek by time period from Paulson (1997). Sediment delivered in cubic yards.

| Illabot Watershed Reaches | 1956 | 1964 | 1972 | 1985 | 1991 | Total |
|----------------------------------------|------------------------|----------------------------|---------------|---------------|---------------|----------------|
| Mainstem, downstream of Bluebell Creek | 20,369 | 7,954 | | | | 28,323 |
| Marten Creek | | 6,017 | | | | 6,017 |
| Iron Creek | 1,437 | | | | | 1,437 |
| Subtotal | 21,806 | 13,971 | 0 | 0 | 0 | 35,777 |
| Mainstem, Bluebell to Otter Creek | 14,526 | 4,686 | 4,191 | 1,947 | 12,168 | 37,518 |
| Bluebell Creek | | | | | | 0 |
| Arrow Creek | | 5,649 | 5,425 | | 1,960 | 13,034 |
| Subtotal | 14,526 | 10,335 | 9,616 | 1,947 | 14,128 | 50,552 |
| Illabot Lake to headwaters | | 120,649 | 17,617 | 12,625 | 654 | 151,545 |
| Otter Creek | | | | | 1,980 | 1,980 |
| Subtotal | N/A^a | 120,649^a | 17,617 | 12,625 | 2,634 | 153,525 |
| Total for Illabot Watershed | 36,332 | 144,955 | 27,233 | 14,572 | 16,762 | 239,854 |

a. Aerial photo coverage of upper Illabot watershed was unavailable for 1956. Much of the mass wasting inventoried in the NU area in 1964 is attributable to a single event of 99,000 yd³ that may have occurred prior to 1956.

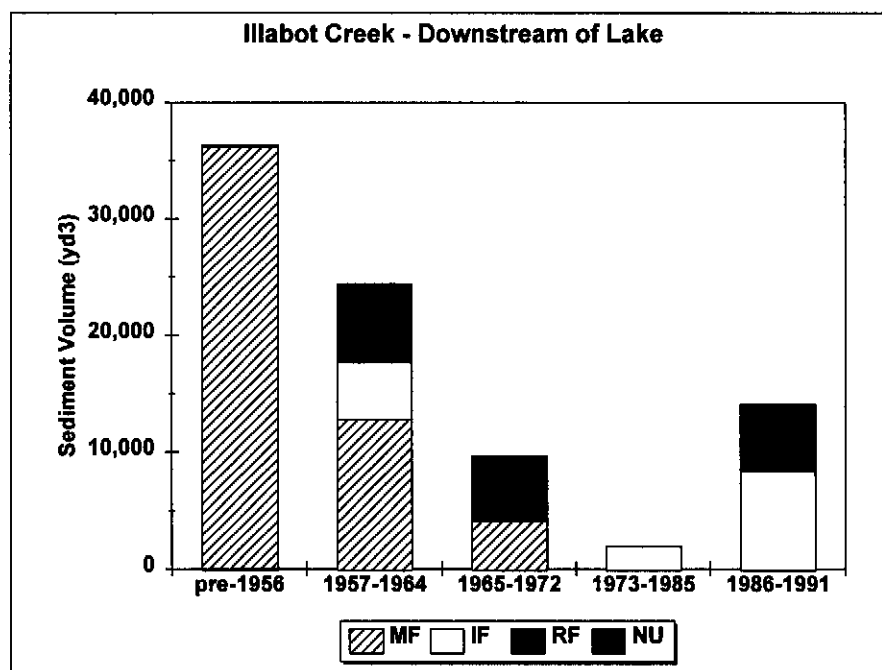


Figure 4-2. Mass wasting sediment volume produced in the Illabot watershed downstream of Illabot Lake (i.e., reach 17) over the period of aerial photograph record (data from Paulson 1997). MF = mass wasting in mature forest, IF = mass wasting in immature forest (< 20 years old), R = road-related mass wasting, NU = mass wasting in naturally unvegetated areas.

4.3.3 RAPID assessment, selection of response reaches

The RAPID assessment documents changes in channel widths over time by measurements of canopy opening width on aerial photos. Changes in channel width were largest (varying by more than a factor of three) in segments 3, 4, 5, 6, and 17 (Figure 4-3). Segments 3, 4, 5, and 6 are in lower Illabot Creek, with reach 6 positioned at the base of several kilometers of a steeper canyon reach (segment 7) and segment 3 (multi-channelled Illabot Creek fan) at the confluence with flow from Illabot ponds (Figure 4-1). This sequence of segments is a long depositional area. Coarser sediments (including cobbles and boulders) are deposited in reach 6, and the size of deposited sediments decreases downstream to reach 3, where gravels are the dominant particle size. Reach 17 is in the Illabot Lake area, which is a low-gradient deposition reach receiving sediment from alpine sources. Virtually all sediment larger than sand is deposited in this reach, indicating that reaches downstream of segment 17 do not receive significant sediment contributions from mass wasting sources upstream of segment 17.

Segments 3, 4, 5, 6, and 17 are considered response reaches because they have responded dramatically to large floods and large sediment inputs in the past. The longitudinal profile (valley slope, Figure 4-4) and changes in bed load transport capacities between reaches (Figure 4-5) indicate that reaches 9, 11, 13, and 14 should also be response reaches. It appears that these segments did not widen in response to large sediment inputs of the 1940 s and 1950 s because virtually no bed load from the upper watershed passes through reach 17 (note extremely low bed load transport capacity for segment 17 in Figure 4-5), and other large sediment influxes occurred in segments 7 and 8 which are downstream of these response reaches.

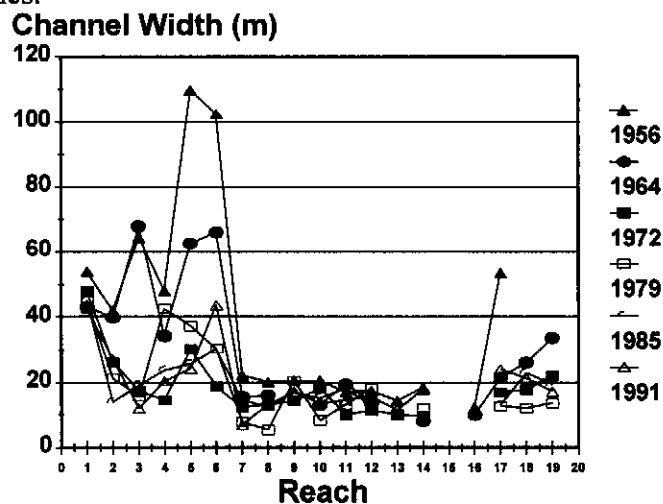


Figure 4-3. Average canopy opening widths for segments of Illabot Creek (measured from aerial photos) for photo years 1956, 1964, 1972, 1979, 1985, and 1991.

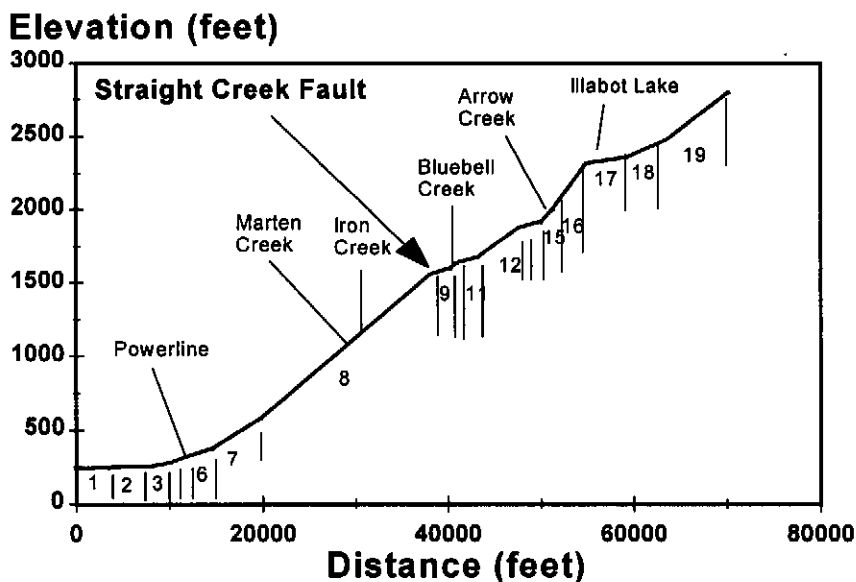


Figure 4-4. Longitudinal profile of Illabot Creek. Measurements from USGS 7.5' quadrangles.

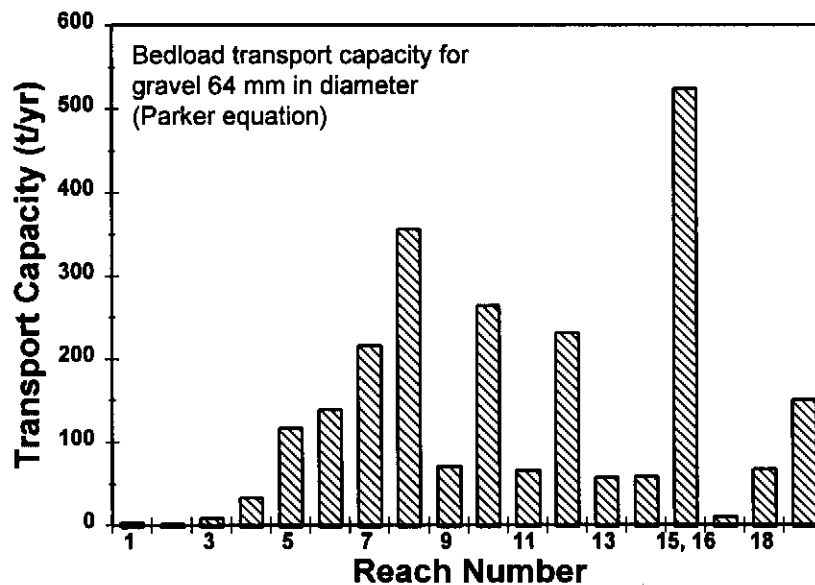


Figure 4-5. Average bed load transport capacities for Illabot Creek segments using Parker equation. Segment slopes measured from USGS 7.5' quadrangles. Average channel widths and depths measured in the field for segments 2-7, 12-14, and 17. Field data were extrapolated or interpolated for remaining segments. Reach 15 and 16 were combined. All estimates for bed load transport capacity were calculated for a bed load D_{50} of 64 mm.

4.3.4 In-channel habitat conditions

This section describes the in-channel habitat conditions of Illabot Creek prior to the completion of the sediment reduction project (summer of 1994) and one year following the project (summer of 1996).

Appendices 5 and 6 contain the results of all measured in-channel habitat conditions for each reach surveyed in 1994 and 1996. For reaches identified for monitoring (section 4.3.3), changes in channel type, reach length, average channel width, average residual pool depth, number of pools, and amount of key sized or larger LWD/100 m of stream length are shown in Tables 4-4, 4-5 and 4-6.

Table 4-4. Summary of channel type and dimensions for monitored segments in Illabot Creek, 1994 and 1996. Channel types are based on Montgomery and Buffington (1997)⁹

| Illabot Stream Reach | Channel Type 1994 | Channel Type 1996 | 1994 Reach Length (m) | 1996 Reach Length (m) | 1994 Ave. Bankfull Width (m) | 1996 Ave. Bankfull Width (m) |
|----------------------|-------------------|-------------------|-----------------------|-----------------------|------------------------------|------------------------------|
| 2 | PR | PR | 950 | 1030 | 31 | 31.4 |
| 2.1 | PRw | PRw | 691 | 513 | 16 | 28.3 |
| 2.2 | fPRw | fPRw | 480 | 520 | 14 | 23.2 |
| 3 | fPRw | fPRw | 540 | 250 | 13 | 17.3 |
| 4 | fPRw | fPRw | 370 | 560 | 19 | 20.6 |
| 6 | fPRw | PR | 605 | 800 | 17 | 32.2 |
| 13 | fPRw | fPRw | 251 | 245 | 16 | 14.3 |
| 14 | fPRw/blr | fPRw/blr | 260 | 250 | 16 | 17.6 |

Table 4-5. Summary of LWD and pool parameters measured in Illabot Creek segments, 1994 and 1996.

| Illabot Stream Reach | 1994 Total LWD/100 m of channel | 1996 Total LWD/100 m of channel | 1994 Key Sized or Larger LWD/100 m of channel | 1996 Key Sized or Larger LWD / 100 m of channel | 1994 Average Residual Pool Depth (m) | 1996 Average Residual Pool Depth (m) | 1994 Number of Pools | 1996 Number of Pools |
|----------------------|---------------------------------|---------------------------------|-----------------------------------------------|-------------------------------------------------|--------------------------------------|--------------------------------------|----------------------|----------------------|
| 2 | 10.2 | 4.9 | 0.42 | 0.49 | 0.75 | 0.85 | 13 | 8 |
| 2.1 | 11.7 | 26.1 | 6.80 | 0.58 | 0.60 | 0.77 | 11 | 4 |
| 2.2 | 34.6 | 25.2 | 10.83 | 9.81 | 0.66 | 0.79 | 17 | 9 |
| 3 | 27.2 | 37.2 | 15.19 | 16.40 | 0.64 | 0.55 | 16 | 4 |
| 4 | 72.2 | 37.1 | 42.97 | 16.61 | 1.01 | 0.90 | 14 | 7 |
| 6 | 52.2 | 24.6 | 26.61 | 3.13 | 0.72 | 0.50 | 9 | 4 |
| 13 | 66.1 | 41.6 | 48.21 | 24.49 | 0.77 | 0.79 | 11 | 10 |
| 14 | 22.3 | 20.8 | 16.92 | 10.80 | NA | 0.85 | 5 | 5 |

⁹ Montgomery and Buffington channel types are briefly described in section 3.3.3.

Table 4-6. Change in monitored habitat conditions for segments in Illabot Creek between summer of 1994 to summer 1996.

| Illabot Stream Reach | Change '94 to '96 Reach Length | Change '94 to '96 Average Bankfull Width | Change '94 to '96 Total LWD/100 m of channel | Change '94 to '96 Key Sized or Larger LWD/100 m of channel | Change '94 to '96 Average Residual Pool Depth | Change '94 to '96 Number of Pools in Reach |
|----------------------|--------------------------------|------------------------------------------|----------------------------------------------|------------------------------------------------------------|-----------------------------------------------|--------------------------------------------|
| 2 | 8% | 2% | -52% | 15% | 14% | -38% |
| 2.1 | -26% | 77% | 123% | -91% | 27% | -64% |
| 2.2 | 8% | 66% | -27% | -9% | 21% | -47% |
| 3 | -54% | 33% | 37% | 8% | -14% | -75% |
| 4 | 51% | 9% | -49% | -61% | -10% | -50% |
| 6 | 32% | 89% | -53% | -88% | -31% | -56% |
| 13 | -2% | -11% | -37% | -49% | 2% | -9% |
| 14 | -4% | 10% | -7% | -36% | | 0% |
| Average | 2% | 34% | -8% | -39% | 1% | -42% |

Changes in segment length and width

The length of individual reaches increased by up to 51% (segment 4), decreased by 54% (segment 3), or stayed approximately the same ($\leq 8\%$) in four of the eight monitored segments. Average channel width increased in all but one segment. However, because the averages are calculated from 10 or less width measurements per segment, only four of the segments showing an increase are significant. Average channel width increased by at least two thirds in segments 2.1, 2.2 and 6 and one third in segment 3.

Changes in LWD

The total amount of LWD for all monitored segments combined decreased slightly (8%) between 1994 and 1996. However, individual segments increased by as much as 123% (segment 2.1) or decreased by $\sim 50\%$ (segments 2,4,6). The amount of key sized or larger LWD¹⁰ changed by minor amounts in three of eight segments monitored. Segments 2 and 3 increased by 15% and 8%, respectively while segment 2.2 decreased by 9%. The remaining five segments all showed decreases in key or larger LWD by 36% or greater. The large decrease in segments 2.1 and 6 correspond to the large increase in average bankfull channel width. Based on channel width data from these segments, LWD classified as "medium" could be expected to create pools in 1994, but only LWD classified as "large" could be expected to create pools in 1996.

¹⁰ The minimum diameter of LWD that creates a pool varies as a function of bankfull channel width. The LWD category "key sized or larger" includes only LWD pieces that are large enough to create a pool based on the average channel width of the segment. We considered LWD classified as "large" as key sized for channels that are 25 m or wider and LWD classified as "medium" and "large" for all other Illabot Creek segments. Data used for determining the minimum diameter of LWD expected to create a pool as a function of channel width is from Beechie and Sibley (1997) and this study (shown in Appendix 6).

Changes in pool characteristics

The number of pools in each of the monitored segments decreased with the exception of segment 14. Average residual pool depth increased in the lower gradient ($<0.5\%$) segments (2, 2.1, 2.2) located downstream of the multi-channeled fan (segment 3) and decreased in segments 3, 4, and 6 (the long depositional area below the base of the steeper canyon reach (segment 7)). Segment 13, just downstream of the confluence of Arrow Creek in the upper part of the watershed, did not change much. Data on residual pool depth for segment 14 was not collected in 1994.

Decreases in residual pool depth in reaches 3, 4, and 6 may have resulted from increased sediment supply, although there were no large increases in sediment supply near this reach in the 1986-1991 photo period. Sediment may have been transported to these reaches from above Bluebell Creek between 1986 and 1996, or mass wasting sediment may have been delivered to Illabot Creek after 1991. Large floods in late 1995 and early 1996 may also have been a cause of the channel widening and decreased residual pool depths in the lower reaches. Channel widening recruits sediment to the reach from the flood plain (which may fill pools), and concomitant shallowing of the channel may also decrease the relative relief of bars and pools. Analysis of subsequent aerial photos should provide data required to support or refute the possibility of mass wasting sediment delivered to these reaches, which should narrow the range of possible explanations of reduced residual depths in reaches 3, 4, and 6.

4.3.5 Habitat use by anadromous salmonids

Coho and steelhead end-of-summer parr production was estimated using habitat-based models to identify the spatial relationship between juvenile fish rearing potential and position in the Illabot Creek watershed. The upper limit of anadromous fish use currently appears to include reach 15. Anadromous-sized adult native char, steelhead, and coho have been observed recently (1992 and 1994) as far upstream as reaches 13 and 14 by the USFS or SSC. Table 4-7 shows the amount of each habitat type by Illabot Creek reach and Table 4-8 summarizes the estimated parr potential for each reach. Figure 4-6 shows parr production along the length of Illabot Creek.

Table 4-7. Summary of habitat area by channel unit type within the anadromous zone of Illabot Creek. Gradients are based on USGS 7.5 minute map elevations and the 1992 survey lengths. Habitat unit area data are based on the USFS 1992 survey of the mainstem and SSC's 1994 survey of side channels in response reaches. Percent boulder in riffle was measured for all reaches except 8-12, and 16 where it was estimated based on a simple regression relationship with gradient.

| Reach # (channel type) | Map gradient | Pool area (m ²) | Glide area (m ²) | Riffle area (m ²) | % Boulder in Riffle | Total area (m ²) |
|------------------------------|-----------------|-----------------------------------|------------------------------------|-------------------------------------|---------------------------|------------------------------------|
| 1 (PR) | 0.2% | 6929 | 18072 | 3074 | 0.0 | 28075 |
| 2 (PR) | 0.2% | 10290 | 4198 | 6048 | 0.0 | 20536 |
| 3(fPR) | 0.8% | 2187 | 34 | 4491 | 1.2 | 6712 |
| 4(fPR) | 1.2% | 2192 | 0 | 2568 | 2.0 | 4760 |
| 5(PB) | 2.4% | 443 | 0 | 6481 | 3.6 | 6924 |
| 6 (fPR) | 1.5% | 2714 | 1069 | 7669 | 6.1 | 11452 |
| 6.2(PB) | 2.0% | 0 | 0 | 7543 | 4.8 | 7543 |
| 7(fPR) | 3.2% | 7297 | 0 | 22562 | 7.7 | 29859 |
| 8(SP) | 6.1% | 4313 | 0 | 47718 | 7.3 | 52030 |
| 9(fPR) | 1.7% | 451 | 0 | 7286 | 2.5 | 7737 |
| 10(SP) | 6.5% | 345 | 0 | 1288 | 7.7 | 1633 |
| 11(fPR) | 1.6% | 1759 | 0 | 5806 | 2.4 | 7565 |
| 12(SP) | 5.6% | 1136 | 0 | 9265 | 6.6 | 10401 |
| 13(fPR) | 1.2% | 2154 | 35 | 987 | 0.0 | 3176 |
| 14(fPR) | 2.3% | 962 | 0 | 2237 | 4.6 | 3199 |
| 15(SP) | 7.4% | 513 | 0 | 1802 | 4.3 | 2315 |
| 16(SP) | 8.1% | 1616 | 0 | 7748 | 9.4 | 9364 |
| 17(fPR) | 1.0% | 1572 | 990 | 2290 | 1.7 | 4852 |
| 17.2(fPR) | 2.0% | 1411 | 0 | 2475 | 0.0 | 3886 |
| 18(fPR) | 1.0% | 588 | 0 | 2288 | 0.8 | 2876 |

Table 4-8 shows that predicted coho summer parr densities were generally high (0.7-1.2 coho parr/m²) in pool-riffle or forced pool-riffle channels, while plane bed channels were predicted to be lower (0.4 to 0.5 coho parr/m²). Step-pool channels were not expected to be important for coho rearing based on gradient. Approximately 115,000 coho summer parr could be produced in Illabot Creek with 46% of the parr potential attributed to reaches 1 and 2 (both within the Skagit River floodplain) and 86% of the parr potential expected to be produced in the first seven kilometers of Illabot Creek (Figure 4-6). Two large oxbow ponds, also in the Skagit floodplain (adjacent to reaches 2 and 3, see Figure 4-1), provide summer rearing habitat closely associated with Illabot Creek. The western pond has an area of 20,000 m² and the eastern pond is 31,000 m² (based on 1:12,000 scale aerial photo). Total potential production of coho summer parr for these ponds is 76,500 fish.

Table 4-8. Estimated end of summer parr and observed chinook redd densities for Illabot Creek. Potential parr densities for coho and steelhead are from Reeves et. al. (1989) and Marshall et. al. (1980) respectively. Chinook surveys from 1994 season.

| Reach # (Channel Type) | Predicted Potential coho parr | Predicted coho density parr/m ² | Predicted Potential steelhead parr | Predicted steelhead density parr/m ² | Observed Chinook spawning redds/km |
|---------------------------|-------------------------------|--------------------------------------------|------------------------------------|-------------------------------------------------|------------------------------------|
| 1 (PR) | 29274 | 1.043 | 606 | 0.022 | NA |
| 2 (PR) | 23690 | 1.154 | 710 | 0.035 | 26 |
| 3(fPR) | 5545 | 0.826 | 190 | 0.028 | 56 |
| 4(fPR) | 4754 | 0.999 | 172 | 0.036 | 41 |
| 5(PB) | 3346 | 0.483 | 162 | 0.023 | 6 |
| 6 (fPR) | 8643 | 0.755 | 360 | 0.031 | 30 |
| 6.2(PB) | 3017 | 0.400 | 187 | 0.025 | 6 |
| 7(fPR) | 21430 | 0.718 | 1133 | 0.038 | 18 |
| 8(SP) | 0 | 0 | 1652 | 0.032 | NA |
| 9(fPR) | 3681 | 0.476 | 153 | 0.020 | NA |
| 10(SP) | 0 | 0 | 60 | 0.037 | NA |
| 11(fPR) | 5313 | 0.702 | 204 | 0.027 | NA |
| 12(SP) | 0 | 0 | 313 | 0.030 | NA |
| 13(fPR) | 4088 | 1.287 | 138 | 0.044 | NA |
| 14(fPR) | 2530 | 0.791 | 112 | 0.035 | NA |
| 15(SP) | 0 | 0 | 73 | 0.031 | NA |

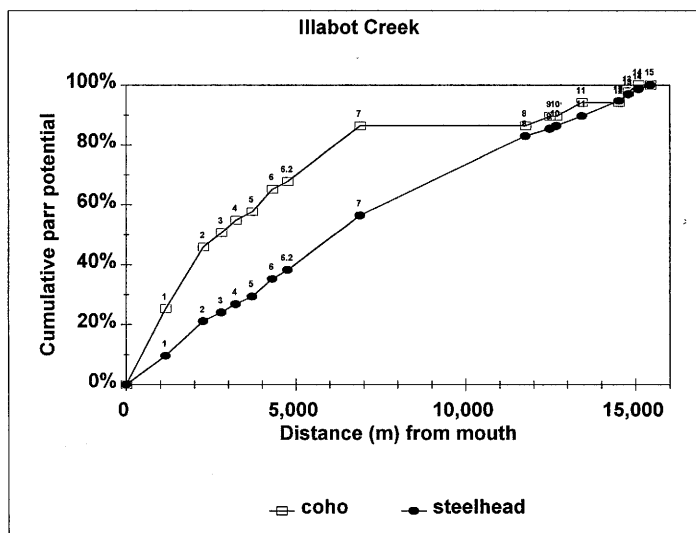


Figure 4-6. The relationship between end of summer parr potential and Illabot Creek reaches down-stream of Illabot Lake (reach 17). Stream reaches are labeled at their upper limit.

Predicted steelhead parr densities (0.03 steelhead parr/m²) were over an order of magnitude less than coho densities (except step pool channels) and more uniform between reaches and channel types (Table 4-8). In contrast to coho, step pool channels

are expected to be important for steelhead parr production. Approximately 6,000 steelhead parr could be produced in Illabot Creek with parr potential declining slightly in upstream reaches (Figure 4-6).

Table 4-8 also shows observed chinook redd density for the season in reaches 2 through 7 of Illabot Creek. Densities ranged from 18 to 56 redds/km in forced pool-riffle and pool riffle channels, while the density in plane bed channels was only 6 redds/km. Data for step-pool channels were not available in Illabot Creek.

The location of juvenile coho potential at the end of summer is concentrated in the lower seven kilometers of Illabot Creek (Figure 4-6). Following summer rearing, the general migratory direction of juvenile coho is downstream to find usable winter habitat areas. Usable winter habitat for juvenile coho is associated with deep pools, low velocity, and substantial woody debris accumulations. Downstream migrations of up to 38 km have been documented before individual fish have migrated the relatively short distance upstream into off-channel or suitable tributary habitat for winter rearing (Scarlett and Cederholm 1984). Usable winter habitats for coho where mean winter water temperature is $< 7^{\circ}\text{C}$ are thought to include only backwater pool areas, ponds, and lakes (Reeves et. al 1989; Beechie et. al. 1994). These areas are most commonly found in unconstrained low gradient stream reaches particularly those with large accumulations of LWD. The migratory behavior of coho and the geomorphology of the Illabot Creek watershed suggests the lower five kilometers of Illabot Creek are the most important for coho production in the winter.

Although no winter habitat survey has been conducted for Illabot Creek, the important winter habitat areas are expected to be associated with reaches 1, 2, 3, 4 and 6. Reaches 1 and 2 are located in the Skagit River flood plain and have abundant secondary channel area. The two large ponds adjacent to reaches 2 and 3 also provide winter rearing habitat. These ponds are capable of supporting up to 39,500 coho smolts (83%) of Illabot Creek's coho smolt potential through the winter rearing season (based on the limiting factors method of Reeves et. al. 1989). Reaches 3 and 6 have a large amount of secondary channel and reach 4 has a high degree of LWD-formed pools. Some winter habitat is present in reaches 9, 11, and 13, but these reaches are isolated from the lower basin by seven to ten kilometers and 1,200 feet of elevation. Very little usable winter habitat is expected in the remaining reaches due to channel gradient.

4.3.6 Other threats to fish habitat in Illabot Creek

The habitat conditions in reach 5 have been severely modified and fish rearing potential is predicted to be reduced. Hydromodification to accommodate the county road bridge crossing and protect power line towers in the vicinity is the primary cause of degradation. When the reach was straightened, the length was reduced, therefore increasing the

channel's gradient and reducing habitat area. LWD recruitment potential is reduced because adjacent riparian stands have been removed or are now isolated from the stream. LWD was probably removed from the channel during the original hydromodification and subsequent maintenance. These disturbances have likely converted reach 5 from a forced pool-riffle channel to a plane bed channel.

Under natural conditions, we would expect habitat conditions and fish potential in reach 5 to be similar to reaches 4 and 6 (adjacent reaches). However, dredging and channelization have significantly altered the habitat characteristics of this reach. Reaches 4 and 6 were forced pool riffle channels in 1994 with pool spacing of 1.4 and 4.0 channel widths per pool while pool spacing was 10.0 channel widths per pool in reach 5. LWD counts for reaches 4 and 6 were high in 1994 (72.2 and 52.2 pieces per 100 meters of channel), while reach 5 has only 5.7 pieces per 100 meters of channel. The amount of wetted area in pool habitat was 46% and 24% for reaches 4 and 6, while reach 5 was only 6% in pool area. Chinook spawning density was five times lower in this reach than in reaches 4 and 6. Coho rearing potential per unit area in reach 5 was about one half of the potential in reaches 4 and 6, while steelhead rearing potential was about one third of that in reaches 4 and 6 (Table 4-8).

4.4 DISCUSSION/CONCLUSIONS

4.4.1 Implementation monitoring

The Illabot Creek road treatment project was implemented as designed. Work completed on Road #16 included:

- replacing 61 (18-48 inch diameter) corrugated metal culverts,
- replacing 1 log culvert,
- clearing debris from 7 culverts,
- re-establishing drainage patterns at 22 crossings,
- placing 1170 yd³ of rip-rap,
- reconditioning 23.7 miles of road surface, and
- removing 7200 yd³ of road fill.

Three miles of road were insloped and 600 yd³ of fill was replaced on Road #1620. For Road # 1600012 and spur, 0.6 miles of road was decommissioned by removing all culverts, constructing drainage channels at crossings where culverts were removed, excavating fillslopes and outsloping the road prism.

4.4.2 Current watershed conditions

The first three hypotheses of current watershed conditions can be evaluated with our initial year monitoring data. The partial sediment budget (the sediment supply portion of

the budget) focuses on the first two hypotheses:

1. Sediment supply has not been significantly increased by land-use in Illabot Creek watershed.
2. Mass wasting has not increased significantly due to road failures in Illabot Creek watershed.

The average annual sediment supply to streams since the early 1950s is about 50% above the “background” rate, but sediment supply in Illabot Creek remains low compared to other basins managed for timber harvest in the North Cascades (Paulson 1997). The increase in sediment supply due to mass wasting from roads was largest during the 1985-1991 photo period, when road-related failures accounted for about 40% of the total sediment produced by mass wasting (Figure 4-2). However, total sediment volume from mass wasting (below Illabot Lake) during the 1985-1991 photo period was less than during the pre-1956 and 1956-1964 periods (14,000 yd³ compared to 36,000 yd³ and 24,000 yd³, respectively). Hence, we conclude that, during the last several years, road related mass wasting has significantly influenced the sediment supply that can be delivered to the monitored reaches (i.e., below Illabot Lake), but also that the total supply is not presently high for Illabot Creek (see Table 4-3).

These results indicate that the periods of largest mass-wasting sediment supply during the photo record (i.e., prior to 1964 and including areas above Illabot Lake) were not significantly influenced by land use (Figure 4-2). However, land use has had an increasing influence on mass-wasting sediment supply in the last three decades. This result does not clearly refute hypothesis 1, but does seem to refute hypothesis 2, at least for the last decade. In other words, mass wasting has significantly increased due to roads in the last decade, but land use overall has been relatively small influence compared to mass wasting from mature forests and naturally unvegetated areas.

The third hypothesis concerns habitat characteristics in Illabot Creek:

3. Residual pool depths have not been significantly affected by changes in sediment supply in Illabot Creek watershed.

Based on the results of the RAPID assessment, the potential response reaches in the upper watershed (reaches 9, 11, 13, and 14) did not show significant widening due to large sediment inputs of the 1950's and 1960's. Approximately 90% of the landslides that occurred during this period occurred either downstream of reach 9 or upstream of reach 17 (which traps virtually all gravel and larger sediment). Hence, sediment supply to these reaches was relatively low during the pre-1964 decade, and the data for these reaches are therefore consistent with hypotheses 1 and 2. Although we currently have no reference

site data to establish that residual depths in these reaches are consistent with other areas of relatively low sediment supply, the lack of evidence for increased sediment supply suggest that hypothesis 3 is also likely to be a correct statement for reaches 9, 11, 13, and 14.

The RAPID method identified reaches 3 through 6 as response reaches (a determination backed by field observation). The trend in channel width since the 1950's and 1960's for these reaches is one of narrowing, implying these reaches are recovering from a large increase in sediment supply and/or large floods that occurred during the decade prior to 1964¹¹. Because land use was only a minor influence on sediment supply during this time period, the data are also consistent with hypotheses 1 and 2 for these reaches. That is, roads had not significantly influenced sediment supply and land-use effects as a whole were a small component of the sediment supply. Nevertheless, sediment supply was naturally high and delivery to streams was only a few kilometers upstream of response reaches 3 through 6. Therefore, the pre-1964 channel widening in these reaches is not inconsistent with an increase in sediment supply.

During the 1985-1991 period when the most road-related mass wasting occurred, these same reaches (with the possible exception of reach 6) showed little widening. However, the majority of landslides in the 1985-1991 period were more than 9 km upstream of these reaches, compared to the pre-1964 period when more than half the landslides were within about 5 km. Recalling also that the sediment input between 1985 and 1991 was < 60% of the sediment input in the decade prior to 1964, the results suggest that reaches 3 through 6 may not have responded to the road-related increase in sediment supply because (1) the increase was too small to significantly affect channel width in reaches 3 through 6, (2) much of the sediment has been stored in upstream reaches, or (3) the sediment has not yet reached these response reaches. These data indicate that roads have significantly increased mass wasting (i.e., they refute hypothesis 2), but do not clearly show that roads have caused an unusually high sediment supply or reduction in residual pool depths (i.e., they do not clearly refute hypotheses 1 and 3).

In-channel habitat changes between 1994 and 1996

In the two year period between the summer of 1994 and 1996, we observed variation in reach length by ~50%, channel width by 89%, and key size or larger LWD abundance by 91%. For pool characteristics, the number of pools and average residual pool depth varied by as much as 75% and 31% respectively. The change in the number of pools in fPR and PB reaches is mostly explained (69%) by the combination of change in segment length, average bankfull channel width, and key sized or larger LWD (Figure 4-7).

¹¹ An exception to this is segment 5 which narrowed because of hydromodification post 1964.

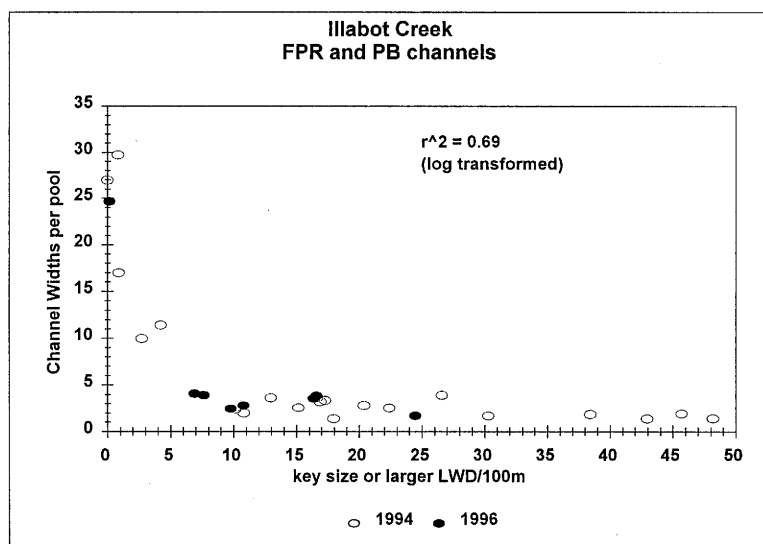


Figure 4-7. Pool spacing (bankfull channel widths per pool) plotted against key sized or larger LWD/100m for forced pool riffle (FPR) and plane bed (PB) reaches in Illabot Creek.

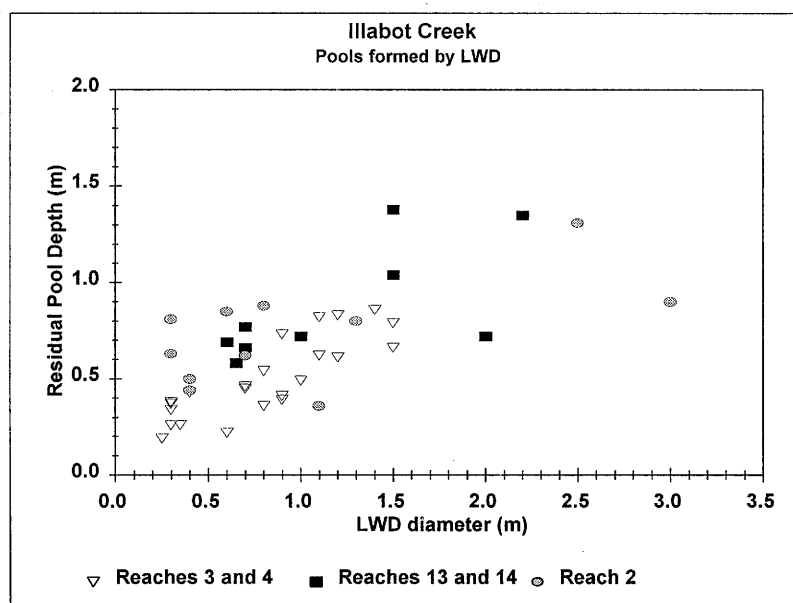


Figure 4-8. Residual pool depth plotted against LWD diameter for pools in three areas of Illabot Creek ($r^2 = 0.52$) LWD diameter is the height of pool-forming LWD (single pieces or jams).

About one half (52%) of the variation in residual pool depth for pools formed by LWD is explained by the height of a log or LWD jam (Figure 4-8). In general, larger obstructions tend to create deeper pools, indicating that a change in the size of LWD over time should lead to a change in residual pool depths. This relationship is important for demonstrating

that changes in residual pool depth that may be measured in the future are (or are not) a function of change in LWD size, rather than a change in sediment supply. We are unable to make this determination for the period between 1994 and 1996 because the height of LWD that formed individual pools in 1994 was not measured and new sediment supply data are not yet available.

We observed a spatial pattern of change in average residual pool depth. All lower gradient segments located downstream of the multi-channeled fan (segments 2, 2.1, 2.2) increased while segments in the long depositional area (segments 3, 4, and 6) below the base of the steeper canyon reach all decreased. Average residual pool depth in segments of the upper watershed (segments 13 and 14) have not changed much during this period. While it is possible that this spatial pattern may be explained by differences in local sediment supply (i.e., at the segment level), the sediment budget through 1991 is insufficient to confirm such a statement. The updated sediment budget in future monitoring years should provide the necessary data to interpret these residual pool depth results.

We also observed complete channel type change in Segment 6 within the two year period. This reach was broken into two segments (6 and 6.2) in 1994 based on very different LWD, channel width, and pool spacing characteristics. Segment 6 was classified as fPRw in 1994, with high LWD abundance (52.2 pcs. per 100 m), and relatively tight pool spacing (4.0 channel widths per pool). Segment 6.2 was classified as PB. By the summer of 1996, this reach had lost its fPR (segment 6 in 1994) and PB (segment 6.2 in 1994) characteristics, and converted to a PR channel with only 4 pools (3 of them free forming) in its 800 m length. The channel type conversion we observed is consistent with our understanding of how channels, within the gradient range of reach 6, should respond to increased width and a reduction in key sized LWD.

The results from this initial two year monitoring period provide us with some important information relevant to continued monitoring. First, we have an idea of the variation expected in the monitored parameters for future years when a 10 to 25 year peak flow event occurs. Second, they illustrate the importance of delineating the monitored segments based on Montgomery and Buffington (1997) channel types which are predictive via an underlying basis in geomorphic process. Third, they show the importance of collecting LWD size and abundance data, at the resolution of individual pools, to enable more accurate interpretation of residual pool depths with respect to changes in sediment supply.

4.4.3 Future effectiveness monitoring

We have collected data that only address hypotheses of current conditions (1 through 3). Thus, there are no results that directly address the remaining two hypotheses:

4. Road-related mass-wasting rates and sediment supply are not expected to increase in the future (assuming road sediment reduction projects are completed).
5. Residual pool depths are expected to remain high in Illabot Creek watershed as road sediment reduction efforts prevent future increases in sediment supply.

Hypothesis 4 is essentially consistent with the data, except that proportion of road-related mass wasting would be expected to decrease from the 40% documented during the 1986-1991 period. However, this does not mean that overall sediment supply will decrease from the 1986-1991 level because the total sediment supply during that period was not unusually high compared to other periods between 1956 and 1991, and was lower than the natural component of mass wasting in the decade prior to 1964.

Hypothesis 5 may be incorrect for reaches 17 through 19 due to the natural increase in sediment supply in the headwaters prior to 1964. However, prior to 1964 there was no unusually large sediment supply delivered to reaches downstream of reach 17. For the upper reaches, our results suggest that residual pool depths may still be in the process of “recovering” from the pre-1964 increase in sediment supply, although this is unlikely. Results from other studies in the region suggest that recovery may be less than a decade, and is somewhat dependent on the magnitude of flood flows. Collins et al. (1994) reported that residual pool depths in Deer Creek had increased three-fold in eight years, but it was not clear whether residual depths had recovered to a depth associated with long-term low sediment supply. Assuming that the Illabot Creek case is somewhat similar to that of Deer Creek, it appears that residual pool depths in reaches 17 through 19 would have recovered significantly over a period of 27 years. For reaches downstream of reach 17, it remains unclear whether any changes in residual depth can be attributed to changes in sediment supply. We therefore presume that Hypotheses 5 remains correct for reaches downstream of reach 17.

Despite results that indicate hypothesis 2 is incorrect for the most recent aerial photo period, only hypothesis 4 should be revised. Therefore, we conclude that Illabot Creek remains a “protection watershed” for this monitoring effort, meaning that an increase in residual pool depths due to decreased sediment supply is expected to be small at best. However, hypothesis 4 should be restated as

4. Road-related mass-wasting rates and sediment supply are *expected to decrease* in the future (assuming road sediment reduction projects are completed).

It also remains that residual pool depths in reaches 3 through 6 may decrease in the next few years if it is true that sediment from the 1986-1991 mass wasting has not yet reached

them. Therefore, potential revision of hypothesis 5 must await data from future monitoring.

4.4.4 Evaluation of the rationale for the Illabot Creek project

The preliminary watershed assessment for the Illabot Creek watershed (attached as Appendix 2) completed by the Skagit local team portrays this watershed as having relatively intact fish resources, but aquatic habitats were described as degraded in the lower reaches and threatened throughout the watershed by road-related sedimentation. This degradation in the lower reaches was attributed to excessive sedimentation and inadequate riparian forests, and was assumed to have resulted in depletion of anadromous fish stocks.

The project prioritization methodology estimated the Illabot Creek project to have the largest protection benefit of all projects prioritized (Table 1 in Appendix 3), suggesting this watershed was functioning as a “refuge” for anadromous fish. Therefore, the Skagit local team characterized the Illabot Creek watershed as a protection watershed. Desired future conditions were described as: (1) maintain existing acceptable fish habitat and restore habitat conditions to allow recovery of viable populations of salmon and steelhead, (2) maintain or enhance habitat for riparian-associated wildlife species and (3) meet or exceed state and federal water quality standards.

Our initial monitoring efforts indicate that the watershed assessment prepared for the local team was generally correct in its assessment of watershed conditions, but that the degree of degradation in the lower reaches (reach numbers 1 through 5) was overstated. Specifically, the assessment described reaches 1 through 5 as sand-filled with minimal structure, and that local channel widening was evident. Our observations showed that sediment deposited on point bars in the lower reaches are cobble and gravel in reach 4 ($D_{50} = 85$ mm), declining to small gravel in reach 1 ($D_{50} = 7$ mm). Furthermore, average bed load transport capacity declines rapidly in the downstream direction, suggesting that such a trend is largely a result of decreasing channel slope from reach 4 (slope = 0.014) to reach 1 (slope = 0.001), and is not related to land use. The RAPID assessment indicated that these reaches have narrowed during the past two decades, except for reaches 2 and 6, where some widening has occurred. However, the degree of widening in the past two decades has been less than half of that recorded in the 1950s and 1960s.

Our data classified reaches 2.2, 3, and 4 as forced pool-riffle channels with moderate to high levels of LWD, and pool spacing of less than 4 channel widths per pool. Hence, these reaches have significant structure, and reaches 1, 2, 2.1, and 5 (a channelized reach under the road and power lines) actually have minimal structure.

A riparian habitat inventory of lower Illabot Creek completed using 1996 aerial

photographs found that 21% and 28% of the riparian corridor along reaches 1 and 2 (respectively) are < 20 meter wide suggesting that riparian functions are degraded in these reaches (Skagit System Cooperative, unpublished data). Except for reach 5 where riparian functions are isolated from the channel due to diking, the rest of the riparian corridor in reaches 1- 4 is ≥ 60 meters wide.

The Illabot Creek watershed assessment also states “Illabot Lake is now filled with gravels and is mainly a series of dry channels due to the absence of beaver populations.” We suspect sediment deposition is the primary cause of change in the Illabot lake area, rather than beaver populations. Because of the reach’s very low sediment transport capacity (Figure 4-5) and the large influx of sediment to this reach around the 1960s, stream channels and ponds in this area appear to have aggraded. The Illabot Lake floodplain area (reach 17) is estimated at 264,600 yd². Sediment supplied to channels upstream of this reach during the 1956-64 time period from mass wasting alone (~121,000 yd³, Table 4-3) was enough to fill the entire floodplain to a depth of ~1.4 ft.

4.4.5 Recommended monitoring protocol and schedule

The partial sediment budget should be updated as new aerial photos become available (every 4-5 years in most cases). Methods should follow those of Paulson (1995, 1997) to preserve validity of comparisons between photo periods. Monitoring analyses should include comparisons between the rate of sediment production (m³/ha/yr.) from treated road segments and untreated road segments, and between treated road segments and forested areas. If road treatments are successful (i.e., effective at reducing sediment supply), rates of sediment production from treated roads should be much lower than those from untreated roads and similar to those from forests.

The RAPID assessment should also be repeated with each new aerial photo series in order to monitor changes in channel width (4-5 year intervals). Channel widening may indicate that sediment supply is increasing in a reach, and channel narrowing may indicate that sediment supply is decreasing. However, changes in channel width are always inconclusive evidence of changes in sediment supply in the absence of other data. One should be reasonably certain that sediment supply is consistent with the interpretation of channel width data, and that floods are unlikely to have caused the observed changes in channel width. For monitoring the effects of this road treatment on stream channels in Illabot Creek, the monitoring analyses should focus specifically on the response reach nearest to and downstream of the road treatments in order to avoid the influence of other sediment sources to the extent possible.

Residual pool depth and LWD surveys should be conducted during the same season as aerial photo flights if possible, and at least once between flights (roughly every 2-3

years). Surveys will include channel type, channel width, pool forming mechanism, pool forming obstruction height and volume, number of pools, residual pool depth, and LWD by size categories for mainstem reaches 2, 3, 4, 6, 13 and 14 as well as multiple channels in reaches 2 and 3. This will permit correlation of changes in residual pool depth with changes in channel width, and will also help identify how rapidly pool depths change over time. Changes in residual pool depth that result from changes in sediment supply will most likely be associated with a change in channel width, and should be independent of changes in LWD abundance or size. As with channel width, one should be reasonably certain that sediment supply is consistent with the interpretation of residual pool depth data, and analyses should focus on the response reach nearest to and downstream of the road treatments in order to avoid the influence of other sediment sources to the extent possible. Results that partially validate hypotheses 3 and 5 should show that residual pool depths in the response reach remain relatively deep.

Additional assurance that pool depth responses are a function of sediment supply rather than other factors can be attained by monitoring residual pool depths at locations where pool forming mechanisms are expected to be stable over the monitoring period. Residual pool depth was measured in several bedrock formed pools in reach 7 in 1996 (Appendix 6). Pools were individually “tagged” so that future monitoring can compare changes in residual depth at the scale of individual pools.

5. MONITORING AND EVALUATION OF FISH PASSAGE IMPROVEMENT PROJECTS

This section describes our approach and rationale for monitoring fish passage improvement projects and how we select parameters for monitoring.

5.1 BACKGROUND

We consider fish passage projects to be restoration projects (as opposed to protection projects). The objective of such projects for anadromous fish is to increase the amount of freshwater habitat available to a targeted species by reestablishing the connection between habitat currently utilized by fish with habitat that is currently isolated from fish. The benefit is thought to occur relatively quickly because existing habitat areas are simply reconnected by the project.

A basic assumption in our monitoring approach is that there exists some relationship between the size of a stock (e.g., number of spawners) and resulting recruitment (e.g., number of smolts). The processes regulating recruitment at small stock sizes are thought to be density-independent, whereas the processes regulating recruitment at large stock sizes are thought to be density-dependent. The relationship over a range of stock sizes is illustrated as some form of curve, such as the dome-shaped Ricker relationship or the asymptotic Beverton-Holt relationship. The asymptotic Beverton-Holt relationship is often used to characterize salmonids with extended freshwater life histories, such as coho and steelhead (Lestelle et. al. 1993b). The equation:

$$R = \frac{S}{bS + a}$$

is used to describe this relationship, where R is the number of smolts and S is the number of female spawners. Density-independent survival ($1/a$) is smolts per female spawner at the theoretical “zero” spawner density, and smolt carrying capacity is $1/b$. The coefficients a and b , which describe the shape of the Beverton-Holt curve, may be interpreted (at least in part) as being related to habitat characteristics (Moussalli and Hilborn 1986). The parameter a is perhaps most closely related to habitat *quality* while the parameter b is more closely related to habitat *quantity* (Lestelle et. al. 1993b). When habitat quality or quantity increase, $1/a$ or $1/b$ increase respectively.

When “new” habitat area is made available to a fish stock by building a fish passage project (i.e., $1/b$ is increased), we expect to see a locally larger parent stock, and subsequently greater recruitment. Curves A and B in Figure 5-1 illustrate two cases where

the habitat capacities are different, but density independent survival is the same. Curve A represents the stock-recruitment curve for a hypothetical coho stream with a carrying capacity ($1/b$) of 10,000 smolts and a density-independent survival rate ($1/a$) of 134 smolts per female spawner¹². Curve B represents the same stream, except carrying capacity has been doubled by a fish passage project, allowing fish to utilize habitat upstream of the previous barrier. At a low spawner level (50 females), the stream can produce about 4,000 smolts before the fish passage project (curve A), but over 5,000 smolts after the project opens up new habitat (curve B). At a high spawner level (400 females¹³), the stream can produce about 8,400 smolts before the fish passage project (curve A) and over 14,500 smolts after completion of the project (curve B), a 73% increase. Curve C represents the same carrying capacity as B, but with poor quality habitat that reduces the stream's overall density independent survival by two thirds. At a spawner level of 50 females, stream C can produce only about 2,000 smolts after the project, compared to the original 4,000 smolts of curve A. Smolt production for curve C does not equal curve A until the level of 300 female spawners, and only shows a minor increase (+12%), at the level of 400 female spawners.

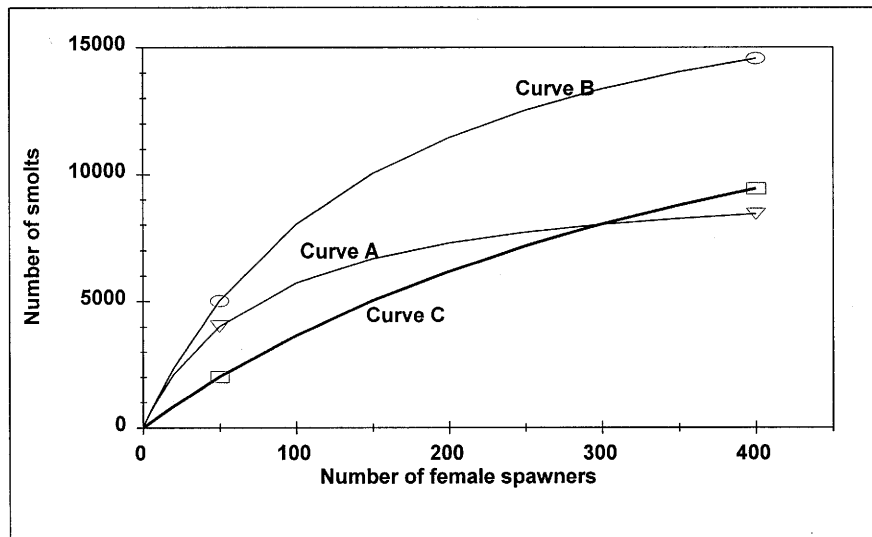


Figure 5-1. Beverton-Holt stock recruitment curves for a hypothetical coho stream indicating capacity (the asymptote) and survival (shape of the curve) for starting conditions (Curve A), doubled capacity (Curve B), and doubled capacity with survival reduced by two thirds (Curve C).

¹² The rate is for female spawner to smolt stage, in streams where the mean winter temperature is $< 7^{\circ}\text{C}$, from Reeves et al. (1989).

¹³ As in Lestelle et. al. (1993b), we consider streams to be “fully seeded” when spawner levels are sufficient to produce $\geq 80\%$ of smolt carrying capacity. In this case, 400 female spawners yield 8,000 smolts, or 80% of carrying capacity.

Several factors may influence the amount of available habitat, and the values of the parameters a and b in a Beverton-Holt stock-recruitment relationship. One of these factors is the “fit” between the life history patterns present and the available habitats for different life history stages (e.g., Lichatowich and Mobrand 1995, Lichatowich et al. 1995, Lestelle et al. 1993a). Elements of this “fit” have been described as relationships between the type, amount, or quality of instream habitat with a variety of fish species and life stages (e.g., Murphy et al. 1986, Swales et al. 1986, Nickelson et al. 1992, Scrivener and Brownlee 1989). Less predictable factors include such natural “disturbances” as flood events during the spawning or intragravel life stages, and drought conditions during the summer rearing period (e.g., Lestelle et al. 1993b). Each of these variables may influence the actual response of a fish population to improved fish passage, and therefore should be accounted for in the monitoring framework.

5.2 DEVELOPMENT OF HYPOTHESES

Our monitoring efforts are guided by hypotheses of how improved fish passage at a specific site will affect the population of the targeted fish species. For fish passage improvement projects, our hypotheses are developed by responding to the following questions.

- What life stages (of the targeted fish species) are expected to utilize the habitat upstream of the project?
- What life history patterns are present in the project area?
- What are habitat conditions (types, amount, and quality) upstream of the project?
- How many adult and juvenile fish are available to use the habitat upstream of the project? Will habitat be fully seeded?
- What stream flow or water quality variables could influence fish production at this site?

If responses to these questions are not based on relatively complete data, the first phase of monitoring should provide data to answer these questions. Each hypothesis can then be “tested” to the extent that habitat, environmental, and biological data can clearly refute or support the hypothesis.

5.3 IDENTIFICATION OF MONITORING TASKS

Three types of monitoring are used to monitor fish passage improvement projects. *Implementation monitoring* evaluates whether the project was constructed as specified in the design. *Effectiveness monitoring* evaluates whether the project has achieved the desired fish passage. *Validation monitoring* evaluates whether the hypothesized cause and effect relationship between the action (improved fish passage) and ecosystem response

(more fish) was correct. For validation monitoring, we propose comparing the *observed* population to a *predicted* population. The predicted population is derived from a habitat-based model (e.g., Beechie et al. 1994, Marshall et al. 1980, Reeves et al. 1989, or others). These models are based on the area of different habitat unit types such as pools, glides, or riffles. For each unit type, there is a corresponding average density of juvenile fish (number of fish per unit area), and an estimated survival to a life stage (e.g., smolt). The estimated production for each unit is $density \times area \times survival$. These models provide a means to formulate a validation hypothesis. Observed smolt population numbers from downstream migrant trapping during the smolt migration period provides a means to test the validation hypothesis.

For fish passage improvement projects the monitoring objectives are:

- Confirm that habitat is suitable (by inventory of the isolated habitat area) and that fish seeding potential is present (by fish use inventory of the project vicinity / watershed) for the targeted species. Ideally this step would be completed during *watershed analysis* prior to project implementation. The habitat inventory method should collect the appropriate parameters to be employed in the habitat-based model.
- Check to see that the facility was constructed as planned. (*implementation monitoring*)
- Measure physical parameters at the project facility such as stream flow, water depth, water velocity, and the height of any steps that fish must jump. Compare the results to determine whether they are within the limitations of the targeted species and life stages. (*effectiveness monitoring*)
- Conduct spawner surveys of the facility and the habitat upstream and downstream of the facility to document whether fish passage has occurred (*effectiveness monitoring*).
- Monitor the population of the targeted species / life stage within the reconnected habitat area of the project. Compare the results to the predicted population (*validation monitoring*).
- Monitor other variables (e.g., number of spawners, number of juvenile immigrants, floods, droughts, temperature, or water quality) hypothesized to potentially influence the monitored population.

5.4 INTEGRATION OF RESULTS

This section describes our rationale for using coho smolt production in validation monitoring and the context for interpreting validation monitoring results.

5.4.1 Using coho smolt production for validation monitoring

Our monitoring strategy requires selecting a specific life stage of a species in order to test the validation hypothesis. We use coho salmon production at the smolt stage because

increased wild coho smolt production was identified as the primary benefit for most recently constructed fish passage projects in the Skagit River basin (e.g., Skagit System Cooperative and Skagit County, 1994).

Documenting effective fish passage does not confirm that the fish passage project increased smolt production (i.e., observing spawners or juvenile fish upstream of the project does not support the validation hypothesis). For example, it is possible that a passage project allows fish to colonize habitat with poor quality. The poor habitat quality could reduce survival and result in less fish in the watershed, even though effectiveness monitoring might show fish passage to have occurred¹⁴. This case is illustrated by curves A and C in Figure 5-1. Curve A represents the stock-recruitment curve for a hypothetical coho stream with a carrying capacity ($1/b$) of 10,000 smolts. Curve C represents the same stream system, but with a doubled carrying capacity and a two thirds reduction density independent survival. In this case, smolt production for curve C does not equal curve A until the level of 300 female spawners, and only shows a minor increase at the level of 400 female spawners.

Because apparent success of a project varies by seeding level, the validation hypothesis should be tested over a range of seeding levels, including fully seeded. When the observed smolt production is significantly less than predicted, other monitoring variables must provide the necessary data to interpret why observed smolt production might be different from predicted.

5.4.2 Variation in coho smolt production

Determining how long to conduct validation monitoring for a fish passage project is important because only one observation is obtained each year and the cost of data collection is relatively high. Too few observations may not detect a difference that is important, while too many observations would be an inefficient use of time and money. Determining the appropriate sample size requires an estimate of the variability about the mean for the population being sampled and the desired minimum detectable difference.

To estimate the interannual variability in natural coho smolt populations, we examined coho smolt production data from nine streams in Western Washington (Lestelle et al. 1993b) and three streams in the Skagit River basin (SSC unpublished data). Mean coho smolt production from these streams ranged from 1,129 to 253,084 fish, and sample sizes (number of years) ranged from eight to eighteen (Table 5-1). Coefficient of variation (CV) ranged from 23% (South Fork Skykomish River) to 67% (Etach/Red Cabin Creek) when all data were included for each site.

¹⁴ If the new habitat and old habitat are both fully seeded, production will increase despite low survival in the new habitat.

Table 5-1. Summary of coho smolt production for twelve stream systems in Western Washington. Seed Orchard, Mannser, and Etach/Red Cabin Creek are in the Skagit River Basin; data are from Skagit System Cooperative. Remaining data were obtained from Lestelle et al. (1993b). The highest coefficient of determination (r^2) is shown for sites where stream flow variables were significantly ($P < 0.05$) related to smolt production.

| Stream System | Average coho smolt production | Standard deviation | Sample size (years of trapping) | CV | r^2 |
|----------------------------------------------|-------------------------------|--------------------|---------------------------------|-----|-------|
| Little Pilchuck Creek (all years) | 28,343 | 7,229 | 15 | 26% | 0.97 |
| Bingham Creek (all years ¹⁵) | 28,373 | 7,577 | 10 | 27% | |
| Harris Creek (all years) | 25,529 | 6,962 | 11 | 27% | 0.31 |
| Mill Creek (all years) | 24,593 | 7,622 | 14 | 31% | |
| Seed Orchard Creek (all years) | 1,129 | 353 | 8 | 31% | 0.74 |
| Mannser Creek (all years) | 13,141 | 4,734 | 9 | 36% | |
| Wildcat/Lost Creeks (all years) | 5,956 | 2,670 | 10 | 45% | |
| Etach/Red Cabin Creeks (all years) | 6,913 | 4,608 | 8 | 67% | |
| S. F. Skykomish River (all years) | 253,084 | 57,655 | 9 | 23% | |
| S. F. Skykomish R. (fully seeded years only) | 289,249 | 50,728 | 5 | 18% | |
| Snow Creek (all years) | 5,924 | 3,038 | 15 | 51% | |
| Snow Creek (fully seeded years only) | 7,679 | 1,585 | 9 | 21% | |
| Deschutes River (all years) | 79,803 | 33,932 | 14 | 43% | |
| Deschutes River (fully seeded years only) | 105,775 | 27,656 | 6 | 26% | |
| Big Beef Creek (all years) | 26,312 | 9,788 | 18 | 37% | 0.59 |
| Big Beef Creek (fully seeded years only) | 28,703 | 10,304 | 9 | 36% | 0.94 |

Lestelle et al. (1993b) used stock-recruitment analysis to estimate the number of female spawners needed to fully seed the available habitat at four sites (South Fork Skykomish River, Snow Creek, Deschutes River, and Big Beef Creek). Using their estimates of full seeding, we recalculated CV for these sites including only fully seeded years and found that CV was reduced in all cases (Table 5-1). Not surprisingly, this indicates that seeding level is a significant predictor of smolt production. However, it should be noted that CV for Big Beef Creek only dropped slightly (37% to 36%). For Big Beef Creek it appears that streamflow explains more of the variation in smolt production (r^2 increased from 0.59 to 0.94).

Variation in streamflow explained 31% to 97% of the interannual variation in smolt production at four of the twelve sites (Bingham, Mill, Wildcat/Lost, and Big Beef Creeks) (Table 5-1). Flow variables (e.g., peak flow during the egg incubation period, low flow during summer rearing) are thought to affect egg incubation success, summer rearing area, or other capacity or survival issues.

¹⁵ Bingham Creek was thought to be fully seeded in all years (see Lestelle et al. 1993b).

These data illustrate the range of variability in coho smolt production for freshwater systems in Western Washington and show that, in some situations, known variables can explain significant parts of the interannual variation. We find that it is unlikely that monitoring coho smolt production at a fish passage improvement site will produce a CV of less than 20%, and that much higher variation is possible (up to 70%). These data also demonstrate the value of collecting other data, such as spawner or flow information, to help reduce variation, and therefore, improve our ability to detect changes in smolt production as a response to the fish passage project.

5.4.3 Minimum detectable population difference and the monitoring period

Data from three sites in Table 5-1 were used as examples to estimate the minimum detectable population difference between the predicted smolt production and mean smolt production over varying monitoring periods. Seed Orchard Creek was selected because it represents the lowest variation in smolt production of the three Skagit River basin sites (CV of 31% after eight years). Etach/Red Cabin Creek represents the highest variation in smolt production in the Skagit with a CV of 67% after eight years of trapping. Snow Creek was selected to represent a population where analyses could be completed using all data (15 years) or only those years where habitat was fully seeded (nine years).

The equation for estimating minimum detectable difference for a one sample t-test (i.e., a test of one mean against a hypothesized value) is:

$$\delta = \sqrt{\frac{s^2}{n}} (t_{\alpha(2),n-1} + t_{\beta(1),n-1})$$

where “ δ ” is the population difference, “ s ” is the sample standard deviation, “ t ” is the critical value of the t-distribution for α (2 tailed) and β (1 tailed), and “ n ” is the number of samples. In the case of smolt population data, n is equivalent to the number of years of smolt trapping.

The sites shown in Figure 5-2 illustrate the range of variability possible in validation monitoring results. For a high variability site such as Etach/Red Cabin Creek (CV = 67%), five years of monitoring would allow us to detect no less than an 105% difference between the observed mean population and the predicted population. Ten years of monitoring would cut this value to 62%, and twenty years of monitoring would reduce it to 41%. By contrast, for a lower variability site (Seed Orchard Creek, CV = 31%), five years of monitoring would allow us to detect a difference of only 49% between the observed population and the predicted population, and ten years of monitoring could detect a 29% difference. After twenty years of monitoring, we should be able to detect a difference as low as 19%. The Snow Creek example in Figure 5-2 illustrates the utility of

being able to control for other variables when testing the validation monitoring hypothesis. When all years are considered, we can detect a population difference no smaller than 81% after five years of monitoring. However, by controlling for seeding level (i.e., using data from fully seeded years only), the minimum detectable population difference would be reduced to 32%.

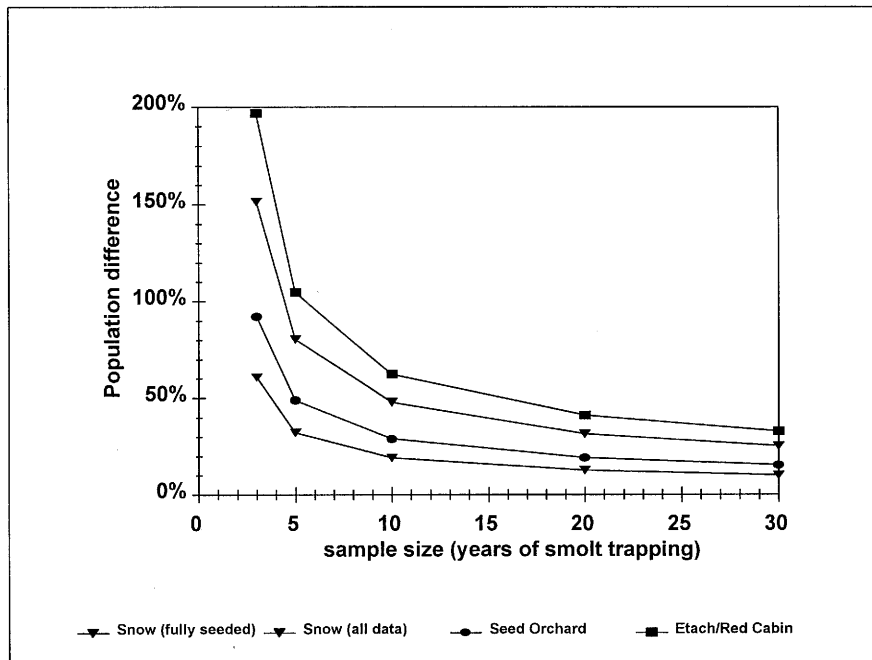


Figure 5-2. Minimum detectable difference in coho smolt production at three example sites as a function of number of years of monitoring ($\alpha = 0.05$, $\beta = 0.25$). Population difference is standardized as a percentage of the mean population.

Figure 5-2 suggests that the minimum monitoring period should probably range from five to ten years depending on variability at the site. Monitoring much beyond ten years does not reduce minimum detectable population difference as much as the earlier monitoring years. This is in light of a relatively constant (or increasing) cost to collect data. Also, hypotheses regarding the effects of flow and seeding should be developed, and monitoring parameters for each variable should be identified and collected during the monitoring period. This will insure that adequate data will be available to interpret the smolt production results after the monitoring period is complete.

6. LITTLE PARK CREEK FISH PASSAGE IMPROVEMENT

6.1 LITTLE PARK CREEK PROJECT DESCRIPTION

The Little Park Creek fish passage improvement project is located where the Baker Lake Road crosses Little Park Creek near Baker Lake (Figure 6-1). The project was designed by the Washington Department of Fisheries and Wildlife (WDFW) for the USFS and consists of a concrete box culvert with fishway (Figure 6-2). The facility was design to pass coho salmon and cutthroat trout. Upstream of the blockage is 20,000 m² of pond and stream habitat. Prior to the completion of this project, the creek discharged from a pond north of Baker Lake Road into Baker lake via two small diameter culverts that were impassable to adult or juvenile salmonids except when the Baker Lake reservoir was at full pool. Because the reservoir is drafted for power generation and flood control storage during the fall and winter months, upstream passage of coho spawners was denied in most years, making fish passage a high priority at this site.

The Washington Administrative Code (WAC) for adult coho salmon in culverts ten to sixty feet in length requires a minimum depth of one foot and maximum velocity of 6 feet per second (fps) in the culvert. Criteria for adult trout is the same for depth, but maximum velocity is 4 fps (WAC-220-110-070). To achieve the latter, more conservative conditions, the design at the Little Park Creek facility was a pool/weir style fishway using 11 pools with a 0.7 foot drop between pools. The lowest two weirs (weirs 1 and 2 on Figure 6-2) were to be countersunk relative to the outlet channel for a factor of safety in case the outlet channel downcut. This culvert / fish ladder facility was predicted to meet the passage criteria for flows up to sixty cubic feet per second (cfs) which is the estimated 10% annual exceedence flow at the Little Park Creek site (personal communication, Bruce Heiner WDFW).

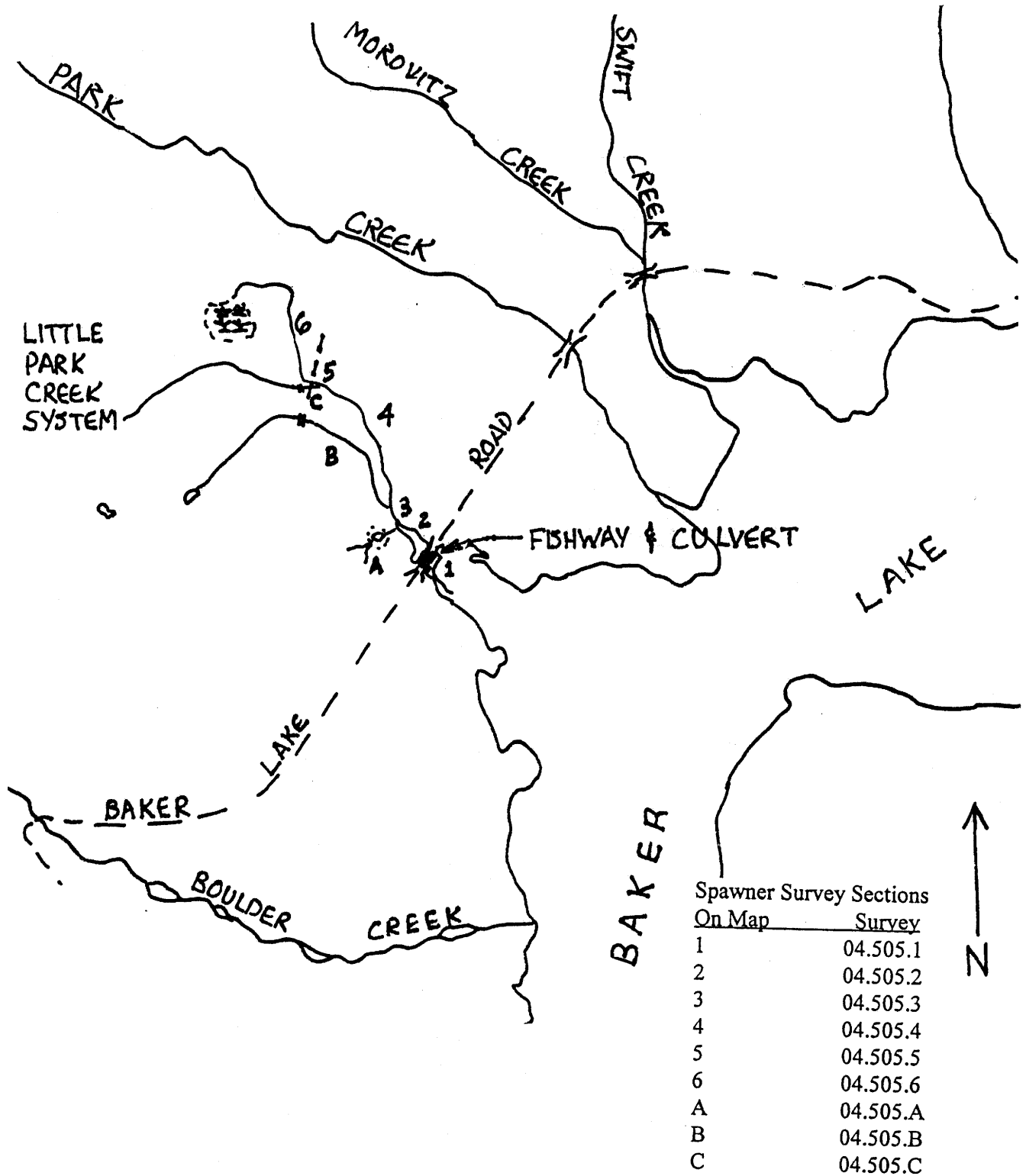


Figure 6-1. Location of Little Park Creek Watershed, spawner survey reaches, and Fish Passage Project.

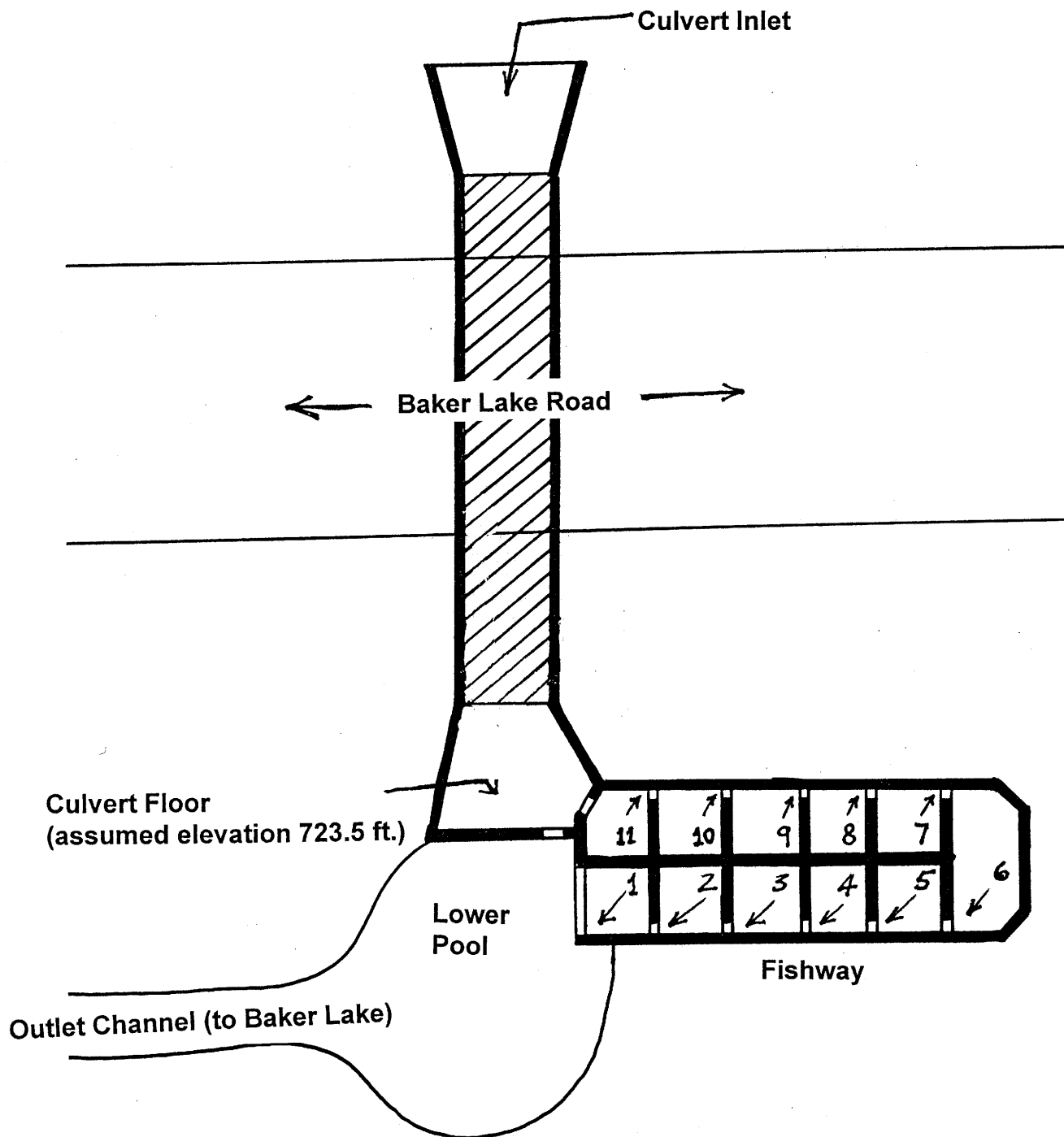


Figure 6-2. Plan view of Little Park Creek Fishway.

6.2 LITTLE PARK CREEK MONITORING HYPOTHESES AND TASKS

Monitoring hypotheses for the Little Park Creek project include statements that describe our understanding of habitat conditions, fish populations, life history patterns, and the anticipated outcome of improved fish passage at the site. Hypotheses 1 and 2 are those that describe the expected outcome of improved fish passage at the site. Hypotheses 3 and 4 are those that describe our understanding of the numbers of fish available to occupy the habitat associated with the project. Hypotheses 5, 6, and 7 are those that describe our understanding of habitat characteristics at the site.

Passage performance and smolt production

1. Upstream and downstream passage of adult and juvenile coho in Little Park Creek will be enabled as a result of constructing the culvert/fish ladder project.
2. Coho smolt production in Little Park Creek upstream of the culvert/fish ladder project will not be significantly different than predicted coho smolt production¹⁶ for rearing conditions that are summer habitat limited.

Spawners and juveniles available to occupy the site

3. There are sufficient numbers of coho spawners available to seed habitat upstream of the project to about 50% of carrying capacity, assuming summer rearing habitat is limiting.
4. There will not be a significant number of juvenile coho immigrating to Little Park Creek winter rearing habitat upstream of the fish ladder from Baker Lake during the fall and winter months.

Potential habitat influences on coho production

5. Spawning and rearing habitat quality is sufficient to allow for "normal" coho survival rates.
6. Water quality is sufficient to allow for "normal" coho survival rates.
7. Flood events in Little Park Creek during the egg incubation phase will reduce incubation success.

If the hypotheses of current habitat conditions or fish seeding levels are shown to be incorrect then the anticipated outcome may change. For example, if initial monitoring shows that spawning area limits smolt production, then hypothesis 2 would be adjusted accordingly.

¹⁶ The prediction incorporates the effect of varying spawner levels using the Beverton-Holt model.

6.3 RESULTS OF LITTLE PARK CREEK MONITORING THROUGH 1996

6.3.1 Implementation monitoring

Implementation monitoring at the Little Park Creek site centered on verifying that the drop between weir steps was consistent with the design. The culvert / fish ladder facility was specified to be a concrete box culvert with an attached pool/weir style fishway with steps of 0.7 feet. The lowest two weirs (weirs 1 and 2) were to be countersunk relative to the outlet pool for a factor of safety in case the outlet channel downcut.

The facility was constructed during the 1995 low flow period. In October of 1995, the fishway, culvert floor, and lower pool water surface elevations were measured using an automatic level and stadia rod. Results show the steps between weirs to be near 0.7 ft. (or less) with the exception of the drop between weir 2 and weir 1 which measured 1.02 feet. We also found that weirs 1 and 2 were not countersunk relative to the lower pool water elevation (Table 6-1).

Table 6-1. Culvert and fishway elevations from the Little Park Creek fish passage improvement facility. The culvert floor was assumed to be the design elevation of 723.5 ft. Survey accuracy is estimated to be ± 0.05 ft. The location of each measured site is shown in Figure 6-2.

| Survey station | Relative elevation (ft.) | Corrected elevation (ft.) | Drop to next weir (ft.) |
|---------------------------|-----------------------------|------------------------------|----------------------------|
| Floor of culvert | 14.52 | 723.50 | |
| Fishway entrance stop log | 13.55 | 724.47 | 0.55 |
| Weir 11 | 14.10 | 723.92 | 0.73 |
| Weir 10 | 14.83 | 723.19 | 0.71 |
| Weir 9 | 15.54 | 722.48 | 0.70 |
| Weir 8 | 16.24 | 721.78 | 0.68 |
| Weir 7 | 16.92 | 721.10 | 0.76 |
| Weir 6 | 17.68 | 720.34 | 0.70 |
| Weir 5 | 18.38 | 719.64 | 0.80 |
| Weir 4 | 19.18 | 718.84 | 0.74 |
| Weir 3 | 19.92 | 718.10 | 0.60 |
| Weir 2 | 20.52 | 717.50 | 1.02 |
| Weir 1 | 21.54 | 716.48 | 0.40 |
| Lower pool water surface | 21.94 | 716.08 | |

The following year (October 1996), the drop between weirs 2 and 1 was found adequate, but the drop between weirs 3 and 2 exceeded one foot. Stop logs may have been changed intentionally, through vandalism, or floated out when the fish ladder was submerged by a fully flooded reservoir during the summer. We corrected the drop between weirs by adjusting stop logs.

6.3.2 Effectiveness monitoring

Little Park Creek effectiveness monitoring included (1) measuring water depth and velocity at the site to determine their consistency with WAC standards for fish passage and (2) fish surveys to determine whether fish actually passed through the constructed facility.

Depth and velocity at the culvert

We measured water depth and velocity in the concrete box culvert on three different dates to compare to the depths and velocities predicted during the design phase of the project (Table 6-2). We attempted to collect measurements during a flood event (November 1995), but were unable to access the site, due to wind fallen trees on the Baker Lake Road.

Table 6-2. Summary of water depth, velocity, and discharge for the Little Park Creek culvert. Predicted discharge and velocity were estimated using data from Heiner (1990). The design criteria were that flows remain deeper than 1 foot and slower than 4 feet per second at all discharges less than 60 cfs.

| Date | Depth (ft.) | Discharge (cfs) | Average velocity (fps) | Predicted discharge (cfs) | Predicted velocity (fps) |
|----------|----------------|--------------------|------------------------------|---------------------------------|--------------------------------|
| 10/11/95 | 1.12 | <1 | not measurable ¹⁷ | | |
| 12/7/95 | 1.50 | 8.7 | 0.73 | 5.5 | 0.46 |
| 1/3/97 | 1.95 | 35.9 | 2.30 | <30.4 | 1.9 |

Stream discharge was calculated as *cross-sectional area* \times *average water velocity*. Cross-sectional area equals 8 ft. multiplied by water depth in the culvert. Because the channel's cross-section is a simple rectangle, we measured velocity with a flow meter at only three points, with three replications at each point within the culvert. The flow meter was set at six-tenths of the depth below the water surface because this approximates average velocity of the water column (Linsley *et. al.* 1982).

Water depth exceeded the one foot minimum depth and velocity was less than the 4 fps criteria listed in WAC at discharges ranging from <1 to 35 cfs. However, *measured* velocity was always higher than *predicted* velocity, suggesting that the 4 fps maximum velocity criteria may be exceeded at flows less than maximum design flow of 60 cfs.

¹⁷ On October 11, 1995 Little Park Creek flow was less than one cfs and water depth in the culvert was 1.12 ft. at the downstream end and 2.50 ft. at the upstream end. The difference in depth was the result of an impoundment caused by a beaver dam constructed inside the culvert. Water velocity and flow were not measured on this date because velocity was too low to measure accurately. The dam was removed manually and colored survey tape was strung across the upstream culvert entrance to discourage further beaver activity in the culvert. Since that time, no further dam building has occurred within the culvert.

Spawner surveys

Following the completion of the fish passage project in the summer of 1995, coho spawner surveys were conducted in the Little Park Creek watershed in the winters of 1995/96 through 1997/98. Surveys were spaced at approximately weekly intervals during the period of mid-November through the first week of January. Redds were flagged with surveyor's tape each week to enable the surveyor to distinguish between redds counted on a previous survey from new redds, thus allowing for a cumulative redd count for the entire spawning season. Surveys were conducted in nine different reaches within the watershed (Figure 6-1). The landmarks for each reach are:

- Reach 04.505.1 -- mainstem from mouth to the first beaver pond, including fishway,
- Reach 04.505.2 -- mainstem from first beaver pond to tributary A,
- Reach 04.505A -- tributary A from mouth to the first upstream barrier,
- Reach 04.505.3 -- mainstem from mouth of tributary A to mouth of tributary B,
- Reach 04.505B -- tributary B from mouth to first upstream barrier,
- Reach 04.505.4 -- mainstem from mouth of tributary B to mouth of tributary C,
- Reach 04.505C -- tributary C from mouth to first upstream barrier,
- Reach 04.505.5 -- mainstem from mouth of tributary C to gravel road crossing, and
- Reach 04.505.6 -- mainstem from gravel road crossing to end of gravel pit.

The number of coho spawners varied dramatically over the three seasons (Table 6-3). In the 1995/96 season, at least 140 different coho adults and 124 redds (93% of all coho redds in Little Park Creek) were observed upstream of the fish passage improvement project. In 1996/97, only 4 redds were observed upstream of the fish ladder while no redds were found upstream of the ladder in 1997/98. However, all years showed evidence of coho spawners passing the fish ladder.

Table 6-3. Little Park Creek coho spawner summary by survey reaches. Reach 04.505.1 is downstream of the fish ladder. All other reaches are upstream of the fish ladder.

| Little Park Creek Reach | 1995/96 Peak count (live + dead) | 1995/96 Cumulative Redds | 1996/97 Peak count (live + dead) | 1996/97 Cumulative Redds | 1997/98 Peak count (live + dead) | 1997/98 Cumulative Redds |
|-------------------------------|----------------------------------------|--------------------------------|----------------------------------------|--------------------------------|----------------------------------------|--------------------------------|
| 04.505.1 | 3 | 9 | 4 | 11 | 6 | 7 |
| 04.505.2 | 7 | 20 | 0 | 0 | 1 | 0 |
| 04.505.3 | 4 | 2 | 0 | 0 ¹⁸ | 0 | 0 |
| 04.505.4 | 23 | 23 | 2 | 2 | 0 | 0 |
| 04.505.5 | 8 | 5 | 0 | 0 | 0 | 0 |
| 04.505.6 | 18 | 10 | 0 | 0 | 0 | 0 |
| 04.505A | 14 | 16 | 0 | 0 | 0 | 0 |
| 04.505B | 50 | 38 | 3 | 2 | 0 ¹⁹ | 0 |
| 04.505C | 16 | 10 | 0 | 0 | 0 | 0 |
| total | 143 | 133 | 9 | 15 | 7 | 7 |

¹⁸ While no coho were observed on the peak date for the entire Little Park Creek system, 2 dead coho were observed in this reach on 12/11/96. However, no redds were ever found.

¹⁹ While no coho were observed on the peak date for the entire Little Park Creek system, 3 live coho were observed in this reach on 12/23/97. However, no redds were ever found.

Juvenile upstream passage

No upstream migrating juvenile fish surveys were planned at the project site or in the Little Park Creek watershed because our initial hypothesis (#4) states there will not be significant numbers of juvenile coho immigrating to Little Park Creek from Baker Lake. However, while adjusting stoplogs in October 1996, we observed several coho parr attempting and failing upstream passage of fish ladder steps.

6.3.3 Validation Monitoring

Validation monitoring at Little Park Creek consists of comparing observed coho smolt production to predicted. Our prediction is based on the Beverton-Holt model (e.g., Figure 5-1). Inputs for the model include: (1) a smolt capacity ($1/b$) derived from habitat surveys, (2) the number of female spawners derived from redd surveys assuming 1 female per redd, and (3) density independent survival ($1/a$) of 134 smolts per female (from Reeves et al. 1989).

Habitat conditions and estimated coho smolt capacity

The identification of the extent, type, and suitability of fish habitat in Little Park Creek began in 1990. The 1990 habitat survey identified tributary A, the existence of 19,400 m² of mostly pond habitat, and a limited amount of spawning habitat in reach 6 (Walsh et. al. 1990). Habitat quality was considered suitable for rearing based on the presence of resident cutthroat trout in Little Park Creek. The habitat inventory also resulted in the hypothesis that spawner access to the existing limited spawning area was questionable due to the numerous beaver dams in reaches 2 through 5. Habitat surveys conducted by SSC in 1993 identified the presence of two other tributaries (tribs. B and C) and freshet flows that over-topped the beaver dams. Tributaries B and C are gravel bedded streams and provide significant amounts of spawning habitat, suggesting that spawning habitat, and spawner access to it, may not be as limiting to coho smolt production as previously thought. Therefore, our current understanding of habitat area and coho smolt capacity in Little Park Creek and its tributaries upstream of the fish passage improvement site is summarized in Table 6-4.

Table 6-4. Little Park Creek habitat area and coho smolt production potential by reach and habitat type. Coho smolt capacity ($1/b$) was estimating by using densities for each habitat type from Beechie et. al. 1994.

| Little Park Creek Reach | Pond area (m ²) | Pool area (m ²) | Riffle area (m ²) | coho smolt capacity ($1/b$ if summer habitat is limiting) | coho smolt capacity ($1/b$ if winter habitat is limiting) |
|----------------------------|--------------------------------|--------------------------------|----------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|
| 2 through 5 | 18,000 | 256 | 544 | 6,951 | 21,212 |
| 6 | 0 | 64 | 136 | 50 | 69 |
| Trib. A | 0 | 42 | 88 | 33 | 46 |
| Trib. B | 0 | 218 | 462 | 171 | 237 |
| Trib. C | 0 | 22 | 48 | 18 | 24 |
| Total | 18,000 | 602 | 1,278 | 7,223 | 21,587 |

Smolt trapping results

No coho smolt trapping was planned in the spring of 1996 because no wild coho smolt production was expected for the area upstream of Baker Lake Road for that year. A downstream migrant trap was operated from April 29 through June 24, 1997 to census coho smolt production resulting from the 1995/96 escapement of 124 redds. The trapping resulted in the capture of 4,941 coho smolts, very close to our prediction of 5,035 (Figure 6-3). Daily outmigration of all species and water temperature data are shown in Appendix 7.

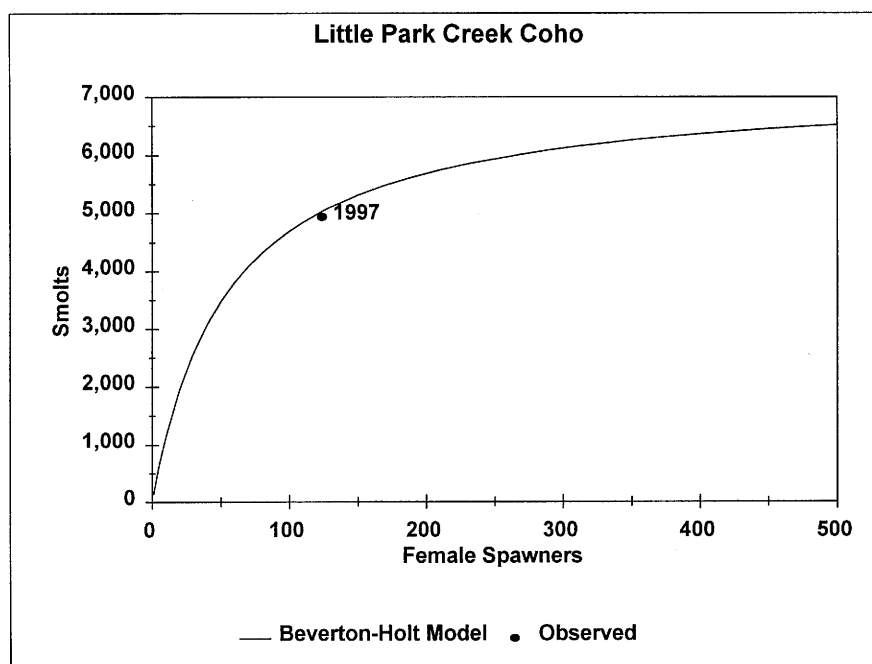


Figure 6-3. Observed and predicted coho smolt production in Little Park Creek.

6.4 DISCUSSION/CONCLUSIONS

6.4.1 Fish passage performance

Hypothesis 1 states “upstream and downstream passage of adult and juvenile coho in Little Park Creek will be enabled as a result of constructing the culvert/fish ladder project.” Both implementation and effectiveness monitoring results support this hypothesis.

Effectiveness monitoring found the minimum water depth in the culvert at low flow to meet the WAC criteria of a minimum 1 foot depth (Table 6-2). Water velocity in the culvert was also well within the WAC criteria over the range of flows measurements were taken (Table 6-2). However, *measured* velocity was always higher than *predicted*

suggesting that the 4 fps maximum velocity criteria may be exceeded at flows less than maximum design flow of 60 cfs. This suggests that juvenile upstream passage may be inhibited at higher flows. We do not yet know if water velocity and jumping heights in the fish ladder are suitable for juvenile coho over the range of flows expected at the site. However, we do not foresee any problems with downstream passage with the possible exception of beaver activity which can be controlled through adequate maintenance.

Spawner surveys documented the site's effectiveness to pass migrating adult coho upstream. Surveys found coho spawners upstream of the fish ladder in all three seasons, with 93% of the coho spawning upstream of the project in 1995/96 season (Table 6-3).

Implementation monitoring found the project constructed as designed, with the following two exceptions. First, the control weir between the lower pool and the outlet channel was constructed approximately one foot too low. This eliminates the safety factor that guards against exceeding the jump criteria at weir 1 in the event of outlet channel down cutting. Second, the drop between weirs 2 and 1 (1.02 ft. in 1995) was not within the 0.7 ft. specified in the plan. However, this was corrected by adjusting stop logs. The drop of 1.02 ft. did not impede the passage of coho adults, as numerous adult coho salmon were observed upstream of the fishway (Table 6-3). However, observations made in October 1996 by SSC staff suggest that a drop this large, does impede upstream passage of juvenile salmonids.

6.4.2 Coho smolt production

Hypothesis 2 is the primary validation hypothesis. It states "coho smolt production in Little Park Creek upstream of the culvert/fish ladder project will not be significantly different than predicted coho smolt production for rearing conditions that are summer habitat limited." Little Park Creek coho smolt capacity is estimated at 7,223 smolts, if summer habitat is limiting, or 21,587 smolts, if winter habitat is limiting (Table 6-4). We predict that summer habitat area will limit the production of juvenile coho due to hypothesis 4 (that juvenile immigration would be insignificant). Smolt trapping results from 1997 are consistent with this prediction (Figure 6-3). Based on the same model, we predict coho smolt production in 1998 and 1999 to be 499 and 0 respectively.

6.4.3 Other factors influencing coho smolt production

Number of coho available to occupy the site

Our third hypothesis states "there are sufficient numbers of coho spawners available to seed habitat upstream of the project to about 50% of capacity, assuming summer rearing habitat is limiting." The hypothesis was based on coho escapement data prior to project construction.

Coho spawning in Little Park Creek has been surveyed since the fall of 1992. Surveys conducted before the fall of 1995 were prior to the construction of the culvert / fish ladder. Regular surveys (weekly) were limited to the area downstream of the blocking culvert while supplemental surveys were conducted in upstream areas²⁰.

Table 6-5. Summary of coho escapement to Little Park Creek, 1992-1996.

| Year of Adult Return | Peak count of Live + Dead Coho | Total Coho Redds in Little Park Creek | Coho Escapement to Baker Lake | Summary of coho fry plants in Little Park Creek |
|----------------------|--------------------------------|---------------------------------------|-------------------------------|-------------------------------------------------|
| 1992/93 | 24 | 80 | 7143 | no plants |
| 1993/94 | 16 | 47 | 4213 | 18,000 winter parr (21 fish/lb.) planted 1/9/92 |
| 1994/95 | 42 | 64 | 4259 | 25,000 fed fry (525 fish/lb.) planted 4/28/92 |
| 1995/96 | 143 | 133 | 5708 | 29,500 fed fry (349 fish/lb.) planted 5/18/93 |
| 1996/97 | 9 | 15 | 3788 | no fry planted |
| 1997/98 | 7 | 7 | 2142 | 64,021 fed fry (349 fish/lb.) planted 5/16/95 |

Assuming 1 redd per female spawner and that most coho spawners would migrate upstream of the blocking culvert if it were fixed, the range of 50 to 80 coho redds per year in Little Park Creek prior to project construction (Table 6-5), corresponds to about 50% of the smolt capacity shown in Figure 6-3. Since project construction however, escapement was sufficient to be considered fully seeded in only one year (i.e., enough spawners to produce 80% of the smolt carrying capacity, Lestelle et. al. 1993b) and very low or absent the other two years. Escapement to Little Park Creek appears to be more a function of Baker Lake coho escapement than the result of fry plants (Table 6-5). We estimate that in years when Baker escapement is less than ~4,000 coho there will not be enough coho escapement to Little Park Creek to reach 50% of full seeding (i.e., hypothesis 3 may not be correct).

Following the summer rearing season, as water temperature decreases and stream flow increases, juvenile coho redistribute to areas where water velocity is negligible. Usable

²⁰ No redds were ever observed upstream of Baker Lake Road before 1995.

winter habitats include backwater pools, dam pools, sloughs, ponds, and lakes. Little Park Creek is dominated by usable winter habitat (Table 6-4), but we do not expect significant numbers of coho parr (i.e., thousands) to immigrate from Baker Lake because the Lake is also usable winter habitat. There would be little incentive for fish to vacate the lake unless it was fully seeded to winter capacity. This forms the basis of hypothesis 4, which is indirectly supported by smolt trapping results that are consistent with summer rearing habitat limiting production. It may need to be revised if monitoring data suggest significant fall immigration has occurred. Future years of smolt trapping, especially monitoring production from low or no escapement years, will be helpful.

Potential habitat influences on coho production

Hypotheses 5, 6, and 7 are not refuted by any monitoring results and the 1997 smolt trapping results are consistent with these hypotheses as stated. In other words, there are no obvious environmental factors altering spawning or rearing survival rates in Little Park Creek.

6.4.4 Evaluation of the rationale for the Little Park Creek project

A "loss of historical habitat including stable spawning and rearing areas" for steelhead, cutthroat, and coho was listed by the USFS as a principle issue in the decline of fish stocks for this watershed (USFS 1994).

The Little Park Creek project was estimated to have the largest restoration benefit of all projects prioritized (8,390 new smolts restored) and no protection benefit (Appendix 2, Table 1). The restoration benefit was expected to begin immediately and persist long-term because no new habitat was created by the project (existing habitat was just being reconnected). Even without a protection benefit, the cost benefit analysis ranked this project fifth out of the nineteen prioritized for the Skagit River basin. This site was also expected to utilize some funding that was available from other sources to economize the funding from the President's Forest Plan for restoration.

Our initial monitoring results are generally consistent with the USFS rationale for doing this project. Spawner surveys show that coho utilized the new habitat during the first spawning season following project construction. This supports the hypothesis that the restoration benefit begins accruing immediately. The potential restoration benefit level appears to be slightly over estimated in the original project proposal. The original proposal estimated that 8,390 coho and steelhead smolts could be produced from Little Park Creek. However, initial monitoring results showed that we have little steelhead habitat in this area. We now believe a more accurate estimate of smolt production capacity would include only coho, and should be about 7,200 smolts. Such a level would be attained only under fully seeded conditions. Over the short-term, the actual restoration benefit (i.e., smolts produced) will likely be much lower than predicted due to lower than

expected coho escapement levels.

6.4.5 Recommended monitoring protocol and schedule

The following monitoring protocol and schedule are recommended for the Little Park Creek fish passage improvement project to enable the testing of effectiveness and validation hypotheses.

1. Measure water velocity in the culvert over a range of flows greater than 35 cfs and approaching 60 cfs to determine if and when maximum velocity requirements are exceeded.
2. Maintain the facility for debris accumulation, beaver dam problems, and the drop between the water surface elevation of the lower pool and weir 1 over the project's life. Monitoring should follow high water events and wind storms that may trigger debris accumulation in the facility or wave damage to the outlet channel control weir. Monitoring for beaver dam problems should coincide with when fish migration is expected.
3. Operate a downstream migrant trap during the spring to assess coho smolt production for a five to ten year period depending smolt production variability and the impact induced by varying escapement levels and peak flows during egg incubation.
4. Monitor the presence and distribution of coho spawners in Little Park Creek each winter during the five to ten year smolt production monitoring period.
5. Add the collection of other biological or environmental parameters (e.g., upstream migrant trapping, summer water temperature) if coho smolt production data are inconsistent with the primary validation hypothesis (hypothesis 2).

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APPENDIX 1.

EXAMPLES OF RESTORATION TREATMENT TYPES AND SPECIFIC ACTIONS.

Summarized from Interagency Task Group 1993.

| Type | Examples of specific actions |
|------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Road Erosion: stormproofing | <p>Correct stream diversion potential at stream crossings, such that if a crossing fails or overtops, streamflow is not diverted down the road or ditchline.</p> <p>Upgrade stream crossings to allow fish passage and to pass at least the 100-year streamflow, plus associated bed load and debris, using a variety of techniques such as: installing larger culverts or trash racks, lowering inlets, changing inlet configuration, hardening crossing fills, controlling sediment and debris loading upstream of the crossing.</p> <p>Remove and reconfigure unstable fills.</p> <p>Reroute road drainage to stable receiving areas.</p> |
| Road Erosion: road upgrading | <p>Relieving inboard ditchlines more frequently.</p> <p>Rocking road surfaces (to armor against road surface erosion and maintain design drainage configuration against traffic impacts, especially where roads must remain open during wet periods).</p> <p>Mulching and revegetating bare, erosion-prone surfaces such as cuts and fills, wherever derived sediments have access to the stream system.</p> <p>Applying site-specific drainage solutions applied wherever erosive concentrations of road drainage or streamflow are causing sediment delivery to streams</p> <p>Adopting maintenance techniques that are specifically designed and conducted to control erosion and sedimentation</p> |
| Road Erosion: road decom-missioning | <p>Removing culverts</p> <p>Decompacting road surfaces (ripping)</p> <p>Outsloping</p> <p>Waterbarring</p> <p>Stabilizing (following analysis) potentially unstable fills</p> <p>Seeding and planting native vegetation, and mulching if needed</p> |
| Riparian Silviculture | <p>Planting on streamside landslides</p> <p>Planting on flood deposit "high-bars" near streams and rivers</p> <p>Planting or seeding in disturbed areas such as skid trails, landings, hot-burned streamside areas, degraded meadows, and cable corridors</p> <p>Interplanting appropriate conifer species</p> <p>Aerial seeding of inaccessible areas, such as landslide surfaces and riparian areas</p> |
| Stream channel restoration: Fish and Aquatic Resources | <p>Improving habitat complexity: introduction of LWD/boulder complexes, off channel pond development, side channel development</p> <p>Improving/creating spawning habitat: install gravel catchments, gravel introductions, gravel cleaning, spawning area cover development</p> <p>Restoring rearing habitat: winter hiding cover, pool development, side channel/off channel pond development</p> <p>Restoring holding habitat: pool development enlargement, cover addition to existing holding areas, modify human access to minimize harassment</p> <p>Improving up/down stream passage: culvert baffling, screening at diversions, fish ladder development</p> |
| Stream channel restoration: Hydrologic Function | <p>Energy Dissipation (introduction of large woody debris and boulders)</p> <p>Sediment Storage (creation of catchments)</p> <p>Bank Stability: bioengineering, structural (rip-rap etc), bank contouring</p> <p>Floodplain/Channel Restructuring: re-establish channel meanders, remove introduced floodplain fill</p> |

APPENDIX 2.

PRELIMINARY WATERSHED ASSESSMENTS FOR SELECTED WATERSHEDS IN THE SKAGIT RIVER BASIN

Skagit River Basin Watershed Restoration Overview

Introduction

The Skagit River basin is located in the North Cascades Mountains and empties into Puget Sound. This 3100 square mile basin is the largest in Puget Sound and second only to the Columbia River in Washington state. The basin's elevation ranges from sea level near Puget Sound to over 2438 meters at the crest of the Cascade Mountains. The climate of the basin is a West Coast marine climate controlled by Pacific Ocean currents. Characteristically the mountains are steep and covered with forests except above timberline where alpine peaks, snow fields and glaciers persist. Although the lower portions of the Skagit River valley have extensive floodplains (90,000 acres), floodplains are essentially absent above the confluence of the Cascade River.

The Skagit Wild and Scenic River System (including portions of the Sauk, Suiattle, Cascade, and Skagit Rivers) was designated by Congress as a federal wild and scenic river in 1978. The Skagit System was designated because it possesses outstandingly remarkable: a) wildlife represented by one of the largest wintering bald eagle populations in the US outside Alaska; b) fish represented by five species of salmon and three species of anadromous trout; and c) outstanding scenic qualities. Under Section 10 (a) of the Wild and Scenic Rivers Act, the USDA Forest Service has responsibility to protect and enhance the system's outstandingly remarkable values. The Skagit System also includes a designation of recreational status on segments of the mainstem of the Skagit River and scenic designation on portions of the Sauk, Suiattle, and Cascade Rivers. The wild and scenic river corridor generally includes a 1/4 mile wide strip on either side of the river.

Wildlife

Wildlife of concern in the Skagit Basin include the federally listed threatened, endangered and sensitive species, along with USFWL designated critical habitat for recovery of listed species. The Skagit Basin includes primary habitat for the bald eagle, northern spotted owl, marbled murrelet, grizzly bear, and gray wolf along with critical habitat for the spotted owl, proposed critical habitat for the marbled murrelet, and grizzly bear recovery zone designation for the North Cascades.

The wintering bald eagle population on the Skagit River system is one of the largest outside of Alaska. The high winter use is due to the availability of food that results from large numbers of chum, and coho salmon that return to the system to spawn and die. Eagles use the riparian vegetation for perching (mostly large deciduous trees) while foraging, and mature to old growth conifer stands (within approx. 2 miles of forage sites) for communal night roosts. Restoration efforts for fish populations contributes to maintaining a critical element for bald eagle use of the Skagit basin. There is historic bald eagle nesting in the Baker Lake area so contributions to fish restoration efforts in that area could benefit year-round eagle residents.

The Northern spotted owl occurs on National Forest throughout the Skagit Basin. Critical Habitat designations include the Illabot Cr., Finney Cr., and

Baker Lake areas as well as portions of the Sauk and Suiattle River drainages. Spotted owl locations and nest sites are primarily below 4000 ft. in elevation and are in tracts of mature to old growth coniferous stands. Riparian and upland management to return processes to the landscape are perceived as being beneficial to maintenance and recovery of habitat used by spotted owls.

Marbled murrelets detections within the basin include behavior which was indicative of likely nesting sites, as well as sites with eggshell fragments and young found on the forest floor. Suitable habitat for nesting murrelets is thought to be primarily provided by conifer stands of 200-250 years of age with large lateral branches on which the egg is laid. Much of the Skagit Basin is included as proposed critical habitat for the marbled murrelet (Federal Register/ Vol 59, No. 18 / January 27, 1994). Seasonal restrictions on operations in and near suitable habitat has been identified by some scientists as a means to avoid disturbing potentially nesting murrelets. Designation of critical habitat conveys added emphasis on these areas for the conservation of the species.

The Skagit basin is also within the North Cascades Recovery Zone for the grizzly bear and includes habitat which is used by the gray wolf. Both of these species are large ranging species with needs for habitat which provides space for foraging, and security from human-caused mortality. Watershed analysis and restoration efforts can contribute to maintaining or restoring habitat conditions which are described as important to these species: space, isolation, denning, safety, vegetation and food. (Almack et al, 1993 - North Cascades Grizzly Bear Ecosystem evaluation, Final Report to the Interagency Grizzly Bear Committee)

Fisheries

Other than the Columbia River system, the Skagit is the only river basin in Washington state naturally producing all five species of pacific salmon and three species of sea-run trout. The Skagit River is one of only four river systems in the State of Washington managed primarily for wild salmon and sea-run trout production (SASSI, 1992). These anadromous populations spawn and rear in the 100 miles of mainstem Skagit River and in over 400 miles of tributary drainages (Puget Sound Task Force, 1970). Within the Skagit River basin are some of the last remaining miles of optimum spawning and rearing habitats for sustaining wild populations of anadromous fish. Fish production in the Skagit River's tributaries is significant to the sport, subsistence and commercial fisheries in the Puget Sound region.

Maintenance, protection and improvement of these fish stocks and habitats is a very significant issue with the public, State, and federal resource managers and the numerous Point-No-Point Treaty Tribes. Chinook, coho, pick, chum, and sockeye along with steelhead and resident trout are extensively managed because they are significant sport/commercial or subsistence species, and because their viability is sensitive to environmental change.

The current status of the five salmon stocks in the Skagit River basin has been defined in a recent report by the Pacific Fisheries Management Council, the Pacific Northwest's regulatory body for commercial fisheries. The report indicates that fish are being lost because of overharvesting and degradation of riverine habitats (Pacific Fisheries Management Council 1992).

Of the salmon stocks within the Skagit River basin, coho and spring chinook salmon have declined the most (Pacific Fisheries Management Council 1992). The escapement goals for the number of returning coho (30,000 fish) and spring chinook (3,000 fish) have not been met since 1988 (Pacific Fisheries Management Council 1992). The coho salmon escapement of 45,000 fish in 1986 have decreased to only 7,800 fish in 1991. The poor status of the stocks is forcing regulators to curtail oceanic commercial and river harvests, and causing much controversy and demand for solutions to the problem.

The American Fisheries Society (AFS) recently provided a list of 214 depleted native naturally-spawning Pacific Salmon stocks from the Pacific Northwest and California (Nehlsen et al, 1991). Nehlsen et al (1991) reported that the sockeye stock, found on Baker River (a major impounded tributary of the Skagit River), is a threatened population. A threatened population is defined as one with a declining production rate, a ratio of approximately one adult returning to spawn per parent spawner, and little likelihood of an increasing adult production rate under existing conditions.

In 1992 the Washington State Salmon and Steelhead Stock Inventory (SASSI) identified the Baker River sockeye as a critical stock. These are defined as stocks in jeopardy of significant loss within stock diversity, or in worst case, extinction. Four other stocks found within the Skagit River basin are listed as depressed. A depressed stock is one whose production is below expected levels, based on available habitat and natural variations in survival rates, but above where permanent damage to the stock is likely.

Although salmon stocks other than the sockeye do not appear to be threatened or critical at the present time, the designation of the sockeye does signal that the Skagit and the Wild and Scenic River System have experienced altered watershed and stream conditions. Salmon are used as an indicator species of ecosystem and habitat health by government agencies, the Tribes and environmental organizations. Declines in the number of salmon suggests that both fish stocks and the Skagit River ecosystem are at risk.

Fish Habitat Condition

The degradation of habitat occurs because many of the stream channels within the Skagit River basin are naturally unstable due to a combination of highly erosive soils and a high sediment load resulting from avalanche and glacial activity. Timber harvest and road building activities on federal lands from 1950 to the mid 1980's have exacerbated this natural instability; much of the existing road system was constructed using excavation techniques with uncontrolled fill placement and inadequate drainage systems. The increased occurrences of sources, delivery and impacts of sediment and debris have reduced water quality, burial or scouring of spawning gravels and loss of fish habitat within the wild and scenic river corridor.

A hydrological cumulative effects analysis was completed as part of the Mt. Baker-Snoqualmie National Forest Plan (June 1990) to address concerns on the relationship between timber management activities and the viability of fish and fish habitat, and to develop a procedure to meet water quality management requirements. Harvesting coupled with rain-on-snow flood events have caused a large increase in sediment yield and transport through debris torrents and landslides. Within the Skagit River basin, Jackman Creek, Finney Creek, Lake

Shannon, Sauk River, and Lower Skagit River have were found to be in an unacceptable condition.

Restoration Partnerships

The Forest Service is involved in two different partnerships within the Skagit River Basin in response to the decline of fish habitat on the Skagit River.

1. The FINNEY working group, comprised of representatives from the Washington Departments of Fisheries (WDF), Wildlife (WDW), and Ecology, the Skagit Systems Cooperative (SSC) (includes representatives of the Sauk-Suiattle, Upper Skagit, and Swinomish tribes), Forest Service, and landowners have been involved in coordinating watershed restoration efforts to restore fish habitat.

2. The BAKER LAKE working group includes representatives from Puget Sound Power and Light, National Marine Fisheries Service, National Park Service, SSC, WDW, WDF and Forest Service. This group organized to try to increase fish numbers on the Skagit River, specifically on the Baker River.

The Forest Service has spent over \$1 million on road decommissioning projects and other watershed restoration efforts in the Skagit River basin to date. The Forest estimates that an additional \$14 million are needed to conduct inventories, implement projects and to conduct monitoring. A long term monitoring program, funded beyond the life of individual projects, is necessary for evaluating project effectiveness, validation of restoration methods and assessment of trends in watershed health. Forest Service personnel estimate that an additional \$15 million would be needed for habitat restoration on private land within the Skagit River basin.

The Forest Service efforts in Finney Creek have prompted one private timber company in the basin to complete a watershed restoration project on their land as mitigation for harvesting timber. Several other landowners have expressed interest in completing restoration projects on their land as well.

Summary

The Forest Service and representatives from the federal, state, county agencies and the tribes have formed a partnership to review watershed restoration efforts on the Skagit River Basin. This group has identified high priority watershed projects for the 1994 watershed restoration effort which are identified in the enclosed project packages. The projects are proposed on federal land and provide a mix to maintain quality fish habitat and restore degraded habitats. Although the emphasis for restoration efforts in 1994 has concentrated on anadromous fish, much of the proposed activities benefit terrestrial species. Future watershed analysis will expand coordination of multiple species concerns in strategies to protect/restore habitat within the Skagit River Basin. The Forest supports the continued cooperative efforts in ecosystem management on both federal and non-federal land.

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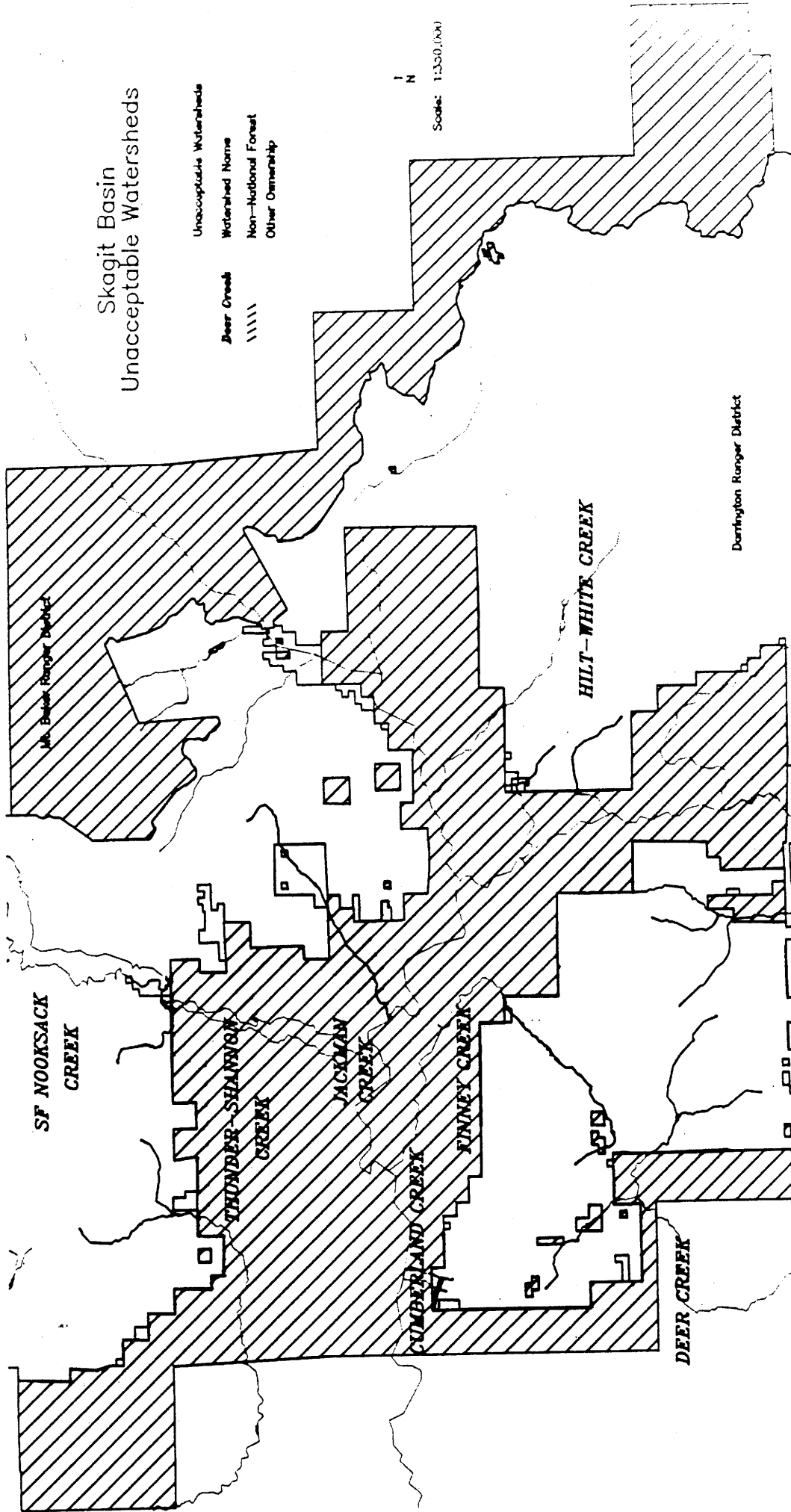
Skagit Basin Unacceptable Watersheds

Unacceptable Watersheds
Watershed Name
Non-National Forest
Other Ownership

Deer Creek
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Scale: 1:350,000



Preliminary Watershed Assessment
Illabot Creek

Principal Issues:

- Degradation of habitat.
- Identification of depressed or sensitive anadromous stocks and bull trout.
- Preservation of intact fisheries.

Existing Condition:

Illabot Creek, a 111 square kilometer watershed, is a tributary of the Skagit River located in the North Cascade Mountains of Washington State. The lower Illabot watershed is comprised of state and private land and the upper watershed primarily of Forest Service lands (roughly three quarters of the watershed). The FEMAT designation of the watershed is late successional old growth.

The drainage is situated southeast of the town of Rockport Washington, where Illabot Creek enters the Skagit River at river mile (RM) 71.60 (Rkm115.3). Elevations in the Illabot Creek Watershed range from 75 meters at its mouth to 2,266 meters at the summit of Snow King Mountain. The Illabot Creek watershed, including the mainstem of Illabot Creek contains 24.3km of mainstem plus 31 tributary streams and two side channels, providing an additional 89.4km of drainage (Williams, 1975).

Illabot Creek is utilized by five stocks of salmon and steelhead (WDF, et. al., 1992). They are listed as Upper Skagit mainstem/tributary summer chinook (healthy), Mainstem Skagit chum (healthy), Skagit coho (depressed), Skagit pinks (healthy), and Mainstem Skagit and tributary winter steelhead (healthy). Chinook, chum, and pinks all depend on Illabot Creek for spawning and brief fry rearing as they migrate to the estuary areas of the Skagit as fry (age 0+). Coho and steelhead are found throughout Illabot Creek. These stocks depend on the watershed for spawning and rearing. Coho rear for over one year in freshwater, while steelhead require over two years. In addition, Dolly Varden use this system for spawning and rearing. Dolly Varden, steelhead and coho salmon were observed in 1992 at RM10 (16km) just below Illabot Lake (Zyskowski, 1994). The main channel has high use by all stocks up to RM1.4 (2.3km), with chinook and pink salmon utilizing the channel up to RM2.7 (4.3km), and coho, steelhead and Dolly Varden the entire channel length.

The majority of the drainages are steeply sloping first and second order channels. The watershed runs NW-SE approximately 120 degrees to Straight Creek Fault which divides the watershed in two. The lower watershed or 40 percent, is comprised of meta-sedimentary and meta-volcanic rocks and the upper watershed is comprised of crystalline rocks, granitic intrusive igneous and gneissic rocks (Brown, et al, 1987). Extensive glaciation occurred during the Pleistocene, leaving a veneer of till covering the upper slopes (Snyder & Wade, 1970) and thick accumulations of glacial outwash gravel, terrace deposits in the Skagit Valley (Klungland and McArthur, 1989), where Illabot Creek crosses

old river terraces and occupied a series of isolated Skagit River side channels and meanders.

One half mile above the Rockport-Cascade Road to the mouth, the stream has been severely impacted by logging and agricultural practices leaving a token riparian area, a sand filled channel with minimal structure, and localized channel widening. Riparian vegetation is dominated by deciduous trees (red alder, cottonwoods, and maple), and young conifers in the clearcuts that approach the stream channels. In the middle reach mature stands remain, with hardwoods along the channel. The upper reaches are dominated by hardwoods, mature timber, and young conifers in the harvest units. From RM2.5 (4.0km) to RM9 (14.5km), the channel is fairly entrenched with gradients ranging from 3 to 12% and has a series of cascades. Flatter gradients (2 to 4%) dominate the two miles (3.2km) below Illabot Lake, RM10 (16.1km). Illabot Lake is now infilled with gravels and is mainly a series of dry channels due to the absence of beaver populations. This lake was potentially a rearing area for coho salmon in the not too distant past. The channel from Illabot lake up has a moderate gradient (3 to 6%) and it enters the upper sub-alpine valley.

Water bodies in this watershed have been listed in the Washington State Department of Ecology's report to the Environmental Protection Agency on Water Quality Impaired Waterbodies, 305(b) Report. According to this report, water quality is impaired in part by siltation, increased temperature, habitat modification, and dissolved oxygen. Some sources for these impairments are silvicultural road construction and maintenance, removal of riparian vegetation, and streambank destabilization.

The State of Washington, in chapter 173-201A, has classified these waters as "Class AA (Extraordinary)". Present characteristic uses are as a water supply, salmonid (and other fish) migration, rearing, spawning, and harvesting, wildlife habitat, and recreation. These waters are also considered suitable for stock watering, crustacean habitat, and commerce and navigation, though they are not used for such purposes at this time. Because of excessive sedimentation and subsequent migratory fish habitat degradation, the aquatic ecosystem has been adversely affected, and anadromous fish stocks depleted.

Desired Future Condition:

Maintain existing acceptable fish habitat and restore habitat conditions (where necessary) to allow recovery of viable populations of salmon and steelhead. Maintain water quality levels at Washington State standard Class AA Extraordinary Standard. Maintain old growth areas to provide additional protection and improved dispersal for spotted owls, additional retention of marbled murrelet nesting habitat, and protection of other species found in riparian areas.

Processes:

Timber harvest has been relatively moderate. Thirteen percent of the Federal lands have been harvested through the 1980's. Old growth stands have already been removed from private lands, and second growth is currently being harvested. Most of the unstable soils occur in association with the Straight Creek Fault and have been avoided to date. There are several inner gorge streambank failures related to unstable soils located in the mainstem Illabot Creek and associated with the Straight Creek Fault. Most slope instability in the roaded zone has been associated with timber harvest on first and second

order channels and road related failures. Road density is low, 3.2km/sq. km., of which 62% were constructed during the 1960's. Road construction specifications called for sidecast excavation with uncontrolled fill placement. This amounts to 85% of the existing road system. Specific examples of fillslope failures occur along the Illabot Creek Road System at approx. mile posts 14, 16, and 22 (USFS C.E. 1990). Currently, Illabot Creek has been impacted by the Upper Slope Timber Sale fire in 1990 and two resulting minor slides and numerous road failures that have either impacted the first and second order tributaries or directly impacted Illabot channel. There have been numerous road drainage structure failures due to inadequate sizing, blockage, and/or upslope debris torrents (USFS C.E. 1990). Most harvest areas are well revegetated except in the upper elevations above 3000 feet. Channel banks along the first and second order streams with debris torrent activity are not revegetated due to constant disturbance. Due to road drainage deficiencies, unconsolidated road fills, steep side slopes (26 degrees plus) and shallow soils, high risk exists of further sediment inputs to Illabot Creek and a continuation of channel degradation. Debris slides and debris torrents initiated from roads are the highest risk based on existing landslide information.

Prescription:

Illabot Creek is an important tributary to the Skagit River with significant anadromous fisheries values throughout at least 16km of its length. Illabot is primarily an intact fishery and refuge in the heavily impacted Skagit River System. It has a high level of natural instability that has been aggravated by locating roads and harvesting timber around tributaries, concentrating water runoff. Road upgrading and storm proofing is needed to prevent the addition of more sediment.

Increased channel stability would increase the amount of valuable anadromous and resident trout fisheries. Land acquisition within one quarter mile on either side of Illabot Creek would provide protection in this critical anadromous reach. The zone would be managed as a greenbelt and buffer to impacts from management activities, and as an important zone for bald eagles.

Following the completion of road upgrading and decommissioning, large woody debris should be imported as a short term strategy into drainages to create fish habitat, and to enhance the hydrologic recovery process. Select instream projects that improve fish refuge habitat i.e. protection from high winter flows, and high summer temperatures with a likelihood of success under existing conditions would also be important short term goals. After 80 years there can be natural recruitment of large woody debris along the riparian corridor, and the continued establishment of riparian vegetation. Finally, the overall stability of the basin is dependent on the re-establishment of mature forest stands throughout the basin.

Long term strategies should include management of the watershed on a landscape or watershed basis, and continued cooperative efforts with landowners, and other government agencies.

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PRELIMINARY WATERSHED ASSESSMENT
FINNEY CREEK

Principal Issues:

- Degradation of water quality and riparian areas due to erosion, and mass wasting primarily coarse sediments.
- Decline of fish stocks.
 - Loss of historical fish habitat including stable spawning and rearing areas
 - Increased stream temperature and turbidity, and loss of riparian shade.
 - Identification of depressed or sensitive anadromous stocks and bull trout.
- Impacts to private property downstream.

Existing Conditions:

The 134 square kilometer Finney Creek watershed is a major tributary of the Skagit River, and is located in the North Cascade Mountains of Washington State. The Finney Creek watershed is comprised of a lower basin located on State and private land (37%) situated southwest of Concrete, Washington (where the creek enters the Skagit River), and an upper basin primarily on National Forest System land (63%). The watershed on National Forest land has been designated as an Adaptive Management Area under FEMAT.

Elevations in the Finney Creek watershed range from 61 meters at its mouth to 1550 meters at the summit of Finney Peak. The Finney Creek watershed, including the main stem of Finney Creek, is comprised of 31 sub-basins which collectively contain 124 kilometers of stream channel (Strahler, 1957). The majority of tributaries are steeply sloping first and second order channels.

Water bodies in this watershed have been listed in the Washington State Department of Ecology's report to the Environmental Protection Agency on Water Quality Impaired Waterbodies, 305(b) Report. According to this report, water quality is impaired in part by siltation, increased temperature, habitat modification, and dissolved oxygen. Some sources for these impairments are silvicultural road construction and maintenance, removal of riparian vegetation, and streambank destabilization.

The State of Washington, in chapter 173-201A, has classified these waters as "Class AA (Extraordinary)". Present characteristic uses are as a water supply, salmonid (and other fish) migration, rearing, spawning, and harvesting, wildlife habitat, and recreation. These waters are also considered suitable for stock watering, crustacean habitat, and commerce, though they are not used for such purposes at this time. Because of excessive sedimentation and subsequent migratory fish habitat degradation, the aquatic ecosystem has been adversely affected, and anadromous fish stocks depleted.

Six stocks of salmon and steelhead utilize this watershed (WDF, et.al., 1992). They are listed as Lower Skagit fall chinook (depressed), Lower Skagit tributary chum (unknown), Skagit coho (depressed), Skagit pinks (healthy), Mainstem Skagit and tributary winter steelhead (healthy), and Finney Cr. summer steelhead (unknown). Chinook, chum, and pinks all depend on Finney Creek for spawning and brief fry rearing as they migrate to the estuary areas of the Skagit as fry (age 0+). Tributary use by these stocks is currently limited or non-existent. Historically, pinks used Hatchery, Quartz, and Ruxall Creeks. Chinook and pinks are found in both the upper and lower reaches of Finney Creek, while chum are only found in the lower reach. Spawning densities are highest in the lower

reach for all these stocks. Coho and steelhead are found throughout Lower Finney Creek and its accessible tributaries. All three of these stocks depend on the watershed for spawning and rearing. Coho rear for over one year, and steelhead for two. Steelhead dominate the upper reach and mainstem, while coho are most abundant in the lower reach, and side and off-channel areas (WDF, et.al., 1992).

Lower Finney Watershed

The lower basin is dominated by steep north facing slopes, and is comprised of Darrington Phyllite Schist (Brown et.al, 1987). Extensive glaciation of the basin occurred during the Pleistocene, leaving a veneer of till covering the upper slopes to the south, and thick accumulations of glacial outwash gravel, terrace deposits and glacial-lacustrine sediments on mid and lower slopes (Klungland and McArthur, 1989). The modern Lower Finney Creek was created by stream incision into these glacial sediments following an infilled fault trace with a northwest/southeast trend.

Slopes in the lower basin are characteristically steep (>26 degrees). Railroad logging began in the lower basin at the turn of the century, with extensive logging of the lower slopes in the 1940-50's, and the upper slopes in the 1970s and 80's. Riparian vegetation in both the lower and upper basin are predominantly deciduous trees (red alder and maple), with few segments of old growth conifers, and a larger percentage of shrubs in the upper basin.

Upper Finney Basin:

The upper basin includes two major rock units. The northern part of the upper basin is comprised of a continuation of the Darrington Phyllite schist, and the southern is primarily comprised of Shuksan greenschist. Minor exposures of Chilliwack sedimentary rock, Deer Peak metamorphics, and ultramafic rocks are also found. These rock units are fault bounded by a series of northwest/southwest trending faults (Brown et.al., 1987). Slopes in the upper basin are characteristically steep (>26 degrees). Glaciation was extensive, leaving a thin veneer of recessional outwash and glacial till on the upper slopes and glacial-lacustrine in the valley bottoms (Snyder and Wade, 1970). The upper basin was first logged in 1956. Four percent of the upper basin was logged in the 50's, 13% in the 60's, 17% in the 70's and 14% in the 80's, a cumulative total of 49%, including private harvests within the Forest boundary.

Desired Condition:

Maintain existing acceptable fish habitat and restore habitat conditions to allow recovery of viable populations of coho, chinook, and steelhead in the watershed area. Water quality is maintained or restored to state Class AA Extraordinary Standard. Maintain old growth areas to provide additional protection and improved dispersal for spotted owls, additional retention of marbled murrelet nesting habitat, and protection of other species found in riparian areas.

Processes:

Lower Finney Basin:

The main tributaries of lower Finney Creek deliver massive amounts of sediment from inner gorge failures. The failure mechanism is primarily one of shallow rapid slides that block steep tributaries. These break during rain-on-snow

events, becoming debris torrents/dam breaks that deposit sediments directly into lower Finney Creek.

Landsliding contributes the major portion of sediment input within Finney Creek (Parks, 1992). This has been found to be the case in other watersheds in the North Cascades (Eide, 1989; Raines, 1990). Inner gorge failures in Darrington Phyllite schist and in over-steeped headwall areas are the primary sediment sources for lower Finney Creek (Parks, 1992).

Slope hydrology alteration has resulted from concentrated surface and subsurface flows and reduction of retention in the system. This altered flow timing and water routing are associated with extensive harvesting, high road densities estimated at 7.2km/ sq. km, and road stacking. During periods of rain-on-snow (Harr, 1981) small, shallow, rapid failures along the tributary inner gorge temporarily block the channel. These dams later fail and create debris torrents leading to dam break floods delivering massive amounts of sediment to the main Finney Creek. These sediments, along with upstream sediment delivery, have resulted in an aggrading condition.

The combination of accelerated sedimentation, the unconfined nature of the valley bottom, and the removal of large wood from the riparian area, have resulted in a channel with little complexity or structure (wide and shallow). The extreme aggradation of the channel has caused a significant increase in the meandering of the stream. This increased meandering has undercut the toe slopes of the terraces north of the channel, adding to already excessive sedimentation.

The lower reach of Finney Creek has a gradient of less than 0.5%, and extends from the mouth to a bedrock constriction at approximately river km 11. Tributary habitat is limited to only a few streams with short (<0.5km) accessible lengths. Most of the habitat is considered degraded (WDF, et.al, 1992). Smolt production loss for coho and steelhead was estimated at 30%, based upon comparing 1984 pool and riffle area to estimates of historic conditions (SSC, unpublished). Channel widening data from aerial photos show that the lower reach is responding to excessive sediment loading by widening, resulting in both decreased pool depths and frequencies, increased summer stream temperatures, and decreased refuge areas. Between 1974 and 1991, the channel width in the lower reach increased by 77%, with 19 of 22 transects showing change. Tributary pool area loss, channel widening in the main stem, and high summer temperatures in excess of 65 degrees F (18 degrees C), all suggest that habitat conditions are presently below their potential for all species. High water temperatures cause stress in fish, avoidance of quality habitats, and can cause mortality. Increased water temperatures can be attributed to the lack of shading in the tributaries, main stem, and to the width of the active channel.

Upper Finney Basin:

Inner gorge failures in Darrington Phyllite and sheared/infilled fault traces are the major sources of sediment in the upper watershed (Parks, 1992). The singular most impacting mechanism in the upper basin are shallow rapid slides becoming debris torrents/dam breaks. These failures deposit sediment, temporarily blocking portions of upper Finney Creek. Along with the confined nature of the channel, these blockages lend themselves to dam break floods, delivering stored sediment to the lower Finney Creek basin area. Dam break floods occur either singularly or in series, and have flushed most of the upper Finney Creek channel. Peak stream flow events in 1977, 1979, 1980, 1983, 1986,

and 1989 have been attributed to rain-on-snow events which have resulted in numerous landslides and debris flows (US Forest Service, 1990). Dam break floods have been observed since 1983 in the upper watershed, and are believed to have occurred during earlier peak flow events.

Extensive harvesting (48%), burning, and an average density of 6.4 road km/sq.km. has altered slope hydrology such that high peak flows can be observed when the following conditions occur within a 24-hour period: Two or more feet of snow at or above 915m elevation, or four inches of rainfall and warm winds at higher elevations. Review of available landslide data indicates that harvest unit and road related landslides were significant sources of coarse sediment. For further discussion of landslide types, sediment delivery, and other measurable features such as slope and elevation influence, see Park, 1992; and Morrison, 1977.

The upper Finney basin is divided into 4 reaches: Reach 1 is from RM 11.8 to 13.3, Reach 2 is from RM 13.3 to 18.5, Reach 3 is from RM 18.5 to 21.1, and Reach 4 is from RM 21.1 to 24.4. Reach 1 is a riffle dominated, low gradient reach with large gravel bars and almost no large woody debris; it tends to be transported out during high flows. Pools are of low quality. A low number of juvenile rainbow trout were observed in this reach, reflecting the degraded habitat and ease of access for anglers. Reach 2 has a moderate gradient, and is a better quality habitat dominated by bedrock which forms a fairly confined, stable structure with equal areas of pools and riffles. Large woody debris is moderately common. Fish observed in this reach were rainbow trout, 81% juveniles, and 19% adults; most adults are between 7 and 9 inches, with a few fish up to 14 inches. Reach 3 is a low gradient, riffle dominated reach with a fair number of pools. Pools are of fair quality with infilling still a problem. Large woody debris is of small size, with recruitment potential low, due to the structure of the riparian vegetation. 92% of the fish were cutthroat trout, and 8% were rainbow. Cutthroat were a mix of 78% juveniles and 22% adults, while the rainbow were a 50-50 mix of juveniles and adults. The small size of the fish (only a few were over 8 inches) reflects the degraded habitat and the ease of angler access. Fish were scattered with concentrations around complex habitats such as log jams. Reach 4 is a poor quality, moderate to high gradient reach with a fair number of small pools. The area has been completely harvested, with infrequent patches of large trees in the riparian area. Small drainages have produced debris torrents which enter the creek. Recruitment potential for large wood is low for the next century. Only one adult cutthroat trout was observed in this reach, reflecting the degradation of habitat (Zyskowski, 1993).

Fish habitat conditions are somewhat intact due to the confined channel nature except in the upper basin where the channel follows the fault contact between Shuksan greenschist and an ultramafic body. In this reach, the channel has been severely impacted (loss of 50% of suitable habitat) due to the number of landslides and the amount of sediment that has reached the channel. Above this area the channel is unconfined and has also been degraded by sediment input. Large woody debris is limited and clumped in a few poorly distributed jams. Extensive harvesting and sedimentation in 1st and 2nd order drainages has resulted in rising water temperatures.

Recovery strategies:

Long term strategies in the upper and lower basin, where sediment delivery is high from tributaries and water concentration from road stacking, should include dispersal of water concentrations by road upgrading and decommissioning. Restoring streamside stability, vegetation, and a large healthy riparian conifer stand are also important. In a cooperative effort this strategy has been adopted by private landowners with an emphasis placed where natural instability is the greatest. Cooperative efforts between landowners and agencies should continue as a long term strategy, and the watershed managed on a landscape or watershed basis. Finally, the overall stability of the water budget in the basin is dependent on the re-establishment a percentage of mature forest stands throughout the basin. Dispersion of harvest activities at a reduced level is imperative if future harvest and resource protection is to be balanced. It has been suggested that a 12% disturbance level might results in a 34% increase in peak flow (Harr 1987). This type of increase would suggest a yearly storm return interval increasing in magnitude of a five or ten year return interval event. A storm of this scale or magnitude would have a significant impact in subbasins tributary to Finney Creek suggesting a much smaller disturbance percentage without having a negative effect on channel structure.

Natural recruitment of large woody debris (30" diameter) from riparian vegetation will likely be establishment after 80 years. As an interim measure, the introduction of large wood in the form of cabled jams would accelerate channel recovery, be beneficial and has been demonstrated to be practical i.e. Deer Creek 15 mile instream. Studies such as Reeves and Benda, currently in progress, addressing basin recovery following fire on the Oregon Coast indicate that there are significant differences in the rate of recovery with the presence of large woody debris. It is recommended that focus of introduced wood be directed at channel recovery. A change in fishing regulations would also promote a quality fishery recovery. In the lower basin planting of conifers on flood deposit and disturbed riparian areas to reestablish vegetation communities along with wide flood plain/terrace no harvest zones would help establish long term stability.

In the upper drainage, Reach 1 would benefit from the reduction of transported sediment (through upslope watershed restoration), the restoration of a healthy riparian conifer stand, moderation of flows through healthy canopy closure recovery, and the addition of channel structures to the existing habitat. Reach 2 is in relatively good condition, but would also benefit from improved watershed storage capacity through canopy closure recovery. Reach 3, in relatively poor condition, would also benefit from the treatments recommended for Reach 1. Reach 4, in poor condition, does not lend itself to the addition of channel structures. Restoring streamside stability and vegetation, restoring a large healthy riparian conifer stand, and upslope watershed restoration are the high priorities for this reach.

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PRELIMINARY WATERSHED ASSESSMENT
Suiattle River

Principal Issues:

- Decline of fish stocks.
 - Loss of historical fish habitat including stable spawning and rearing areas.
 - Turbidity, and riparian area conditions.
 - Identification of depressed or sensitive anadromous stocks and bull trout.
 - A. Spring Chinook - unique to Suiattle drainage
 - B. Skagit Coho
- Degradation of water quality due to erosion and sedimentation.

Existing Condition:

The Suiattle River is a major tributary of the Sauk River, which is a direct tributary of the Skagit River. The Suiattle is located in the North Cascade Mountains of Washington State and is 838 square kilometers in size. The lower half of the drainage is under State and private land ownership, and includes 29 subdrainages and 341km of channel. The upper three quarters of the watershed is in National Forest and is designated as part of the Skagit Wild and Scenic River system. Management activities have occurred to river mile (RM) 27 (Rkm43.5), at Downey Creek. The lower watershed has 30 subdrainages and 374km of channel. The total number of subdrainages is 59, with 108km of channel in the mainstem (Williams, 1973).

Elevations in the Suiattle drainage range from 122m at its mouth to 2439m in the headwater area near the crest of the Cascade Mountains.

The upper Suiattle River drainage is a series of lahar deposits with a veneer of glacial deposits. The lower drainage is composed of glacial-lacustrine sediments covered by glacial outwash. The Suiattle River is a high-energy glacial river, with heavy sediment loads during the summer season; it is a braided channel that experiences annual channel shifts. The amount of coarse sediment in the channel is tremendous, and the increased mobilization of the sediment in the lower channel is directly affected by timber harvesting. The broad lower valley has well developed terraces, and extremely steep upper slopes with deposits of unconsolidated material. The majority of drainages are steeply sloping first and second order channels. Suiattle River tributaries are the dominant fish habitats in the drainage.

The upper drainage of the Suiattle is primarily in Wilderness, and is timbered. The lower drainage riparian areas are composed of mixed old growth and hardwood stands, with hardwood stands dominating the lowest segments.

There is a fault line that runs N-S along the Straight Creek drainage that separates Pre-upper Jurassic metamorphic rock strata from Pre-upper Jurassic gneiss. The instability of this fault line is reflected in Big, Grade, and Straight Creek drainages.

Water bodies in this watershed have been listed in the Washington State Department of Ecology's report to the Environmental Protection Agency on Water Quality Impaired Waterbodies, 305(b) Report. According to this report, water quality is impaired in part by siltation, fecal coliform, increased temperature, habitat modification, and dissolved oxygen. Some sources for these impairments

are silvicultural road construction and maintenance, removal of riparian vegetation, and streambank destabilization.

The State of Washington, in chapter 173-201A, has classified these waters as "Class AA (Extraordinary)". Present characteristic uses are as a water supply, salmonid (and other fish) migration, rearing, spawning, and harvesting, wildlife habitat, and recreation. These waters are also considered suitable for stock watering, crustacean habitat, and commerce and navigation, though they are not used for such purposes at this time. Because of excessive sedimentation and subsequent migratory fish habitat degradation, the aquatic ecosystem has been adversely affected, and anadromous fish stocks depleted.

Four stocks of salmon and steelhead utilize this watershed (WDF, et. al., 1992). They are listed as Suiattle spring chinook (depressed), Skagit coho (depressed), Skagit pinks (healthy), and Mainstem Skagit and tributary winter steelhead (healthy). Spawning for all stocks is located primarily in the tributaries and clear-water side channel areas of the Suiattle. Most spring chinook spawning is limited to Buck, Big, Tenas, Lime, Straight, Sulphur, and Downey Creeks (WDF, unpublished spawning data). This stock of chinook has a variable freshwater life history. Some smolt at age 0+ (19-58% depending on the year) with the rest migrating to sea at age 1+ (WDF, unpublished scale data). Some of the yearling smolts do remain in the spawning tributaries at least until the end of summer (USFS unpublished snorkel data) although this is thought to be a low percentage of all the yearling smolts. Pinks are present for spawning and brief fry rearing as they migrate to the estuary areas of the Skagit as fry (age 0+). Coho and steelhead are found throughout the watershed, primarily in tributaries and side and off-channel areas of the Suiattle River. Coho dominate the smaller low gradient areas, while steelhead are more abundant in the larger higher energy systems (SSC, unpublished trapping data, USFS unpublished snorkel data). Coho rear for over one year in freshwater, while steelhead require over two years.

Desired Future Condition:

Maintain existing acceptable fish habitat and restore habitat conditions to allow recovery of viable populations of all salmonids in the watershed area. Maintain or restore water quality to state Class AA Extraordinary Standard.

Processes:

Road building has occurred on both sides of the Suiattle River drainage, with highest road densities in the Grade Creek-Big Creek area on the north side of the drainage, and in the Conrad to Straight Creek area on the south side. Road densities were 2.3km/sq km in the lower drainage and 1.1km/sq km in the upper drainage (MBS Forest Plan, 1990). Channel encroachment by roads has occurred on both sides of the drainage, especially in the upper portion of the lower drainage. In the 1960's and 1970's, road construction and timber harvesting were concentrated in Grade, Conrad and Tenas Creeks, tributaries of the lower drainage. Harvest was concentrated in these areas during the Roadless Area Review Evaluation I and II deliberations.

Age-class distribution: The upper half of the Suiattle watershed is in wilderness designation with primarily older age class conifers. The portion of the Suiattle outside of wilderness has had approximately 15% of the area

harvested since 1950. Salvage of merchantable logs from the river occurred up to late 1982, when piles of logs from the 1980 flood were removed.

In-channel stability: Much of the drainage shows little evidence of channel downcutting or aggradation. Most channel scouring is concentrated in first and second order channels. Smolt production loss for coho and steelhead in Suaittle River tributaries was estimated at 11% (with a range of -38% loss to a 7% gain, N=30) based on comparisons of 1984 pool and riffle areas with estimates of historic conditions (SCC, unpublished). Channel widening data from aerial photos show that Suaittle River reaches are responding to excessive sediment loading by widening. This can result in decreases in pool depth and frequency, increased summer temperatures, and decreased refuge areas. This study also indicates that two channels have blown out, and two channels have remained intact from 1963 to 1992 (SSC, unpublished).

In portions of Grade, Tenas, Conrad, Straight, and Circle Creeks, scouring to bedrock has been aggravated by road failures and ground disturbance. Pool frequency in the scoured areas is noticeably less (MBS Forest Plan, 1990). The downstream transport of sediment from disturbed areas aggrade in-channel pools (resulting in decreased pool depths) and create large tributary mouth deposits. These alluvial fan deposits can limit both anadromous fish passage and juvenile rearing.

Large Woody Debris: Based on observational flights in 1986 and review of aerial photos from 1992, large woody debris is well distributed throughout the main Suaittle River channel. The flood of 1990 redistributed this material resulting in both channel shifts and log jam accumulation. First and second order stream LWD recruitment is impacted in areas where past timber harvest removed the older age class of conifers or where instream and/or riparian operations were authorized.

Prescription:

Road decommissioning and upgrading should be implemented in areas where sediment delivery has occurred from road failure. The road prism has a high level of natural instability that has been aggravated by past management activities. These prescriptions would increase available anadromous and resident fish habitat by increasing the frequency of pools, and residual pool depth in affected channels. After 80 years, natural recruitment of large woody debris will occur along riparian corridors, with the continued establishment of riparian vegetation.

Long term strategies should include management of the basin on a watershed or landscape basis, and continued cooperative efforts with landowners and agencies.

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PRELIMINARY WATERSHED ASSESSMENT
Sauk River

Principal Issues:

- Degradation of water quality and riparian areas due to erosion, and mass wasting primarily coarse sediments.
- Decline of fish stocks.
 - Loss of historical fish habitat including stable spawning and rearing areas.
 - Increased stream temperature and turbidity, and loss of riparian shade.
 - Identification of depressed or sensitive anadromous stocks and bull trout.

Existing Condition:

The Sauk River is a major tributary of the Skagit River, and is located in the North Cascade Mountains of Washington State. The Sauk encompasses 848 square kilometers, with 841 square kilometers located on Forest lands. Most of its length lies within the Skagit Wild and Scenic River system. There are 247 linear kilometers in the total drainage, with 37km in the mainstem, and 210km in the tributaries.

Elevations in the Sauk River drainage range from 61m at its mouth to 1585m at the headwaters of the North Fork, and 2134m at the headwaters of the South Fork Sauk. It is a high-energy glacial river, with heavy sediment loads during the summer season. Primary source of the glacial sediment is from the White Chuck tributary. The lower Sauk River channel below Darrington experiences channel shifts annually. The broad lower valley has well developed terraces, with extremely steep upper slopes and deposits of glacial outwash (sands and gravels). The Sauk River channel from Darrington upstream is located on a series of lahar deposits with a thin veneer of glacial outwash. Channel change is minimal in this section. The Sauk from Whitechuck to below Monte Cristo Lake has experienced channel change creating a series of side channels which are critical fish habitat. This section of the river is incised in glacial-lacustrine sediment covered with a veneer of unconsolidated outwash. The Upper Sauk is located in a confined channel for much of its length below the upper basin Monte Cristo area. This section of river is located in a series of rock canyons that are infilled with glacial outwash. The majority of the tributaries are steeply sloping first and second order channels. The amount of coarse sediment in the channel is tremendous, and the increased mobilization of sediment in the channel section below Monte Cristo Lake is directly affected by timber harvesting.

Water bodies in this watershed have been listed in the Washington State Department of Ecology's report to the Environmental Protection Agency on Water Quality Impaired Waterbodies, 305(b) Report. According to this report, water quality is impaired in part by siltation, fecal coliform, increased temperature, habitat modification, and dissolved oxygen. Some sources for these impairments are silvicultural road construction and maintenance, removal of riparian vegetation, and streambank destabilization.

The State of Washington, in chapter 173-201A, has classified these waters as "Class AA (Extraordinary)". Present characteristic uses are as a water supply, salmonid (and other fish) migration, rearing, spawning, and harvesting, wildlife habitat, and recreation. These waters are also considered suitable for stock watering, crustacean habitat, and commerce and navigation, though they are not

used for such purposes at this time. Because of excessive sedimentation and subsequent migratory fish habitat degradation, the aquatic ecosystem has been adversely affected, and anadromous fish stocks depleted.

Riparian vegetation in the upper Sauk drainage is primarily conifers with hardwoods along the channel banks. The lower drainage is dominated by hardwoods along the channels adjacent to natural and agricultural fields. Six stocks of salmon and steelhead utilize this watershed (WDF, et.al., 1992). They are listed as Upper Sauk spring chinook (healthy), Lower Sauk summer chinook (depressed), Sauk chum (healthy), Skagit coho (depressed), Skagit pinks (healthy), and Sauk winter steelhead (healthy). Pinks spawn throughout the Sauk mainstem, side channels and larger tributaries. Chum spawning is in side channels and the lower portions of tributaries throughout the Sauk. Summer chinook spawning is primarily upstream of it (WDF, unpublished spawning data). Up to 70% of the spring chinook juveniles smolt at age 1+ with the rest migrating to sea at age 0+ (WDF, unpublished scale data). The rearing locations in freshwater habitat for yearling smolts is not known. Summer chinook, chum, and pinks rear only briefly as they migrate to the estuary areas of the Skagit as fry (age 0+). Coho and steelhead are found throughout the watershed. Coho dominate the smaller low gradient tributaries, side channels, and off-channel areas of the Sauk, while steelhead are more abundant in the mainstem and larger higher energy tributary systems (SSC, unpublished trapping data, USFS unpublished smorkel data). Coho rear for over one year in freshwater, while steelhead require over two years.

Road building has occurred throughout the Sauk River drainage, with highest road densities in the lower Sauk River area, primarily in the Dan Creek drainage. Total road kilometers in this portion of the drainage is 277km with an average density (kilometers/sq. kilometers) of 4km. The upper drainage has 61.8 total road kilometers, with a density of 0.62km. A major tributary of the Sauk River, the White Chuck, has 68.8 total road kilometers and an average density of 2.7km. All of existing roads are attributed to the District timber harvest program, and channel encroachment by roads is a problem for half the length of the lower drainage.

There are approximately 155,000 acres within the Sauk River drainage on National Forest land. 50,000 acres lie within forested, harvestable habitat.

Age-class distribution: The major drainages in the Sauk River valley show a fairly uniform harvest pattern throughout the recent decades:

| <u>Date</u> | <u>Total Harvest Acres</u> |
|-------------|----------------------------|
| 1984-1993 | 4,533 |
| 1983-1974 | 5,001 |
| 1964-1973 | 5,530 |
| 1954-1963 | 6,285 |
| 1944-1953 | 2,881 |
| 1934-1943 | 4,596 |
| 1900-1933 | 2,247 |

Total 31073 = 62% of Forest Commercial Land

Salvage of merchantable logs from the river occurred up until late 1982, when piles of logs from the 1980 flood were removed.

Desired Condition:

Maintain existing acceptable fish habitat and restore habitat conditions to allow recovery of viable populations of all salmonids in the watershed area. Maintain or restore water quality to state Class AA Extraordinary Standard. Maintain old growth areas to provide additional protection and improved dispersal for spotted owls, additional retention of marbled murrelet nesting habitat, and protection of other species found within riparian areas.

Processes:

In-channel stability: Due to annual channel-shifting, many of the streams are frequently scoured, and exhibit raw banks. This is especially true in Decline, Conn, and Clear Creeks, and tributaries on north facing slopes i.e. Dutch, Goodman, Murphy, Falls, Brown, and Peek-A-Boo Creeks (MBS Forest Plan, 1990). Pool frequency in scoured areas is noticeably less, and the downstream transport of sediment from disturbed areas aggrades in-channel pools (resulting in decreased pool depths) and creates large deposits at tributary mouths. These alluvial fan deposits can limit both anadromous fish passage and juvenile rearing.

Channel instability is major factor in the Sauk drainage above the Whitechuck River. Road building and harvesting around unstable tributaries i.e. Bedal Creek have resulted in slope failures and increased sediment delivery to the Sauk. This increased sediment delivery, in combination with increased peak water flows and concentrations on glacial-lacustrine deposits (also the result of road building and logging), have caused significant sediment and water quality problems i.e. the 1980 Sauk slide. Sauk River meanders are significant fish habitat; most of these channels remain intact.

Large Woody Debris (LWD): Based on observational flights in 1986 and review of aerial photos from 1992, large woody debris is well distributed throughout the main Sauk River channel. The flood of 1990 redistributed this material resulting in both channel shifts and log jam accumulation. First and second order stream LWD recruitment is impacted in areas where past timber harvest removed the older age class of conifers or where instream and/or riparian harvest operations were authorized. In this watershed less than 10% of the streams have been harvested on both banks (MBS Forest Plan, 1990).

Recovery Strategy:

Road decommissioning and upgrading should be implemented in areas where sediment delivery has occurred from road failure. The road prism has a high level of natural instability that has been aggravated by past management activities. These prescriptions would increase available anadromous and resident fish habitat by increasing the frequency of pools, and residual pool depth in affected channels. After 80 years, natural recruitment of large woody debris will occur along riparian corridors, with the continued establishment of riparian vegetation.

Long term strategies should include management of the basin on a watershed or landscape basis, and continued cooperative efforts with landowners and agencies.

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APPENDIX 3.

**PROJECT PRIORITY METHODS AND RATIONALE
FOR 1994 SKAGIT WATERSHED PROJECT PACKAGES,
MARCH 4, 1994.**

Prepared for:

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**Project Priority Methods and Rationale
1994 Skagit Watershed Project Packages**

March 4, 1994

Rationale:

A task of the Skagit team was to prioritize the list of proposed activities. Two main purposes were: (1) to estimate the relative differences between high and low value projects in the likely event that all projects would not be funded, and (2) ease the process of decision making by providing a method based on science that compares project benefits to cost. The basic method was the sum of benefits to all natural resources (fish + wildlife + etc.) within the ecosystem divided by the cost of achieving the benefits. This estimate (benefit/\$) would then be used along with a rank of risk to sort the activities. However, we were unable to estimate the value of wildlife and other ecosystem benefits, so we used benefits to fish in prioritizing projects.

Specific activities were proposed at the team's first meeting and cost estimates were associated with each. The activities were assumed to benefit the ecosystem, but these were undescribed.

In order to answer the benefit question, we decided to use anadromous fish as an index of the ecosystem benefits for the following reasons:

- 1.FEMAT direction states that fish stocks are a major part of the benefit equation and a significant reason why restoration dollars were available in 1994;
- 2.Eighteen (18) of the nineteen (19) projects proposed by the Skagit team are expected to have impacts on stream channels where fish are present;
- 3.Fish respond to habitat conditions and are therefore assumed to be a good biological indicator of overall watershed health; and
- 4.The team had fish and habitat data available for each of the project areas.

A system of estimating "real" numbers of fish benefiting from a project and the years each project would provide the benefit was selected over a system of ranking each parameter. Ranking requires "weighing" each parameter, while the other method doesn't. The outcome of a ranking system would be based more on how parameters were weighted, rather than a direct comparison of benefits to cost. For example, a logarithmic relationship might be misrepresented as a linear relationship or there might be a mixing of "real" units with "ranked" units. In these cases, the outcome would be skewed. We believed it was better to estimate each parameter (fish, benefit years, and cost) as "real" numbers, and try to understand the variability around the prioritization. The rest of this paper documents the specific methodology used by the Skagit team for the 1994 projects.

Methods:

The unit of measure in which projects were sorted is Smolts/\$. Smolts/\$ is calculated:
 $[(FP*B1)+(F*B2)]/C$ where:

FP =number of fish (smolts) protected annually by the project,
B1 =amount of time (years) the project is expected to protect FP,
F =number of new fish (smolts) restored annually by the project,
B2 =amount of time (years) the project is expected to achieve F, and
C =project cost in dollars (not including monitoring costs).

FP (fish protected):

In order to estimate benefits, individual activities were assembled into project packages by a common zone of impact. The zone for any project package was the sum of anadromous fish habitat thought to be measurably impacted by the project package. This was done through air photo analysis and consultation with the watershed staff familiar with the area. Habitat was quantified by combined data from SSC, WDF, and USFS habitat surveys. The next step was to sum the anadromous resource (specific methods listed below) within the zone and adjust it by the percent of resource expected to be impacted by the project. For the initial FP value, we attempted to estimate each species at the last juvenile life stage it is present in the zone. However, we were limited by data and models available, so steelhead were estimated at second summer parr stage; coho at smolt stage; while pink, chum, and chinook were estimated at the migrating fry stage. Cutthroat and Dolly Varden/Bull trout were generally known to be present, but no estimate was made due to a lack of quantifiable data. The initial FP value was multiplied by the percentage of road treated. This resulted in the final fish protected number (FP). FP values (> 0) were only estimated for sediment reduction projects. Fish passage and structure projects were not expected to have a protection benefit.

For coho we used methods described in Beechie et. al. (1993) to convert habitat data to coho smolts. Steelhead were estimated using the Parr Production Model described in Gibbons et. al. (1985) if no channel unit data were available or by a model from the Keogh River, B.C. (Marshall et. al. 1980) where channel unit data were available. Pink, chum and chinook values were all expanded from average spawning densities (redds per km) times average fecundity times survival to migrating fry. Spawner data sources were from SSC and WDF, fecundity (except chinook) and survival data were from Heard, W. R. (1991); Salo, E. O. (1991); and Healy, M. C. (1991) for pink, chum, and chinook respectively. Mean values for streams within the same geographic region were used in all cases. Chinook fecundity was the average fecundity of the Suiattle Spring chinook broodstocking program (Pete Castle, personal comm.).

F (fish restored):

The stock-production relationship is affected by habitat quality and quantity. Density independent survival is affected by habitat quality, while the capacity parameter is related to habitat quantity (Lestelle et. al., 1993; Moussalli and Hilborn, 1986). Therefore, a restoration benefit is expected when either habitat quantity or quality is improved. Benefits from improving habitat quality were not addressed, although the benefit is likely to be high for areas where habitat quality is severely degraded and significant numbers of fish still exist (e.g. Finney Cr.).

The number of new fish (F) is an estimate of the number of fish restored by the project based on habitat capacity. Species and life stage are the same as for FP (see above). For fish passage projects we used the affected habitat area converted to smolts (methods described above). For structure projects, we used the expected part/structure by species times the number of structures in the project, which was based on snorkel surveys of similar projects (USFS, Darrington Dist.). For sediment reduction projects, we compared current (mid 1980's) pool and riffle areas to estimates of historical using methods described in Beechie et. al. (1993) and then converted these estimates to losses in coho and steelhead smolts (Beechie et. al. 1993; and Marshall et. al. 1980). The average loss in coho and steelhead smolts (current v. historic) for 63 streams in the Sauk and Suiattle watersheds was -4%. For six known degraded streams the average was -34%. FP was multiplied by the estimated smolts gained (4% if habitat conditions were average, 34% if conditions were degraded, or the specific value if we had data for the zone). In calculating the restoration value in this way, we understand that a project is not expected to completely restore the stream channel and riparian area. However, since the project will reduce sediment which will increase pool depth, frequency and area parameters, we believed it to be a reasonable way to estimate F. We assumed that all species experienced a magnitude of loss similar to those estimated for steelhead and coho. Spawner surveys indicate that the number of Pink and Chum spawners have generally declined in areas considered degraded, but remain stable in high quality areas. (Buck, Lime, Illabot Creek are stable to increasing while Finney, Big, and Straight Creeks have declined).

B1 & B2 (years of protection and restoration):

The length of time (years) each project is estimated to provide a benefit (B1 & B2) was assigned one of four benefit types. Benefit types are shown in figure 1. The area under the curve is the benefit in years. In order to quantify each type, we assumed project life not to exceed 50 years and the following:

- (1) Delayed Shortterm (DS): benefits achieve 100% level (100% of the FP or F values) after 10 years, but this condition persists for less than 20 years;
- (2) Immediate Shortterm (IS): 100% level before 10 years, persists < 20 years;
- (3) Delayed Longterm (DS): 100% level after 10 years, persists > 20 years; and
- (4) Immediate Longterm (IL): 100% level before 10 years, persists > 20 years.

Values for each benefit type were then calculated using the areas of the four regions (A-D) shown in figure 2. Benefit value in A or B could range from 0-5 with an assumed mean of 2.5 years. Benefit value in C or D could range from 0-20, mean of 10 years. Therefore, Delayed Shortterm was assigned the value of 12.5 years ($A_{\text{mean}} + C_{\text{mean}}$); Immediate Shortterm = 17.5 years ($A_{\text{max}} + B_{\text{mean}} + C_{\text{mean}}$); Delayed Longterm = 32.5 years ($A_{\text{mean}} + C_{\text{max}} + D_{\text{mean}}$); and Immediate Longterm = 37.5 years ($A_{\text{max}} + B_{\text{mean}} + C_{\text{max}} + D_{\text{mean}}$).

B1 values for sediment reduction projects were assumed to be immediate longterm. No protection value was expected for fish passage and structure projects. B2 values for sediment reduction projects were assigned delayed longterm, while fish passage and (terrace tributary only) structure projects were assigned immediate longterm. No shortterm benefit projects are proposed.

We limited the potential of B1 & B2 to fifty years because structure life is not expected to

exceed fifty years. Culverts wear out in 10–50 years depending on a variety of factors (e.g. thickness, soil acidity, abrasiveness of sediment); Log structures in streams are not expected to last longer than 50 years. Forest road standards target a design life of 50 years for concrete bridges and fords, while culverts are 25 years. Using fifty years as the timeline for benefits is reasonable for projects that use structures, but it probably underestimates benefits for road decommissioning projects.

The break at ten years for immediate and delayed benefits was based on the following. Fish utilize the new habitat upstream of a fish passage project or an instream structure essentially immediately after construction is complete. However, the full benefit level may not be achieved for a few years due to a variety of factors (scour at structure site increase pool size, debris accumulation on structure increases its value, time is required for fish to fully utilize all the available habitat upstream a passage problem – cycling). These processes were thought to occur within ten years. The cutoff between longterm and shortterm at 20 years was based primarily on expected structure life.

Sediment reduction projects were not expected to achieve the full restoration benefit until after 10 years. We expected the persistence of an aggraded condition in a channel to be shortest in higher gradient reaches because sediment transport capacity is high (<2 years). In these cases, the restoration benefit may be immediate. However, aggraded conditions should persist longest in small low-gradient streams because of a lower capacity to transport sediment (50–80 years) and larger low gradient streams are expected to be sensitive to increases in sediment supply, but may recover more quickly because of higher capacity to transport sediment (2–10 years). These groups are where most of the anadromous fish are located. A model of sediment thickness over time predicts these relationships for an Oregon Coast Range basin (Benda, L. 1994.) and data from Deer Creek (Stillaguamish) appears to corroborate part of the model. Average residual pool depths have tripled (from 0.26 to 0.76 meters) between 1986 and 1992 (Beechie, T. 1994).

Risk:

Risk is not used in the smolts/\$ calculation, but should be used along with the priority list for final decision making regarding project funding. It is a rank of the relative risk of a project failing to achieve the estimated benefits. The team had to devise a method that could compare road upgrade and decommissioning, fish passage, and instream structures together. Our risk assessment subjectively examined the potential for failure from (1) not properly identifying the problem and therefore designing an improper solution, (2) failure of the project due to events that exceed the design specification, and (3) events from other sources masking or overriding the potential benefits of the project.

Risk values for road upgrading and decommissioning were considered low because high risk sediment sources (road prism and side cast fills) are removed and drainage is increased. Risk for the fish passage projects was considered low. This is based on about 95% success rate for structural design (B. Heiner, personal comm.) and the documentation of adequate numbers of spawners located in the project vicinity to seed the available habitat. Risk values for structure projects could range from high to moderate. This is based on (Frissell and Nawa, 1992) where median failure and damage rates to structures were reported to be 18.5% and 60% following flood magnitudes that recurs every 2–10 years. Doyle (1991), after inventorying the Forest's

structures following the 1990 floods, found similar failure rates (24%), but suggested that terrace tributaries have the lowest risk of all structure projects when stratified by channel type. All of the Skagit's structure projects for 1994 are located in terrace tributaries and were assigned a value of moderate.

Limitations of the Assessment:

How accurate are the fish estimates? Measured coho smolt production in Skagit tributaries (n=25) averaged 0.27 smolts/m² compared to estimates of 0.32 smolts/m² for summer rearing and 0.22 smolts/m² for winter rearing (Beechie et. al., 1993). However, at an individual site, the difference between the average measured smolt production (steelhead and coho combined) and the estimated smolt production can be as large as 60% with an average error of 32% (5 sites over 8 years; SSC, unpublished data). Smolts at these sites were comprised of coho, cutthroat, steelhead and chinook; chum and pink salmon were not present. Figure 3 illustrates the results of this error when incorporated into the project priority list. With respect to annual variability, the coefficient of variation was $\pm 43\%$ for all species combined. The impact of this variation is assumed to be relatively unimportant for projects with longterm benefits because its effect is diminished over time.

How does the range in values in time benefit curves impact project priority? Delayed longterm ranges from 20 ($A_{\min} + C_{\max} + D_{\min}$) to 45 years ($A_{\max} + C_{\max} + D_{\max}$), while immediate longterm ranges from 25 ($A_{\max} + B_{\min} + C_{\max} + D_{\min}$) to 50 years ($A_{\max} + B_{\max} + C_{\max} + D_{\max}$). Figure 4 shows the distribution of the range when incorporated into the project priority list.

The initial FP value was adjusted to reflect the true amount of resource the project was expected to benefit. This was done by multiplying it by the percentage of road treated. It is not likely that all road problems are evenly distributed over the road length, but this was the only parameter we had for all projects.

Results and recommendation:

Smolt/\$ values ranged widely between the 19 projects (attached table, figures 3 and 4). Several major groups of projects can be detected when variability is taken into account. Generally, protecting existing resource (particularly strong multi-species areas) rated high, while pure restoration rated lower. Also, project packages that dealt with the majority of the problems for a zone of impact rated high. These results are consistent with what has been echoed recently by Reeve et. al. (1991) that protection is more cost effective than trying to restore what has been lost.

This list should be integrated with the strategies listed in the Preliminary Watershed Assessments and an overall strategy for the Skagit. The team believes each project package is consistent with the Preliminary Watershed Assessment for each watershed and recommends using the list in priority order. However, if other factors such as partnerships and jobs offer other benefits, may warrant reordering within major groups.

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FIGURE 1.

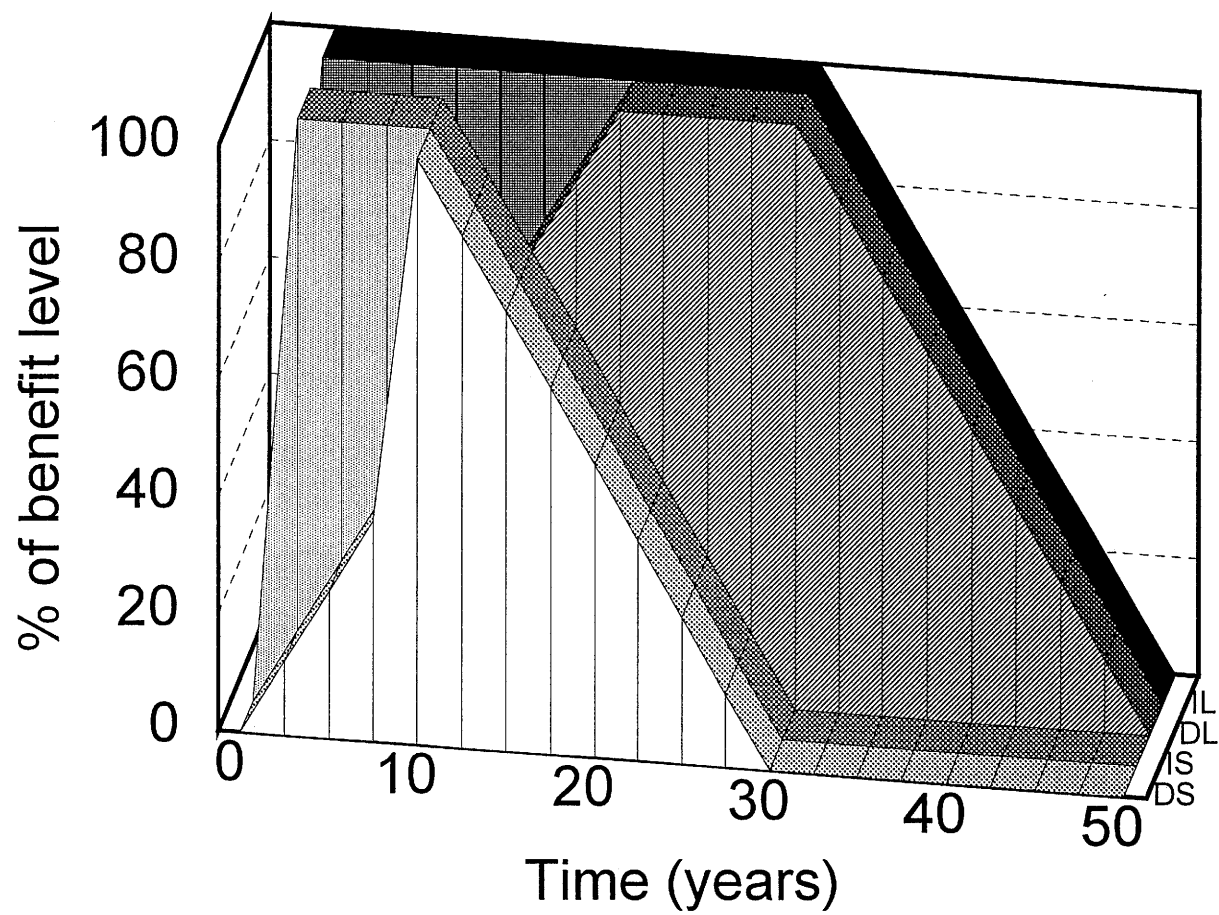


FIGURE 2.

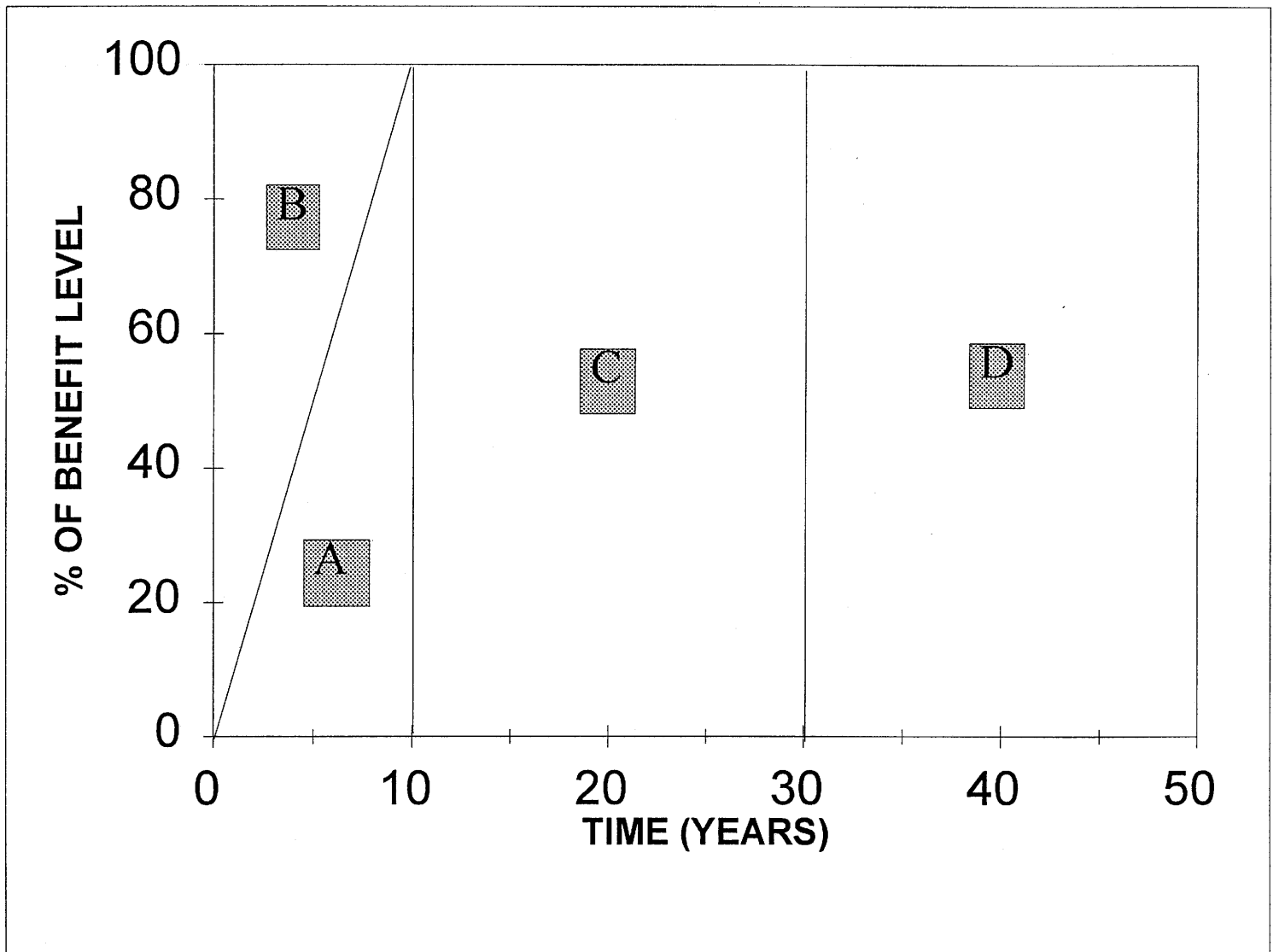


FIGURE 3.

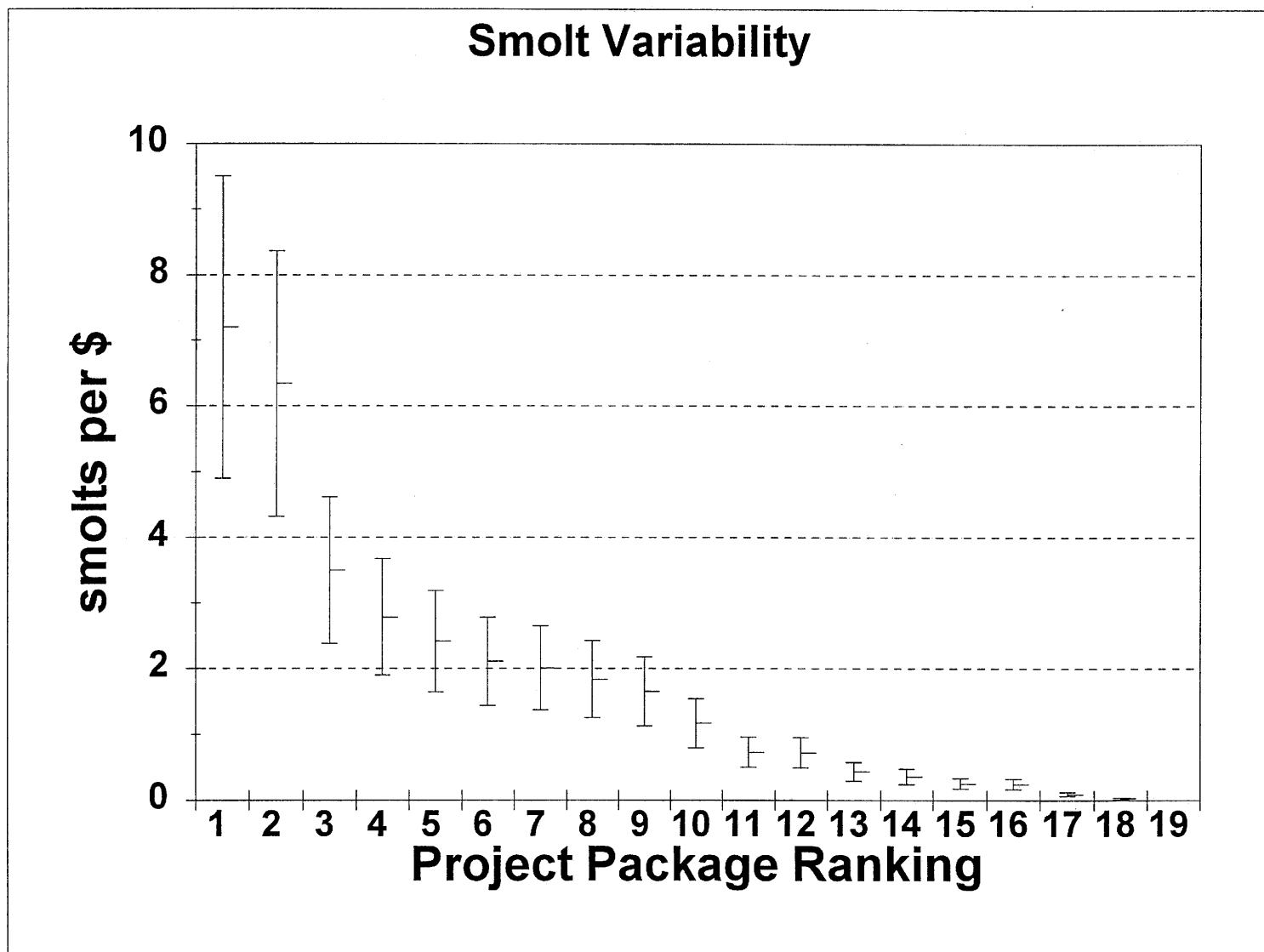


FIGURE 4.

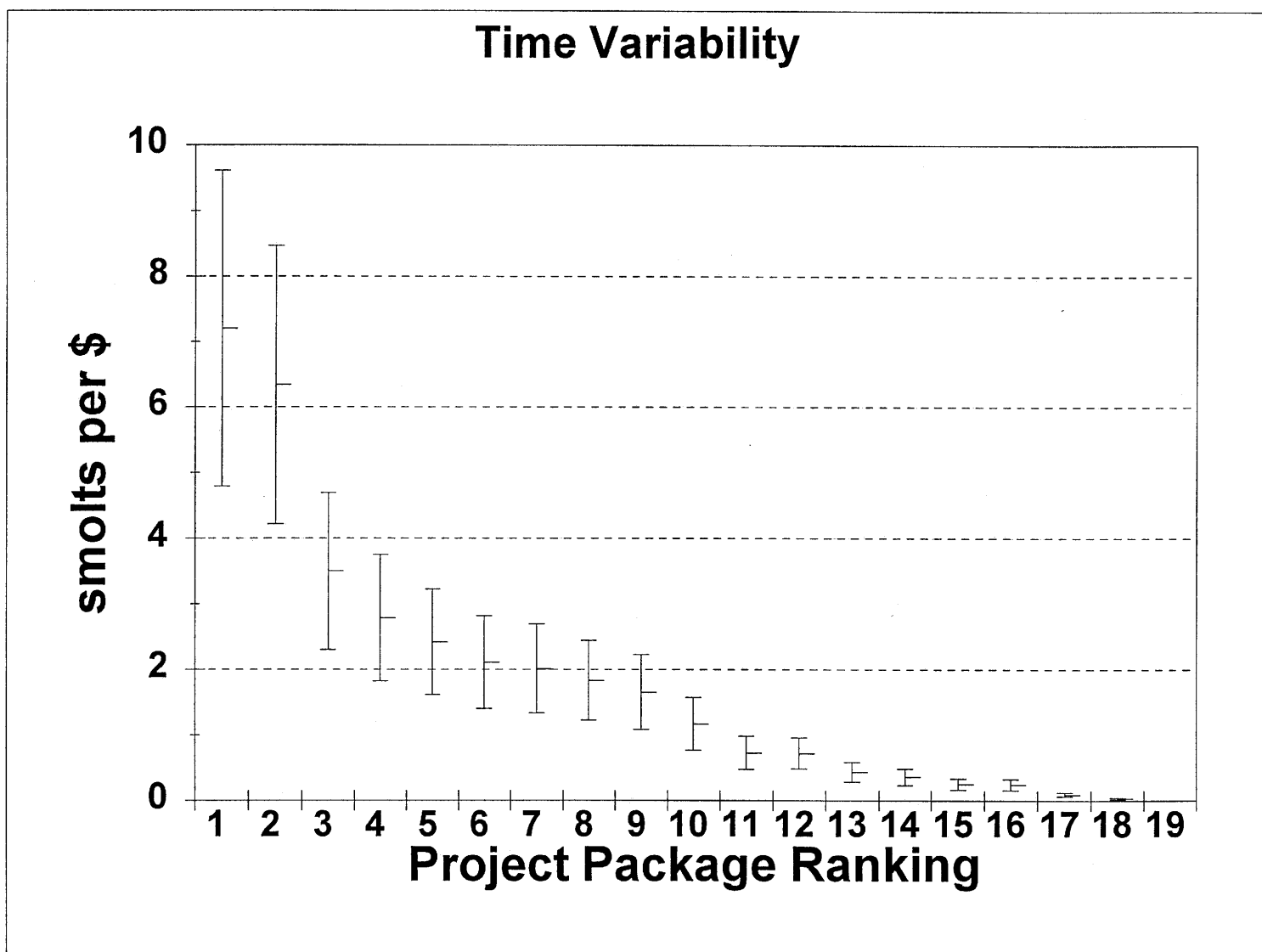


TABLE 1.

SUMMARY OF 1994 SKAGIT PROJECTS IN PRIORITY ORDER **

| Priority | watershed | project package | cost (not including monitoring) | #fish protected (smolts) | protection benefit (years) | #of new fish (smolts) | fish benefit (years) | Prob. of failure (rank) | smolts per \$ (FPB1)/(F*B2)/C |
|----------|------------------|---------------------------------|---------------------------------------|--------------------------------|----------------------------------|-----------------------------|----------------------------|-------------------------------|-------------------------------------|
| | | | C | FP | B1 | F | B2 | R | |
| 1 | SUIATTLE 624-626 | Lime Road and Slide Rehab. | \$68,000 | 12624 | 37.5 | 505 | 32.5 | low | 7.203 |
| 2 | ILLABOT 416 | Illabot Creek Rds. | \$586,000 | 95782 | 37.5 | 3831 | 32.5 | low | 6.342 |
| 3 | SUIATTLE 624-626 | Conrad Cr. roads | \$82,000 | 6481 | 37.5 | 1349 | 32.5 | low | 3.499 |
| 4 | FINNEY 722 | Finney Creek Roads - B | \$92,000 | 5283 | 37.5 | 1796 | 32.5 | low | 2.788 |
| 5 | BAKER LAKE 509 | Little Park Creek culvert. | \$130,000 | 0 | 0 | 8390 | 37.5 | low | 2.420 |
| 6 | SAUK RIVER 623 | Falls Rds. | \$78,000 | 4058 | 37.5 | 383 | 32.5 | low | 2.110 |
| 7 | SAUK RIVER 623 | Dan Creek Rds. (& beaver trans) | \$138,500 | 7125 | 37.5 | 356 | 32.5 | low | 2.013 |
| 8 | SUIATTLE 624-626 | Boundary Creek culvert. | \$81,000 | 0 | 0 | 3966 | 37.5 | low | 1.836 |
| 9 | SUIATTLE 624-626 | Big Creek Rds. | \$85,000 | 2890 | 37.5 | 983 | 32.5 | low | 1.651 |
| 10 | FINNEY 722 | Finney Creek Roads - A | \$570,000 | 13736 | 37.5 | 4670 | 32.5 | low | 1.170 |
| 11 | FINNEY 722 | Finney Creek Roads - C | \$493,000 | 7396 | 37.5 | 2515 | 32.5 | low | 0.728 |
| 12 | SUIATTLE 624-626 | Clear Beaver Cr. structures | \$25,000 | 0 | 0 | 480 | 37.5 | mod | 0.720 |
| 13 | SAUK RIVER 623 | Goodman Rds. | \$32,000 | 341 | 37.5 | 36 | 32.5 | low | 0.436 |
| 14 | SUIATTLE 624-626 | Homemade Culvert Cr. str. | \$25,000 | 0 | 0 | 240 | 37.5 | mod | 0.360 |
| 15 | SUIATTLE 624-626 | Gibson Falls Cr. structures | \$30,000 | 0 | 0 | 200 | 37.5 | mod | 0.250 |
| 16 | SUIATTLE 624-626 | Circle - Harriet Cr. Rds. | \$71,000 | 416 | 37.5 | 54 | 32.5 | low | 0.244 |
| 17 | UPPER SKAGIT 514 | Diobsud trib. br. | \$100,000 | 0 | 0 | 259 | 37.5 | low | 0.097 |
| 18 | SUIATTLE 624-626 | Milk Cr. Trail | \$58,000 | 50 | 37.5 | 2 | 32.5 | low | 0.033 |
| 19 | SUIATTLE 624-626 | Pacific Crest Trail | \$25,000 | 0 | 0 | 0 | 0 | low | 0.000 |

APPENDIX 4.

1994 MONITORING STRATEGY WATERSHED RESTORATION PROJECTS.

1994 MONITORING STRATEGY
WATERSHED RESTORATION PROJECTS
Mt. Baker Ranger District

The Monitoring component of the Aquatic Conservation Strategy in FEMAT outlines the following objectives: 1) determine if Best Management Practices have been implemented, 2) determine the effectiveness of management practices at multiple scales, ranging from individual sites to watersheds and 3) validate whether ecosystem function and processes have been maintained as predicted (FEMAT, pp. V-61).

FEMAT suggests that a stratified monitoring program include:

- A- Post-project site review
- B- Reference sub-drainages
- C- Basin monitoring
- D- Water quality network
- E- Landscape integration of monitoring data

as part of the total Aquatic Conservation Strategy. Water Quality Standards will be maintained through the implementation of Best Management Practices as outlined in the WAC CH 173-201/202 and MOU between USDA/USFS and WA DOE*.

A monitoring strategy has been developed for the 1994 Watershed Restoration effort on the Mt. Baker Ranger District. Monitoring will be implemented on a watershed scale as opposed to solely on a site-by-site basis. Each Activity Category will have a monitoring strategy. These strategies will be complementary and when implemented will provide the opportunity to evaluate the direct and indirect effects of project implementation from a watershed perspective. Monitoring at a watershed scale allows future restoration activities to be included as they are implemented.

In order to adequately evaluate restoration efforts, monitoring must be carried out for a minimum of 5-10 years following project implementation. (Funding will have to be attached to the monitoring plan as opposed to projects in order to have a consistent, long-term program with valid results). In addition, monitoring efforts should be expanded to non-federal lands through partnerships in order to get a true picture of overall watershed condition. (In the Skagit an opportunity exists to implement The Skagit Wild & Scenic River Water Resource Monitoring Plan 1994).

This is a brief outline of the Mt. Baker Districts' monitoring strategy for 1994. This data collection effort should be coordinated with those conducted by other agencies. Most of the survey protocols are established. A final plan will be developed when the restoration package is approved by the Province Team. The following list represents a broad level of monitoring. Not all parameters will be measured in each watershed. Certain parameters may be measured in a pilot project in a single watershed. It may be advisable to have an interagency meeting solely for the purpose of review and coordination of monitoring. Other parameters may be identified for inclusion in the final plan. It is the Districts intent to contract most of the the following work.

Direct Monitoring (see DRAFT Surface Erosion Monitoring Plan)

One objective of this effort is to quantify the amount of material that was mechanically removed from a particular site and therefore did not fail and enter the stream system. This information, in combination with other relevant data, will be used to answer questions about the sediment produced as a result of treatments vs. the potential production without treatment.

- Cross-sections of the road prism
- Longitudinal profile and cross-sections of stream crossings
- Photo points
- Erosion troughs
- Sediment sampling

Indirect Monitoring (see 1994 Fisheries Monitoring Proposal)

One objective of this effort is to assess the downstream impacts of restoration projects on fish habitat. The goal will be to detect trends over time in both physical and biological characteristics.

Physical

- Stream Survey Level II and Level III; include all standard parameters as well as the following:
 - width/depth ratio, residual pool depth, bankfull width
- Channel Stability Index (Pfankeuch)
- Riffle Stability Index (Kapesser)
- Channel Cross-sections and channel scour
- Photo points

Biological in conjunction with surveyed reaches

- Snorkel survey
- Macro invertebrate surveys (Plotnikoff, Pflakin)
- Spawner survey
- Bull Trout survey
- Smolt traps/ outmigrant survey

Riparian condition survey (of greater intensity than Level II Stream Survey)

*Memorandum of Understanding: The Washington Department of Ecology and US Department of Agriculture, Forest Service (7/79), and "Attachment A" referred to in the MOU (Implementation Plan for Water Quality Planning on National Forest Lands in the Pacific Northwest 12/78).

PACKAGE SUMMARY

The Mt. Baker District will take the lead and coordinate with other agencies and interested parties. Monitoring will be implemented on a watershed scale with complementary strategies applied to each activity category which, when implemented, will provide the opportunity to evaluate the effects of project implementation from a watershed perspective. Direct monitoring should include post-project site review, photo points and measurement of relevant parameters. Indirect monitoring will measure physical and biological stream characteristics to assess trends in fish habitat parameters which may be the result of restoration activities. (see Mt. Baker Ranger District: 1994 Watershed Restoration Monitoring Strategy) Administrative monitoring will be completed through analysis of project database files in RESTFY94 and FWPRO.

Supporting documentation:

- Movassaghi, G. 1994. DRAFT Surface Erosion Monitoring Plan.
- Ralph, S.C., B.Ryan, B.LaRock. 1994. The Skagit Wild and Scenic River Water Resource Monitoring Plan.
- USFS Region 6. 1993. Stream Inventory Handbook, Version 7.0
- USFS Region 6. 1992. Fisheries Habitat Monitoring and Evaluation Procedures
- USFS Region 6. 1985. FSH 2609.23 Fisheries Habitat Evaluation Handbook: Monitoring
- Doyle, J. 1994. Fish Habitat Management Strategy: Mt. Baker-Snoqualmie National Forest FY 1994.

ROAD EROSION AND SEDIMENTATION ACTIVITIES

Project evaluation will follow the methodology outlined in the DRAFT Surface Erosion Monitoring Plan. The sample size will be determined following project selection. Parameters may include: cross-sections of the road prism and stream crossings before and after treatment to quantify fill volumes, installation of erosion troughs or sediment fences to evaluate sediment transport, site reviews to evaluate implementation of Best Management Practices, and permanent photo points. In order to give a complete picture of sediment delivery in a watershed, further analysis may be done of the mass wasting data.

At a larger scale, both physical and biological measurements of fish habitat will be made. This evaluation will follow established protocols for Region 6 Level II or III stream inventory with the possible addition of: Channel Stability Index (Pfankeuch), Riffle Stability Index (Kapesser), channel cross-sections and channel scour measurements, and photo points. Additional biological parameters may include: macro-invertebrate, smolt or outmigrant counts, and spawner surveys.

INSTREAM ACTIVITIES

Project evaluation will follow the methodology outlined in DRAFT 1994 Fisheries Monitoring Proposal. Project reaches to be surveyed will be determined following project selection. At a minimum stream attributes will be sampled starting one reach above the project site and extending one reach past the site. The maximum level of survey would include Level II protocols for the full length of a stream with Level III (more intensive) survey in project locations. Not all parameters will necessarily be measured in each watershed.

This proposal includes measurements of physical and biological stream characteristics. Region 6 protocols for Level

II and II stream survey include but are not limited to: channel type, width/depth ratio, discharge, bankfull width, habitat types, residual pool depth, large woody debris, temperature and substrate. Additional physical measurements may be made using these procedures: Riffle Stability Index (Kapesser), Channel Stability Rating (Pfankeuch) and cross-sections with scour monitors.

Biological parameters to be surveyed include: macro-invertebrates, fish populations including spawners and smolts, cover, and riparian vegetation.

APPENDIX 5.

IN-CHANNEL HABITAT CONDITIONS FOR ILLABOT CREEK SEGMENTS, 1994 AND 1996.

Stream reaches are delineated based on channel type and identified by a stream reach number.

Channel types and other methods are described in section 3.3.3 of this report. "Dom. PFC" is the dominant mechanism that forms pools in the reach.

Reach numbers that contain single numbers or decimals (e.g., 2 , 2.1) are individual channels that we considered were likely to persist over the monitor period. Reach numbers that include "#" (e.g., 2-#3, 3-#6, 13-#1) refer to secondary channels associated with main channel reaches that we considered not likely to persist through the monitoring period. For example, a channel identified as 2-#3 is the third secondary channel surveyed in reach 2. Also, the channel identified as 2-#3 in 1994 and 1996 are not necessarily the same channel.

Summary of Illabot Creek Survey, 1994

| Stream Reach # | channel type | Reach Length(m) | grad. (%) | grad. (%) | grad. (%) | ave. BF Width (m) | clino grad. (%) | LWD pcs. L >50cmx>=5m | LWD pcs. M 20-50cmx>=3m | LWD pcs. S 10-20cmx>=2m | # pools | dom. PFC | Total LWD per 100m | LWD "L" per 100m | LWD "L+M" per 100m | LWD per 100m Key | Channel Widths per pool |
|----------------------|-----------------|--------------------|--------------|--------------|--------------|-------------------------|-----------------------|-----------------------------|-------------------------------|-------------------------------|------------|--------------|--------------------------|------------------------|--------------------------|------------------------|-------------------------------|
| 1 | PR | 940 | 0.2% | 0.1% | 0.1% | 41 | <1 | 4 | 26 | 37 | 3 | bank scour | 7.1 | 0.43 | 3.19 | 0.43 | 7.6 |
| 2 | PR | 950 | 0.2% | | | 31 | <1 | 4 | 44 | 49 | 13 | bank scour | 10.2 | 0.42 | 5.05 | 0.42 | 2.4 |
| 2.1 | PRw | 691 | 0.2% | | | 16 | <1 | 11 | 36 | 34 | 11 | bank/wood | 11.7 | 1.59 | 6.80 | 6.80 | 3.9 |
| 2.2 | FPRw | 480 | 0.2% | | | 14 | <1 | 1 | 51 | 114 | 17 | wood | 34.6 | 0.21 | 10.83 | 10.83 | 2.0 |
| 2-#3 | FPRw | 50 | 0.2% | | | 12 | <1 | 0 | 9 | 10 | 3 | wood | 38.0 | 0.00 | 18.00 | 18.00 | 1.4 |
| 2-#4 | PR | 241 | 0.2% | | | 14 | <1 | 0 | 9 | 7 | 2 | wood | 6.6 | 0.00 | 3.73 | 3.73 | 8.6 |
| 3 | FPRw | 540 | 0.8% | 0.7% | 0.7% | 13 | <1-1.5 | 5 | 77 | 65 | 16 | wood | 27.2 | 0.93 | 15.19 | 15.19 | 2.6 |
| 3-#1 | FPRw | 358 | 0.8% | | | 7 | <1-1.5 | 11 | 51 | 33 | 15 | wood | 26.6 | 3.07 | 17.33 | 17.33 | 3.4 |
| 3-#6 | FPRw | 172 | 0.8% | | | 10 | <1-1.5 | 2 | 33 | 17 | 6 | wood | 30.3 | 1.17 | 20.40 | 20.40 | 2.9 |
| 4 | FPRw | 370 | 1.2% | 2.3% | 2.3% | 19 | 3 | 31 | 128 | 108 | 14 | wood | 72.2 | 8.38 | 42.97 | 42.97 | 1.4 |
| 5 | PB | 510 | 2.4% | 2.2% | 2.2% | 17 | 1-2.5 | 1 | 13 | 15 | 3 | riprap | 5.7 | 0.20 | 2.75 | 2.75 | 10.0 |
| 6 | FPRw | 605 | 1.5% | | | 17 | 1-2 | 12 | 149 | 155 | 9 | wood | 52.2 | 1.98 | 26.61 | 26.61 | 4.0 |
| 6-#1 | PB | 378 | 1.5% | | | 11 | 1-2 | 0 | 16 | 12 | 3 | wood | 7.4 | 0.00 | 4.24 | 4.24 | 11.4 |
| 6-#3 | PB | 357 | 1.5% | | | 6 | 1-2 | 1 | 2 | 2 | 2 | wood | 1.4 | 0.28 | 0.84 | 0.84 | 29.8 |
| 6-#4 | PB | 164 | 1.5% | | | 6 | 1-2 | 0 | 0 | 0 | 0 | no pools | 0.0 | 0.00 | 0.00 | 0.00 | 27.0 |
| 6.2 | PB | 450 | 2.0% | | | 26 | 3 | 4 | 49 | 28 | 0 | no pools | 18.0 | 0.89 | 11.78 | 0.89 | 17.0 |
| 7 | FPRbdrk | 1880 | 3.2% | 3.3% | 3.3% | 17 | 1.5-4 | 29 | 83 | 41 | 23 | bedrock | 8.1 | 1.54 | 5.96 | 5.96 | 4.8 |
| 13 | FPRw | 251 | 1.2% | 1.2% | 1.2% | 16 | 0.5-1.5 | 27 | 94 | 45 | 11 | wood | 66.1 | 10.76 | 48.21 | 48.21 | 1.4 |
| 13-#1 | FPRw | 70 | 1.2% | | | 18 | 0.5-1.5 | 8 | 24 | 12 | 2 | wood | 62.9 | 11.43 | 45.71 | 45.71 | 1.9 |
| 13-#2 | FPRw | 13 | 1.2% | | | 7 | 0.5-1.5 | 3 | 2 | 4 | 1 | wood | 69.2 | 23.08 | 38.46 | 38.46 | 1.9 |
| 13-#3 | FPRw | 66 | 1.2% | | | 13 | 0.5-1.5 | 10 | 10 | 12 | 3 | wood | 48.5 | 15.15 | 30.30 | 30.30 | 1.7 |
| 14 | FPRw/blr | 260 | 2.3% | 2.4% | 2.4% | 16 | 1-3 | 8 | 36 | 14 | 5 | wood/boulder | 22.3 | 3.08 | 16.92 | 16.92 | 3.3 |
| 15 | SP | 290 | 7.4% | 5.3% | 5.3% | 21 | 6 | 24 | 62 | 21 | 8 | boulders | 36.9 | 8.28 | 29.66 | 8.28 | 1.7 |
| 17 | FPRw | 410 | | 0.8% | 0.8% | 10.0 | <1-3 | 16 | 76 | 59 | 16 | wood | 36.8 | 3.90 | 22.43 | 22.43 | 2.6 |
| 17.2 | FPRw | 404 | | 0.8% | 0.8% | 15.0 | <1-3 | 2 | 39 | 45 | 11 | wood | 21.3 | 0.50 | 10.15 | 10.15 | 2.4 |
| 18 | FPRw | 616 | 1.0% | 1.7% | 1.7% | 14.0 | 1-3 | 17 | 63 | 31 | 12 | wood | 18.0 | 2.76 | 12.99 | 12.99 | 3.7 |
| 19 | FPRw | 354 | 1.7% | 2.0% | 2.0% | 16.0 | 1-3 | 26 | 33 | 13 | 6 | wood | 20.3 | 7.34 | 16.67 | 16.67 | 3.7 |

PR Pool-riffle channels
 FPRw Forced Pool-riffle channels where pools are formed primarily by LWD
 FPRw/blr Forced Pool-riffle channels where pools are formed primarily by LWD and boulders
 FPRbdrk Forced Pool-riffle channels where lateral scour pools are formed primarily by bedrock outcrops
 PB Plane-bed channels
 SP Step-pool channels

Summary of Illabot Creek Survey, 1996

| Stream Reach # | channel type | Reach Length (m) | ave. BF Width (m) | clino grad. (%) | LWD pcs. L >50cm>-5m | LWD pcs. M 20-50cm>-3m | LWD pcs. S 10-20cm>-2m | # pools | dom. PRC | %PFC that is LWD | Total LWD per 100m | LWD per 100m "L" | LWD per 100m "L-M" | LWD per 100m Key | Channel Widths per pool |
|----------------------|-----------------|------------------------|-------------------------|-----------------------|----------------------------|------------------------------|------------------------------|------------|-------------|------------------------|--------------------------|------------------------|--------------------------|------------------------|-------------------------------|
| 2 | PR | 1030 | 31.4 | <1 | 5 | 21 | 24 | 8 | bank | 13% | 4.9 | 0.49 | 2.52 | 0.49 | 4.1 |
| 2-#3 | PRW | 95 | 7.6 | <1 | 0 | 5 | 10 | 5 | bank | 40% | 15.8 | 0.00 | 5.26 | 5.26 | 2.5 |
| 2.1 | PRW | 513 | 28.3 | <1 | 3 | 35 | 96 | 4 | bank/wood | 50% | 26.1 | 0.58 | 7.41 | 0.58 | 4.5 |
| 2.2 | FPR | 520 | 23.2 | <1 | 4 | 47 | 80 | 9 | wood | 67% | 25.2 | 0.77 | 9.81 | 9.81 | 2.5 |
| 3 | FPR | 250 | 17.3 | <1-1.5 | 6 | 35 | 52 | 4 | wood | 75% | 37.2 | 2.40 | 16.40 | 16.40 | 3.6 |
| 3-#1 | PRW | 195 | 8.9 | <1-1.5 | 0 | 3 | 32 | 7 | bank | 43% | 17.9 | 0.00 | 1.54 | 1.54 | 3.1 |
| 3-#2 | PRW | 250 | 7.1 | <1-1.5 | 2 | 12 | 54 | 14 | bank | 43% | 27.2 | 0.80 | 5.60 | 5.60 | 2.5 |
| 3-#3 | FPR | 170 | 4.3 | <1-1.5 | 0 | 13 | 25 | 10 | wood | 70% | 22.4 | 0.00 | 7.65 | 7.65 | 4.0 |
| 3-#4 | PR | 70 | 5.4 | <1-1.5 | 0 | 4 | 9 | 4 | bank | 0% | 18.6 | 0.00 | 5.71 | 5.71 | 3.2 |
| 3-#5 | FPR | 130 | 7.9 | <1-1.5 | 4 | 5 | 34 | 4 | wood | 75% | 33.1 | 3.08 | 6.92 | 6.92 | 4.1 |
| 4 | FPR | 560 | 20.6 | 3 | 13 | 80 | 115 | 7 | wood | 57% | 37.1 | 2.32 | 16.61 | 16.61 | 3.9 |
| 5 | PB | 610 | 24.7 | 1-2.5 | 1 | 4 | 18 | 1 | rip rap | 0% | 3.8 | 0.16 | 0.82 | 0.16 | 24.7 |
| 6 | PR | 800 | 32.2 | 1-3 | 25 | 79 | 93 | 4 | bank | 25% | 24.6 | 3.13 | 13.00 | 3.13 | 6.2 |
| 13 | FPR | 245 | 14.3 | 0.5-1.5 | 21 | 39 | 42 | 10 | wood | 60% | 41.6 | 8.57 | 24.49 | 24.49 | 1.7 |
| 14 | FPR | 250 | 17.6 | 1-3 | 8 | 19 | 25 | 5 | wood | 60% | 20.8 | 3.20 | 10.80 | 10.80 | 2.8 |

PR Pool-riffle channels
 FPRW Forced Pool-riffle channels where pools are formed primarily by LWD
 FPRw/blr Forced Pool-riffle channels where pools are formed primarily by LWD and boulders
 FPRbdrk Forced Pool-riffle channels where lateral scour pools are formed primarily by bedrock outcrops
 PB Plane-bed channels
 SP Step-pool channels

APPENDIX 6.

RESIDUAL POOL DEPTH DATA FOR ILLABOT CREEK SEGMENTS, 1994 AND 1996.

Reach numbers that contain single numbers or decimals (e.g., 2 , 2.1) are individual channels that we considered were likely to persist over the monitor period. Reach numbers that include “#” (e.g., 2-#3, 3-#6, 13-#1) refer to secondary channels associated with main channel reaches that we considered not likely to persist through the monitoring period. For example, a channel identified as 2-#3 is the third secondary channel surveyed in reach 2. Also, the channel identified as 2-#3 in 1994 and 1996 are not necessarily the same channel.

For the 1996 data “PFC” is the mechanism that formed the pools. PFC was not recorded in 1994.

Summary of residual pool depth by Illabot Creek reaches, 1994.

| Illabot Reach | Mean | S.D. | Min. | Max. | Sample Size |
|--------------------------|-------------|-------------|-------------|-------------|------------------------|
| 2 | 0.75 | 0.26 | 0.40 | 1.47 | 13 |
| 2.1 | 0.60 | 0.34 | 0.30 | 1.40 | 10 |
| 2.2 | 0.66 | 0.21 | 0.38 | 1.12 | 13 |
| 2-#3 | 0.43 | 0.19 | 0.30 | 0.65 | 3 |
| 2-#4 | 1.03 | 0.18 | 0.90 | 1.15 | 2 |
| 3 | 0.64 | 0.24 | 0.25 | 1.08 | 16 |
| 3-#1 | 0.68 | 0.90 | 0.25 | 3.90 | 15 |
| 3-#6 | 0.38 | 0.14 | 0.20 | 0.50 | 6 |
| 4 | 1.01 | 0.38 | 0.40 | 1.48 | 11 |
| 6 | 0.72 | 0.36 | 0.29 | 1.34 | 7 |
| 6-#1 | 0.56 | 0.20 | 0.40 | 0.79 | 3 |
| 6-#3 | 0.30 | 0.03 | 0.28 | 0.32 | 2 |
| 13 | 0.77 | 0.21 | 0.50 | 1.04 | 9 |
| 13-#1 | 0.95 | 0.19 | 0.81 | 1.09 | 2 |
| 13-#2 | 0.47 | ERR | 0.47 | 0.47 | 1 |
| 13-#3 | 0.61 | 0.30 | 0.33 | 0.92 | 3 |
| 17.2 | 0.49 | 0.16 | 0.23 | 0.75 | 11 |
| 17 | 0.80 | 0.35 | 0.44 | 1.65 | 16 |

Summary of residual pool depth by Illabot Creek reaches, 1996.

| Illabot Reach | Mean | S.D. | Min. | Max. | Sample Size |
|--------------------------|-------------|-------------|-------------|-------------|------------------------|
| 2 | 0.85 | 0.29 | 0.56 | 1.45 | 7 |
| 2.1 | 0.77 | 0.38 | 0.44 | 1.24 | 4 |
| 2.2 | 0.79 | 0.30 | 0.36 | 1.31 | 9 |
| 2-#3 | 0.71 | 0.11 | 0.56 | 0.81 | 5 |
| 3 | 0.55 | 0.30 | 0.22 | 0.86 | 4 |
| 3-#1 | 0.43 | 0.20 | 0.18 | 0.82 | 7 |
| 3-#2 | 0.41 | 0.16 | 0.18 | 0.74 | 14 |
| 3-#3 | 0.29 | 0.10 | 0.18 | 0.46 | 10 |
| 3-#4 | 0.30 | 0.10 | 0.21 | 0.39 | 4 |
| 3-#5 | 0.66 | 0.21 | 0.43 | 0.83 | 3 |
| 4 | 0.90 | 0.42 | 0.61 | 1.76 | 7 |
| 5 | 0.39 | ERR | 0.39 | 0.39 | 1 |
| 6 | 0.50 | 0.17 | 0.32 | 0.71 | 4 |
| 13 | 0.79 | 0.30 | 0.39 | 1.38 | 10 |
| 14 | 0.85 | 0.30 | 0.59 | 1.35 | 5 |

Residual Pool data from Illabot Creek Survey, 1994

| Stream Reach # | max. depth (m) | tailcrst depth (m) | residual pool depth (m) |
|----------------------|----------------------|--------------------------|-------------------------------|
| 2 | 1.04 | 0.36 | 0.68 |
| 2 | 1.00 | 0.23 | 0.77 |
| 2 | 0.68 | 0.28 | 0.40 |
| 2 | 0.84 | 0.31 | 0.53 |
| 2 | 1.02 | 0.28 | 0.74 |
| 2 | 1.01 | 0.24 | 0.77 |
| 2 | 0.97 | 0.22 | 0.75 |
| 2 | 0.80 | 0.25 | 0.55 |
| 2 | 1.06 | 0.28 | 0.78 |
| 2 | 1.07 | 0.36 | 0.71 |
| 2 | 1.16 | 0.24 | 0.92 |
| 2 | 1.70 | 0.23 | 1.47 |
| 2 | 1.08 | 0.46 | 0.62 |
| 2.1 | 0.45 | 0.05 | 0.40 |
| 2.1 | 0.65 | 0.25 | 0.40 |
| 2.1 | 1.50 | 0.10 | 1.40 |
| 2.1 | 0.75 | 0.20 | 0.55 |
| 2.1 | 0.50 | 0.20 | 0.30 |
| 2.1 | 0.40 | 0.05 | 0.35 |
| 2.1 | 0.50 | 0.10 | 0.40 |
| 2.1 | 0.80 | 0.10 | 0.70 |
| 2.1 | 0.70 | 0.10 | 0.60 |
| 2.1 | 0.95 | 0.05 | 0.90 |
| 2.2 | 0.78 | 0.38 | 0.40 |
| 2.2 | 0.88 | 0.38 | 0.50 |
| 2.2 | 0.87 | 0.20 | 0.67 |
| 2.2 | 0.94 | 0.34 | 0.60 |
| 2.2 | 1.25 | 0.35 | 0.90 |
| 2.2 | 1.24 | 0.32 | 0.92 |
| 2.2 | 0.82 | 0.30 | 0.52 |
| 2.2 | 0.66 | 0.28 | 0.38 |
| 2.2 | 1.38 | 0.26 | 1.12 |
| 2.2 | 1.02 | 0.28 | 0.74 |
| 2.2 | 1.14 | 0.58 | 0.56 |
| 2.2 | 0.98 | 0.38 | 0.60 |
| 2.2 | 1.05 | 0.42 | 0.63 |
| 2-#3 | 0.75 | 0.10 | 0.65 |
| 2-#3 | 0.45 | 0.10 | 0.35 |

Residual Pool data from Illabot Creek Survey, 1994

| Stream Reach # | max. depth (m) | tailerst depth (m) | residual pool depth (m) |
|----------------------|----------------------|--------------------------|-------------------------------|
| 2-#3 | 0.30 | 0.00 | 0.30 |
| 2-#4 | 1.20 | 0.30 | 0.90 |
| 2-#4 | 1.50 | 0.35 | 1.15 |
| 3 | 0.63 | 0.20 | 0.43 |
| 3 | 1.07 | 0.38 | 0.69 |
| 3 | 1.04 | 0.35 | 0.69 |
| 3 | 1.23 | 0.25 | 0.98 |
| 3 | 0.98 | 0.45 | 0.53 |
| 3 | 1.38 | 0.46 | 0.92 |
| 3 | 1.10 | 0.34 | 0.76 |
| 3 | 0.65 | 0.35 | 0.30 |
| 3 | 0.93 | 0.18 | 0.75 |
| 3 | 0.75 | 0.23 | 0.52 |
| 3 | 1.15 | 0.31 | 0.84 |
| 3 | 0.68 | 0.43 | 0.25 |
| 3 | 0.76 | 0.32 | 0.44 |
| 3 | 0.90 | 0.48 | 0.42 |
| 3 | 1.28 | 0.20 | 1.08 |
| 3 | 0.83 | 0.23 | 0.60 |
| 3-#1 | 0.40 | 0.15 | 0.25 |
| 3-#1 | 0.55 | 0.05 | 0.50 |
| 3-#1 | 0.85 | 0.10 | 0.75 |
| 3-#1 | 0.40 | 0.05 | 0.35 |
| 3-#1 | 0.50 | 0.10 | 0.40 |
| 3-#1 | 0.40 | 0.10 | 0.30 |
| 3-#1 | 4.00 | 0.10 | 3.90 |
| 3-#1 | 0.80 | 0.10 | 0.70 |
| 3-#1 | 0.35 | 0.10 | 0.25 |
| 3-#1 | 0.65 | 0.10 | 0.55 |
| 3-#1 | 0.55 | 0.10 | 0.45 |
| 3-#1 | 0.50 | 0.10 | 0.40 |
| 3-#1 | 0.75 | 0.10 | 0.65 |
| 3-#1 | 0.40 | 0.10 | 0.30 |
| 3-#1 | 0.55 | 0.10 | 0.45 |
| 3-#6 | 0.40 | 0.10 | 0.30 |
| 3-#6 | 0.55 | 0.05 | 0.50 |
| 3-#6 | 0.55 | 0.05 | 0.50 |
| 3-#6 | 0.55 | 0.05 | 0.50 |
| 3-#6 | 0.35 | 0.10 | 0.25 |

Residual Pool data from Illabot Creek Survey, 1994

| Stream Reach # | max. depth (m) | tailerst depth (m) | residual pool depth (m) |
|----------------------|----------------------|--------------------------|-------------------------------|
| 3-#6 | 0.30 | 0.10 | 0.20 |
| 4 | 1.80 | 0.32 | 1.48 |
| 4 | 1.35 | 0.38 | 0.97 |
| 4 | 1.80 | 0.38 | 1.42 |
| 4 | 1.30 | 0.28 | 1.02 |
| 4 | 0.75 | 0.35 | 0.40 |
| 4 | 1.17 | 0.35 | 0.82 |
| 4 | 1.56 | 0.41 | 1.15 |
| 4 | 1.08 | 0.55 | 0.53 |
| 4 | 1.50 | 0.32 | 1.18 |
| 4 | 1.80 | 0.33 | 1.47 |
| 4 | 1.08 | 0.43 | 0.65 |
| 6 | 1.30 | 0.36 | 0.94 |
| 6 | 0.72 | 0.43 | 0.29 |
| 6 | 0.85 | 0.48 | 0.37 |
| 6 | 1.08 | 0.32 | 0.76 |
| 6 | 0.86 | 0.32 | 0.54 |
| 6 | 1.65 | 0.31 | 1.34 |
| 6 | 1.13 | 0.35 | 0.78 |
| 6-#1 | 1.05 | 0.26 | 0.79 |
| 6-#1 | 0.75 | 0.25 | 0.50 |
| 6-#1 | 0.75 | 0.35 | 0.40 |
| 6-#3 | 0.52 | 0.20 | 0.32 |
| 6-#3 | 0.48 | 0.20 | 0.28 |
| 13 | 1.42 | 0.38 | 1.04 |
| 13 | 1.14 | 0.62 | 0.52 |
| 13 | 1.10 | 0.55 | 0.55 |
| 13 | 1.30 | 0.28 | 1.02 |
| 13 | 1.10 | 0.32 | 0.78 |
| 13 | 0.95 | 0.45 | 0.50 |
| 13 | 1.20 | 0.45 | 0.75 |
| 13 | 1.20 | 0.37 | 0.83 |
| 13 | 1.50 | 0.55 | 0.95 |
| 13-#1 | 0.98 | 0.17 | 0.81 |
| 13-#1 | 1.10 | 0.02 | 1.09 |

Residual Pool data from Illabot Creek Survey, 1994

| Stream Reach # | max. depth (m) | tailerst depth (m) | residual pool depth (m) |
|----------------------|----------------------|--------------------------|-------------------------------|
| 13-#2 | 0.82 | 0.35 | 0.47 |
| 13-#3 | 0.68 | 0.09 | 0.59 |
| 13-#3 | 0.45 | 0.12 | 0.33 |
| 13-#3 | 1.04 | 0.12 | 0.92 |
| 17.2 | 0.85 | 0.15 | 0.70 |
| 17.2 | 0.85 | 0.37 | 0.48 |
| 17.2 | 0.82 | 0.20 | 0.62 |
| 17.2 | 0.67 | 0.30 | 0.37 |
| 17.2 | 0.70 | 0.27 | 0.43 |
| 17.2 | 0.75 | 0.24 | 0.51 |
| 17.2 | 0.65 | 0.35 | 0.30 |
| 17.2 | 0.84 | 0.38 | 0.46 |
| 17.2 | 0.75 | 0.18 | 0.57 |
| 17.2 | 0.55 | 0.32 | 0.23 |
| 17.2 | 1.05 | 0.30 | 0.75 |
| 17 | 0.93 | 0.45 | 0.48 |
| 17 | 0.95 | 0.43 | 0.52 |
| 17 | 0.95 | 0.15 | 0.80 |
| 17 | 1.03 | 0.43 | 0.60 |
| 17 | 1.90 | 0.25 | 1.65 |
| 17 | 1.05 | 0.12 | 0.93 |
| 17 | 1.00 | 0.21 | 0.79 |
| 17 | 1.00 | 0.20 | 0.80 |
| 17 | 0.80 | 0.23 | 0.57 |
| 17 | 0.59 | 0.15 | 0.44 |
| 17 | 1.07 | 0.18 | 0.89 |
| 17 | 1.12 | 0.54 | 0.58 |
| 17 | 0.72 | 0.25 | 0.47 |
| 17 | 1.65 | 0.14 | 1.51 |
| 17 | 1.12 | 0.12 | 1.00 |
| 17 | 1.04 | 0.24 | 0.80 |

Residual Pool data from Illabot Creek Survey, 1996

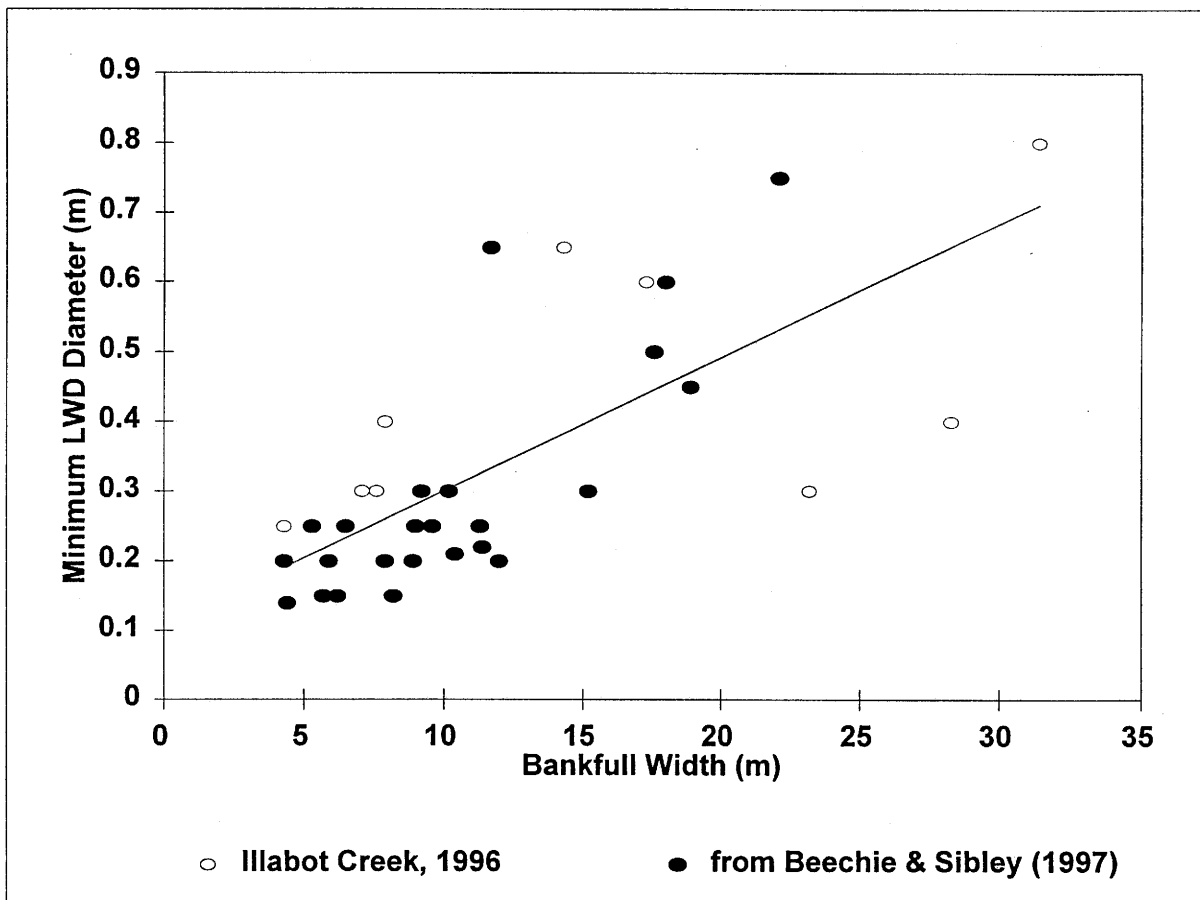
| Stream Reach # | Pool forming char.(PFC) | PFC ht. (m) | PFC vol. (m3) | max. depth (m) | tailerst depth (m) | residual pool depth (m) |
|----------------------|-------------------------------|----------------|------------------|----------------------|--------------------------|-------------------------------|
| 2 | bank scour | | | 1.03 | 0.18 | 0.85 |
| 2 | wood (log) | 0.8 | 4.17 | 1.08 | 0.20 | 0.88 |
| 2 | bank scour | | | 1.32 | 0.51 | 0.81 |
| 2 | bank scour | | | 1.01 | 0.19 | 0.82 |
| 2 | bank scour | | | 0.82 | 0.23 | 0.59 |
| 2 | bank scour | | | 1.70 | 0.25 | 1.45 |
| 2 | bank scour | | | 0.98 | 0.42 | 0.56 |
| 2.1 | bank scour | | | 0.68 | 0.20 | 0.48 |
| 2.1 | wood (log) | 0.4 | 0.30 | 0.65 | 0.21 | 0.44 |
| 2.1 | bank scour | | | 1.38 | 0.14 | 1.24 |
| 2.1 | wood (jam) | 3.0 | 48.00 | 1.22 | 0.32 | 0.90 |
| 2.2 | wood (log) | 0.4 | 0.31 | 0.92 | 0.42 | 0.50 |
| 2.2 | bank scour | | | 1.28 | 0.14 | 1.14 |
| 2.2 | wood (jam) | 1.1 | 8.25 | 0.86 | 0.50 | 0.36 |
| 2.2 | wood (log) | 0.3 | 0.22 | 0.91 | 0.28 | 0.63 |
| 2.2 | wood (jam) | 1.3 | 3.90 | 1.08 | 0.28 | 0.80 |
| 2.2 | bank scour | | | 0.92 | 0.25 | 0.67 |
| 2.2 | bank scour | | | 1.09 | 0.21 | 0.88 |
| 2.2 | wood (jam) | 0.6 | 5.66 | 1.32 | 0.47 | 0.85 |
| 2.2 | wood (jam) | 2.5 | 16.50 | 1.52 | 0.21 | 1.31 |
| 3-#1 | bank scour | | | 0.37 | 0.06 | 0.31 |
| 3-#1 | bank scour | | | 0.22 | 0.04 | 0.18 |
| 3-#1 | wood (jam) | 1.0 | 1.54 | 0.54 | 0.05 | 0.49 |
| 3-#1 | bank scour | | | 0.53 | 0.06 | 0.47 |
| 3-#1 | wood (jam) | 1.1 | 2.46 | 0.86 | 0.04 | 0.82 |
| 3-#1 | bank scour | | | 0.33 | 0.03 | 0.30 |
| 3-#1 | wood (jam) | 0.7 | 0.46 | 0.53 | 0.08 | 0.45 |
| 3-#2 | bank scour | | | 0.50 | 0.12 | 0.38 |
| 3-#2 | wood (log) | 0.3 | 0.14 | 0.56 | 0.18 | 0.38 |
| 3-#2 | wood (jam) | 1.1 | 6.60 | 0.82 | 0.20 | 0.62 |
| 3-#2 | bank scour | | | 0.63 | 0.25 | 0.38 |
| 3-#2 | bank scour | | | 0.45 | 0.15 | 0.30 |
| 3-#2 | bank scour | | | 0.45 | 0.16 | 0.29 |
| 3-#2 | convergence | | | 0.56 | 0.26 | 0.30 |
| 3-#2 | wood (jam) | 1.2 | 2.88 | 0.73 | 0.12 | 0.61 |
| 3-#2 | convergence | | | 0.42 | 0.19 | 0.23 |
| 3-#2 | convergence | | | 0.32 | 0.14 | 0.18 |
| 3-#2 | wood (log) | 0.8 | 2.51 | 0.82 | 0.28 | 0.54 |
| 3-#2 | wood (jam) | 0.9 | 2.08 | 0.79 | 0.40 | 0.39 |

Residual Pool data from Illabot Creek Survey, 1996

| Stream Reach # | Pool forming char.(PFC) | PFC ht. (m) | PFC vol. (m3) | max. depth (m) | tailerst depth (m) | residual pool depth (m) |
|----------------------|-------------------------------|----------------|------------------|----------------------|--------------------------|-------------------------------|
| 3-#2 | bank scour | | | 0.88 | 0.14 | 0.74 |
| 3-#2 | wood (log) | 0.3 | 0.17 | 0.49 | 0.12 | 0.37 |
| 2-#3 | wood (jam) | 0.7 | 1.58 | 0.83 | 0.21 | 0.62 |
| 2-#3 | bank scour | | | 0.64 | 0.08 | 0.56 |
| 2-#3 | wood (log) | 0.3 | 0.42 | 0.94 | 0.13 | 0.81 |
| 2-#3 | convergence | | | 0.96 | 0.20 | 0.76 |
| 2-#3 | bank scour | | | 0.94 | 0.15 | 0.79 |
| 3-#3 | convergence | | | 0.46 | 0.28 | 0.18 |
| 3-#3 | wood (jam) | 0.3 | 0.14 | 0.42 | 0.16 | 0.26 |
| 3-#3 | wood (log) | 0.4 | 0.23 | 0.40 | 0.14 | 0.26 |
| 3-#3 | bank scour | | | 0.38 | 0.15 | 0.23 |
| 3-#3 | wood (log) | 0.3 | 0.21 | 0.43 | 0.24 | 0.19 |
| 3-#3 | wood (rw) | 0.9 | 0.89 | 0.57 | 0.16 | 0.41 |
| 3-#3 | convergence | | | 0.37 | 0.16 | 0.21 |
| 3-#3 | wood (jam) | 0.7 | 0.80 | 0.56 | 0.10 | 0.46 |
| 3-#3 | wood (log) | 0.3 | 0.23 | 0.47 | 0.13 | 0.34 |
| 3-#3 | wood (jam) | 0.8 | 0.93 | 0.60 | 0.24 | 0.36 |
| 3-#4 | bank scour | | | 0.26 | 0.04 | 0.22 |
| 3-#4 | bank scour | | | 0.24 | 0.03 | 0.21 |
| 3-#4 | convergence | | | 0.46 | 0.07 | 0.39 |
| 3-#4 | bank scour | | | 0.41 | 0.04 | 0.37 |
| 3-#5 | bank scour | | | 1.10 | 0.38 | 0.72 |
| 3-#5 | wood (rw) | 1.2 | 5.28 | 1.15 | 0.32 | 0.83 |
| 3-#5 | wood (log) | 0.4 | 0.40 | 0.68 | 0.25 | 0.43 |
| 3-#5 | wood (log) | 0.6 | 0.96 | oops! | 0.12 | |
| 3 | wood (log) | 0.6 | 1.51 | 0.60 | 0.38 | 0.22 |
| 3 | wood (jam) | 1.4 | 5.88 | 1.40 | 0.54 | 0.86 |
| 3 | convergence | | | 0.80 | 0.42 | 0.38 |
| 3 | wood (jam) | 0.9 | 8.10 | 1.20 | 0.47 | 0.73 |
| 4 | bank scour | | | 1.15 | 0.42 | 0.73 |
| 4 | wood (jam) | 1.5 | 18.00 | 1.13 | 0.47 | 0.66 |
| 4 | wood (jam) | oops! | oops! | 0.96 | 0.32 | 0.64 |
| 4 | wood (jam) | 1.5 | 36.00 | 1.14 | 0.35 | 0.79 |
| 4 | bank scour | | | 2.10 | 0.34 | 1.76 |
| 4 | bank scour | | | 1.05 | 0.44 | 0.61 |
| 4 | wood (jam) | oops! | oops! | 1.58 | 0.44 | 1.14 |

Residual Pool data from Illabot Creek Survey, 1996

| Stream Reach # | Pool forming char.(PFC) | PFC ht. (m) | PFC vol. (m3) | max. depth (m) | tailcrst depth (m) | residual pool depth (m) |
|----------------------|-------------------------------|----------------|------------------|----------------------|--------------------------|-------------------------------|
| 5 | bank (riprap) | | | 0.86 | 0.47 | 0.39 |
| 6 | bank scour | | | 0.92 | 0.40 | 0.52 |
| 6 | bank scour | | | 0.93 | 0.50 | 0.43 |
| 6 | wood (jam) | 1.0 | 4.20 | 1.05 | 0.34 | 0.71 |
| 6 | bank scour | | | 1.05 | 0.73 | 0.32 |
| 7tag#25 | bedrock | | | 2.60 | 0.90 | 1.70 |
| 7tag#26 | bedrock | | | 2.35 | 0.82 | 1.53 |
| 7tag#27 | bedrock | | | 2.40 | 0.66 | 1.74 |
| 7tag#28 | bedrock | | | 2.60 | 0.57 | 2.03 |
| 13 | wood (log) | 0.7 | 2.31 | 0.98 | 0.32 | 0.66 |
| 13 | wood (jam) | 1.5 | 27.00 | 1.23 | 0.19 | 1.04 |
| 13 | boulder | 1.0 | 1.50 | 0.90 | 0.18 | 0.72 |
| 13 | wood (jam) | 0.6 | 5.40 | 1.03 | 0.34 | 0.69 |
| 13 | wood (log) | 0.7 | 3.42 | 0.76 | 0.18 | 0.58 |
| 13 | bank scour | | | 0.81 | 0.23 | 0.58 |
| 13 | convergence | | | 0.54 | 0.15 | 0.39 |
| 13 | wood (jam) | 2.0 | 11.70 | 0.94 | 0.22 | 0.72 |
| 13 | wood (rw) | 1.5 | 12.60 | 1.72 | 0.34 | 1.38 |
| 13 | bank scour | | | 1.50 | 0.36 | 1.14 |
| 14 | wood (log) | na | na | 1.20 | 0.54 | 0.66 |
| 14 | wood (jam) | 2.2 | 63.36 | 1.80 | 0.45 | 1.35 |
| 14 | wood (jam) | 0.7 | 8.40 | 1.22 | 0.45 | 0.77 |
| 14 | bank scour | | | 1.12 | 0.53 | 0.59 |
| 14 | bank scour | | | 1.80 | 0.90 | 0.90 |



Regression Statistics

| | |
|-------------------|-----------|
| Multiple R | 0.7172031 |
| R Square | 0.5143803 |
| Adjusted R Square | 0.4996646 |
| Standard Error | 0.1269972 |
| Observations | 35 |

Analysis of Variance

| | <i>df</i> | <i>Sum of Sq</i> | <i>Mean Squ</i> | <i>F</i> | <i>Significance F</i> |
|------------|-----------|------------------|-----------------|-----------|-----------------------|
| Regression | 1 | 0.563755 | 0.563755 | 34.954414 | 1.25E-06 |
| Residual | 33 | 0.5322336 | 0.0161283 | | |
| Total | 34 | 1.0959886 | | | |

| | <i>Coefficient</i> | <i>Standard</i> | <i>t Statistic</i> | <i>P-value</i> | <i>Lower 95.</i> | <i>Upper 95.00%</i> |
|-----------|--------------------|-----------------|--------------------|----------------|------------------|---------------------|
| Intercept | 0.1083039 | 0.0437119 | 2.4776762 | 0.0183517 | 0.0193714 | 0.1972364 |
| x1 | 0.0191946 | 0.0032466 | 5.9122258 | 1.12E-06 | 0.0125893 | 0.0257998 |

APPENDIX 7.

LITTLE PARK CREEK SMOLT TRAP DATA, SPRING 1997

LITTLE PARK CREEK COHO OUTMIGRATION TRAP DATA 1997

| DATE | COHO DAILY TOTAL | NUMBER MORTS | AVERAGE FKLN(mm) | WATER TEMP.(F) | GAGE HEIGHT | TROUT 0 | RB 1+ | CT 1+ | CT 2+ |
|-------|------------------------|-----------------|---------------------|-------------------|----------------|---------|-------|-------|-------|
| 04/29 | 0 | 0 | | | | 0 | 0 | 0 | 0 |
| 04/30 | 1 | 0 | 90.0 | | | 0 | 1 | 0 | 0 |
| 05/01 | 0 | 0 | | | 31 | 0 | 0 | 0 | 0 |
| 05/02 | 92 | 3 | 103.9 | | 23 | 0 | 0 | 0 | 0 |
| 05/03 | 30 | 0 | 77.1 | | 21 | 0 | 0 | 0 | 0 |
| 05/04 | 155 | 0 | 77.5 | 44 | 21 | 0 | 0 | 0 | 0 |
| 05/05 | 103 | 0 | 76.9 | 46 | 21 | 0 | 0 | 0 | 0 |
| 05/06 | 71 | 0 | 76.5 | 46 | 25.5 | 0 | 0 | 0 | 0 |
| 05/07 | 195 | 0 | 110.5 | 44 | 25 | 0 | 0 | 0 | 1 |
| 05/08 | 72 | 0 | 102.9 | 44 | 26 | 0 | 0 | 1 | 0 |
| 05/09 | 54 | 0 | 115.1 | 44 | 26 | 0 | 0 | 2 | 1 |
| 05/10 | 73 | 0 | 89.7 | 45 | 23.5 | 1 | 0 | 0 | 0 |
| 05/11 | 75 | 0 | 99.8 | 44 | 20 | 0 | 0 | 1 | 0 |
| 05/12 | 124 | 0 | 108.3 | 44 | 20 | 0 | 0 | 0 | 0 |
| 05/13 | 151 | 0 | 111.4 | 48 | 19 | 0 | 0 | 0 | 0 |
| 05/14 | 172 | 0 | 106.8 | 44 | 20 | 0 | 0 | 1 | 0 |
| 05/15 | 204 | 0 | 101.9 | 44 | 21 | 0 | 0 | 0 | 0 |
| 05/16 | 151 | 1 | 99.5 | 44 | 21 | 0 | 0 | 0 | 0 |
| 05/17 | 164 | 2 | 96.4 | 44 | 21 | 0 | 0 | 0 | 0 |
| 05/18 | 115 | 0 | 94.7 | 49 | 21 | 0 | 0 | 0 | 0 |
| 05/19 | 67 | 0 | 122.9 | 48 | 21 | 0 | 0 | 0 | 0 |
| 05/20 | 66 | 0 | 105.3 | 48 | 21 | 0 | 0 | 0 | 0 |
| 05/21 | 85 | 0 | 90.7 | 48 | 20 | 0 | 0 | 0 | 0 |
| 05/22 | 62 | 1 | 90.2 | 48 | 20 | 0 | 0 | 0 | 0 |
| 05/23 | 30 | 0 | 101.9 | 52 | 20 | 0 | 0 | 1 | 0 |
| 05/24 | 244 | 0 | 96.4 | 48 | 21.5 | 0 | 0 | 0 | 0 |
| 05/25 | 133 | 1 | 99.0 | 49 | 22 | 0 | 0 | 0 | 0 |
| 05/26 | 244 | 0 | 98.9 | 49 | 21 | 0 | 0 | 0 | 0 |
| 05/27 | 31 | 1 | 102.9 | 50 | 21 | 0 | 0 | 0 | 0 |
| 05/28 | 258 | 0 | 94.4 | 50 | 22 | 0 | 0 | 0 | 0 |
| 05/29 | 241 | 1 | 96.8 | 50 | 23 | 0 | 0 | 0 | 0 |
| 05/30 | 441 | 0 | 98.3 | 50 | 23 | 1 | 0 | 0 | 0 |
| 05/31 | 466 | 0 | 89.5 | 50 | 30 | 0 | 0 | 1 | 0 |
| 06/01 | 205 | 0 | 94.7 | 49 | 29 | 0 | 0 | 0 | 0 |
| 06/02 | 81 | 1 | 93.7 | 49 | 28 | 0 | 0 | 0 | 0 |
| 06/03 | 57 | 1 | 85.8 | 49 | 27 | 1 | 0 | 0 | 0 |
| 06/04 | 25 | 1 | 86.8 | 48 | 24 | 0 | 0 | 0 | 0 |
| 06/05 | 31 | 1 | 96.7 | 49 | 24 | 0 | 0 | 0 | 0 |
| 06/06 | 23 | 0 | 89.5 | 49 | 27 | 0 | 0 | 0 | 0 |
| 06/07 | 16 | 0 | 90.9 | 49 | 28 | 0 | 0 | 0 | 0 |
| 06/08 | 15 | 2 | 92.4 | 50 | 28 | 0 | 0 | 0 | 0 |
| 06/09 | 22 | 0 | 88.6 | 50 | 28 | 0 | 0 | 0 | 0 |
| 06/10 | 14 | 0 | 88.4 | 54 | 28 | 0 | 0 | 0 | 0 |
| 06/11 | 21 | 0 | 94.5 | 52 | 28 | 0 | 0 | 0 | 0 |
| 06/12 | 11 | 0 | 93.1 | 54 | 29 | 0 | 0 | 0 | 0 |
| 06/13 | 13 | 0 | 92.2 | 52 | 29 | 0 | 0 | 0 | 0 |
| 06/14 | 9 | 0 | 90.0 | 52 | 29 | 0 | 0 | 0 | 0 |
| 06/15 | 6 | 0 | 93.0 | 54 | 29 | 0 | 0 | 0 | 0 |
| 06/16 | 8 | 0 | 104.0 | 52 | 27 | 0 | 0 | 0 | 0 |
| 06/17 | 6 | 0 | 100.3 | 52 | 25 | 0 | 0 | 0 | 0 |
| 06/18 | 6 | 0 | 94.7 | 52 | 24 | 0 | 0 | 0 | 0 |
| 06/19 | 0 | 0 | | 54 | 26 | 0 | 0 | 0 | 0 |
| 06/20 | 1 | 0 | 95.0 | 50 | 26 | 0 | 0 | 0 | 0 |
| 06/21 | 1 | 0 | 80.0 | 52 | 26 | 0 | 0 | 0 | 0 |
| 06/22 | 0 | 0 | | 50 | 24 | 0 | 0 | 0 | 0 |
| 06/23 | 0 | 0 | | 52 | 26 | 0 | 0 | 0 | 0 |
| 06/24 | 0 | 0 | | 52 | 21 | 0 | 0 | 0 | 0 |
| TOTAL | 4941 | 16 | | | | 3 | 1 | 7 | 2 |