2014 ANNUAL REPORT

Project Effectiveness Monitoring Program

WASHINGTON STATE
RECREATION AND CONSERVATION OFFICE
Salmon Recovery
Funding Board

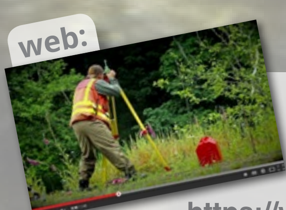
TETRA TECH

Project partner:

Additional funding provided by:

COVER PHOTOS: Top left – Fields in Eastern Washington; top right – Entiat River; bottom left – Surveying the Wenatchee River via inflatable raft. **INSIDE COVER PHOTO:** School of juvenile Chinook and coho salmon

TABLE OF CONTENTS



For more information on project effectiveness monitoring in the Pacific Northwest, see our video presentation at:

https://www.youtube.com/watch?v=6YX1j0EYupo

Large woody debris on Entiat River providing cover and creating/maintaining pool scour

INTRODUCTION

Efforts to restore salmon populations and habitat are widespread across the range of Pacific salmon. Billions have been spent on restoration efforts from both state and federal sources, and thus, there is an ongoing need to track the effectiveness of these restoration projects.

In working toward achieving the salmon recovery plan goals established for listed Evolutionarily Significant Units (ESUs) of Pacific salmon, the state of Washington receives federal funding and supplements their own state funding to implement recovery actions. More than $477 million in state and federal funds have been distributed across 31 counties in Washington since 1999. In 2004, the state developed a project scale effectiveness monitoring program (Project Effectiveness Monitoring) designed to track the results of restoration efforts. Categories of projects are sampled through this monitoring program, allowing the available funding to be optimized by focusing on the most effective project types.

The goals of Project Effectiveness Monitoring were to address several management questions developed by the Salmon Recovery Funding Board (SRFB) and the Governor's Salmon Recovery Office (GSRO), including:

1. Are restoration treatments having the intended effects in terms of improvements in localized habitats and use by salmon?
2. Are some treatment types more effective than others at achieving specific results?
3. Can project monitoring results be used to improve the design of future projects?

Because monitoring every project for effectiveness was not possible under the allocated monitoring budgets, the SRFB identified *categories* of projects that were commonly implemented across the state. These categories could then be subsampled using a random selection of projects from within the category to represent the average effectiveness of that category. The categories of projects included the following:

- Fish passage projects (culverts, bridges, dam removal)
- Instream habitat projects (placement of rock or wood in the active channel)
- Riparian planting projects (planting within the riparian areas to provide shade)
- Livestock exclusion (to protect vegetative buffers and reduce erosion)
- Floodplain enhancement projects (to increase floodplain connectivity, remove levees, reconnect off-channel habitat, create off-channel habitat)
- Spawning gravel placement (to supplement natural gravels in spawning-limited systems)
- Diversion screening projects (to prevent fish entrainment into water diversion systems)
- Habitat protection projects (to protect high-quality habitat for its existing function)

For each category, protocols were developed using a peer-review process with specific objectives and success criteria that related to each of the project categories. In fish passage projects, for example, a 20 percent increase in juvenile and adult fish above the barrier by five years post project implementation (as compared to baseline and control conditions) was one of the success criteria. For a riparian planting project, the objectives of the protocols were to measure changes in stream shading, vegetation layers, and bank erosion to determine whether these indicators of project effectiveness had improved significantly in 10 years since project implementation. Each indicator selected in a given protocol was matched with a success criterion. Success of a category could also be based on the overall performance of the group of projects. For example, for instream habitat projects, at least 80 percent of the structures placed across 80 percent of the projects monitored needed to remain in place for the project category to be considered successful.

Since not all the projects for monitoring were identified in 2004, the program included a rotating panel design based on the start year for a project and the frequency of monitoring as determined by the protocol. Some project types (e.g., fish passage) were expected to take less time than others (e.g., floodplain enhancement) to show change, and were therefore monitored for a shorter period of time but at a higher frequency. Fish passage projects were monitored for one year pre-project and then in years 1, 2, and 5 post-project. Floodplain projects were monitored for one year pre-project and then in years 1, 3, 5, and 10 post-project. In addition to the original sample size established by the SRFB, other funding entities at the local, state and federal level have also been able to support sampling of projects *using the same protocols*. Those sites have been be added to the SRFB sample set for additional information about the project category. Coordinating groups that have contributed funding and project data include the Upper Columbia Salmon Recovery Board (UCSRB), the Oregon Watershed Enhancement Board (OWEB), and the Bonneville Power Administration (BPA). Table 1 shows the project categories and the number of projects in each as funded across all groups.

Table 1. Project sample sizes by category

Monitoring Category	Number of Projects	Coordinating Agencies
Fish Passage	11	SRFB and BPA
Instream Habitat	29	SRFB, UCSRB, BPA
Riparian Planting	9	SRFB only
Livestock Exclusion	13	OWEB and SRFB and BPA
Floodplain Enhancement	43	SRFB, UCSRB, BPA
Spawning Gravel	1	Category ended for lack of projects
Habitat Protection	10	SRFB only

Monitoring Questions and Objectives

Project scale monitoring is one of several different types of monitoring that is designed to measure the localized effects of project actions on the surrounding habitat and fish communities. This type of monitoring is not intended to address changes at the fish population or watershed level, but is targeted on determining which project types are effective at achieving localized changes in habitat, thus addressing specific limiting factors or ecological concerns. Once projects are implemented and monitored, these incremental gains can then be summed over a larger area. Project scale monitoring is a tool to try to enhance the efficiency of salmon recovery efforts and to help keep the programs on track; however, this type of monitoring should be integrated with other monitoring efforts focused at the watershed and population scales to determine whether recovery goals at those levels are being met. Project monitoring can provide information about single projects or groups of projects, but will not be able to predict how much restoration is needed in a watershed, or whether fish populations will meet minimum recovery targets.

One of the best uses of project monitoring data is to provide near-term feedback on project performance—feedback that helps determine whether recovery actions are progressing in the right direction during a 10- to 20-year timeframe before salmon population recoveries are likely. This type of monitoring aids in the adaptive management of restoration efforts and spending such that the projects funded are those most effective in achieving the desired changes in habitat, and those that are being used by the target species and life stages.

In order to address the management questions at the project category level, success criteria for each indicator in each protocol were established. For example, in floodplain enhancement projects, a minimum of a 20 percent increase in residual pool depth would need to be detected within 10 years of project implementation. Similarly, a 20 percent increase in fish use over 10 years is also expected. Specific criteria were established for each indicator, and the combination of indicators that are met are used to provide feedback on whether the projects as a category are achieving their overarching goals.

At the scale of a single project, data can also be compared to project-specific goals to determine whether they are being achieved and whether target species and life stages are using restoration projects. This information is collected across all projects, and then made available through the Washington State Habitat Work Schedule, the Upper Columbia Salmon Recovery Board website, and the Action Effectiveness Monitoring website for project sponsors to compare

web:

Habitat Work Schedule:
http://www.hws.ekosystem.us/?p=Page_2dcf09fe-c011-4d40-a62f-710d1d97c13e

Upper Columbia Salmon Recovery Board:
http://www.ucsrb.org/

Action Effectiveness Monitoring:
https://www.aemonitoring.org/

data with project-specific goals. For example, if the goal of a livestock exclusion project was to decrease bank erosion by 10 percent within five years, the amount of change in the percent of banks actively eroding could be compared to the baseline to determine how much erosion has been reduced over time.

The protocols developed for each project category share common data collection methods for common metrics and indicators. This approach allows for comparison of project effectiveness across categories for those metrics and indicators in common among project types. For example, fish-use data for salmonids is collected at both instream habitat projects and floodplain enhancement projects. In many situations, either or both of these project actions may be appropriate to use at a project site. Having a data set that identifies the approaches yielding the greatest changes for specific indicators (including specific fish species and life stages) can assist project sponsors in determining which approach most closely meets the needs of their particular watershed and project site. Collecting data from sites across the state allows sponsors to select projects in areas similar to their project site to obtain additional comparable results.

While effectiveness can be measured by a change in a particular habitat metric or indicator, or by use by a specific fish species and life stage, cost effectiveness is another measurement of efficiency of project actions. As part of this program, project costs were compared to the overall change in a particular metric to evaluate the cost effectiveness of different projects and different types of projects. There is substantial variability in some of these data based on differences in cost in different project areas and on the size of the projects. However, the evaluation of the amount of improvement per dollar spent (the "bang for the buck") is critical to making informed decisions about funding those projects that are likely to make the greatest use of restoration funding.

Use of monitoring data to improve project design is an ongoing effort as we learn to develop better communication strategies between communities of scientists and communities of project designers and project sponsors. Figure 1 shows a schematic of the information flow through the recovery cycle from planning to project implementation through monitoring toward increases in survival and population levels.

The role of project effectiveness monitoring data is pivotal in connecting the project actions to the habitat outcomes that result from those actions. Projects are too often implemented but not monitored, and then the same action is implemented again without taking the time to analyze whether the action was effective in achieving the intended goals. Improving communication between those doing the monitoring and those implementing the projects is, therefore, an important step to continuous improvement of restoration science. This adjustment in efforts is the essence of *adaptive management* providing a feedback mechanism for project implementation and funding. Development of usable output in the form of hydraulic models and design criteria for specific species and life stages are some of the currently emerging elements of this program that are targeted at achieving that goal. Working with design groups and project sponsors, Tetra Tech, Inc. (Tetra Tech) is making progress toward the goal of more effectively implementing true adaptive management in stream restoration.

Monitoring Tasks Completed in 2014

Monitoring in 2014 under the SRFB program included surveys at 17 project sites across the state of Washington. Of these sites, 1 is a habitat protection project, 7 are floodplain enhancement projects, 1 is a livestock exclusion, 2 are riparian planting projects, and 6 are instream habitat projects. Also included in this reporting period are the data

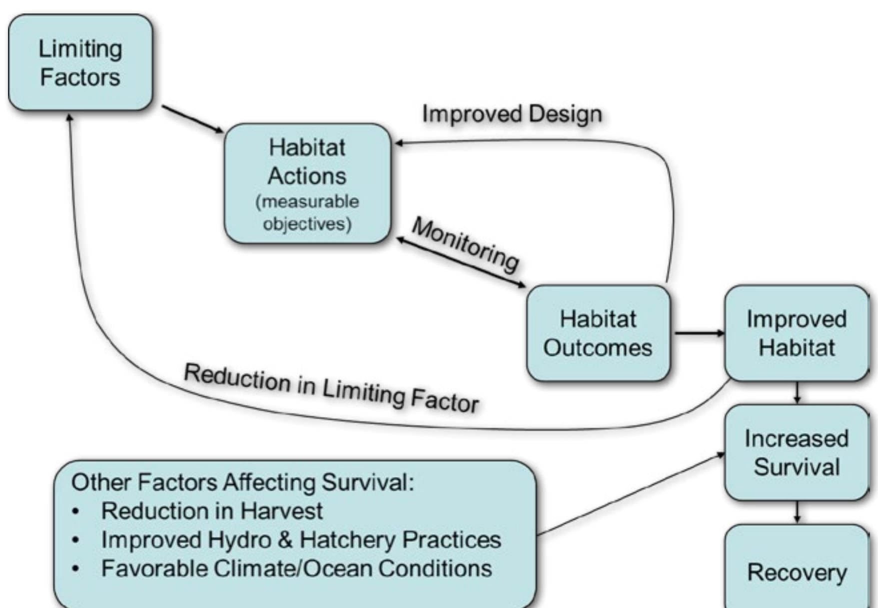


Figure 1. Information Flow through the Salmon Recovery Cycle

To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science

— Albert Einstein

Installed LWD jam – Upper Trout Creek

processing of topographic data, the data analysis for all the projects in the SRFB program, the integration of data sets from other programs, and the development of this annual report. Monthly progress reports containing detailed information on accomplishments and outreach over the previous reporting periods are available through the Project Information System (PRISM) website.

> **web:** **Monthly progress reports can be found at the following PRISM website:**
> **https://secure.rco.wa.gov/Prism/Sponsor/**

Collaboration with other monitoring programs, and coordination with project sponsors and local monitoring entities (lead entities and regional staff), are also supported as part of this grant. Coordination with the UCSRB and BPA programs has been an active part of monitoring under the SRFB program, and specific presentations were developed for both the Upper Columbia and Snake River regions as part of this funding. In accordance with requests made by the Tucannon Regional Technical Team in the Snake River Region, Tetra Tech provided the Snake River Regional staff video of fish use at specific projects, and presented a summary of fish response to habitat projects in the Tucannon basin to the working group. Tetra Tech staff also coordinated with the SRFB Monitoring Panel, and regional organizations such as the Puget Sound Partnership (PSP), through the freshwater indicators workgroup. The coordination of efforts and funding across multiple agencies allows the individual investment by each group to be multiplied for the greater benefit of all groups. For example, funding by BPA to create a centralized database and data-processing tool eliminated the need for processing by hand the topographic data sets collected under this program, as had been done in previous years. This savings allowed the development of hydraulic models for certain sites that could then be used to inform predictive modeling about habitat quality, and to compare with site-specific fish observations to provide life stage and species-specific design criteria for project development.

Wood structure on the Dungeness River

CHOOSING THE RIGHT PROJECT ACTIONS:

EVALUATING THE EFFECTIVENESS OF RESTORATION PROJECT CATEGORIES

Design and implementation of restoration projects is often an iterative process. As part of recovery planning, many regions have identified sections of watersheds where restoration is warranted and limiting factors have been identified. From these areas, specific project sites are selected based on the ability to affect positive change at a given site and, in some cases, an opportunity to access a project site. Within a given project, many decisions are made on the types of actions that could be implemented. In many instances, these decisions involve comparing the benefits of one project action against another, and weighing the cost of those options. Comparison of the relative effectiveness of project types to achieve specific objectives provides useful information that can be incorporated into the planning process. In this section, we describe the methods used to monitor projects and the results of projects, both within and across categories.

Data Collection Methods

Standard data collection methods are one of the cornerstones of repeatable and scientifically rigorous monitoring programs. Methods for project effectiveness are specific to each monitoring category and include field data collection methods, data analysis methods, and established success criteria for each indicator. Methods are available online through the Washington Habitat Work Schedule.

Field sampling indicators and techniques were adapted from the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (Peck et al. 2003) and the Columbia Habitat Monitoring Program (CHaMP 2013). Projects were evaluated using a Before-After-Control-Impact (BACI) experimental design (Stewart-Oaten et al. 1986). The detailed protocols used to monitor projects are available in select monitoring effectiveness protocol documents (Crawford and Tetra Tech EC 2011a-g, Crawford and Arnett 2011), and in the 2011 Monitoring Protocols on the Washington Habitat Work Schedule website (Washington State RCO 2013). The protocols include goals and objectives for each category, detailed field data collection descriptions, functional assessment methods, summary statistics, and data analysis procedures.

Instream habitat measurements included thalweg profile, wetted width, bankfull width, channel unit, and substrate characterization. Riparian habitat was monitored using visual estimations of canopy, understory, and ground cover, as well as shading measurements using a densiometer. Estimates of erosion along the banks were also made for riparian planting and livestock exclusion projects. Riparian planting projects were also surveyed for plant survival during the first two years, and percent woody cover in years three, five and ten after implementation. Habitat protection project monitoring included an assessment of terrestrial vegetative community condition in terms of the level of succession in the terrestrial vegetation, and the level of invasive species present. Aquatic health for habitat protection projects was measured using a macroinvertebrate index and a fish community index from macroinvertebrate samples and snorkel surveys conducted in the stream reaches at the site.

Fish Survey Methods

At most sites, juvenile abundance is assessed by snorkel survey. Snorkel surveys are generally conducted by one to three snorkelers, depending on the size and complexity of the system. The reach is set up prior to surveys, with flags indicating habitat units and evenly spaced transects. Surveyors generally snorkel a reach from downstream to upstream. There are occasional exceptions, such as in large river systems where the reach is snorkeled upstream along the edge of the channel followed by snorkeling downstream through the middle of the channel if safe to do so. Surveyors record fish species, number, and size (to the nearest 10 millimeter). Because it is impossible to differentiate between juvenile rainbow trout and steelhead (both *Oncorhynchus mykiss*) at a young age, this report uses "steelhead" to refer to all juvenile steelhead observed even though resident rainbow juveniles may be present in the sample. In addition, each fish observation is coded for association with structure use (such as placed wood, natural wood, or boulders) and flow conditions (fast, slow, backwater, edge). Fish observations are recorded by transect and/or channel unit.

Additional observations of fish behavior or associated structure use and/or fish location may also be recorded. This can provide additional clarification of fish use, for example, at sites where structures have been placed. Such information allows for assessment of whether fish appear to be preferentially selecting habitat associated with restoration work. In addition, notes on how fish are using these habitats provide feedback to project design teams and sponsors regarding actual use versus intended use. These notes, combined with video footage, can provide easy-to-interpret results that can clarify information provided in the standard metric results reported from the full reach survey.

Underwater video footage was obtained at certain sites to supplement quantitative survey data. Snorkelers collected video footage at structures to aid in showing fish use, or lack thereof, of habitat and placed structures or existing large woody debris (LWD). In addition, digital recording was sometimes performed during general snorkel surveys at reach locations where fish were particularly numerous; this was done to show habitat conditions selected by fish as well as to aid in validating quantitative survey data.

Video footage provides visual information on how habitats are being utilized by various species. When video footage is gathered at placed structures, the footage can inform how the structure is performing underwater (providing a look at the geomorphic changes, or lack of change), as well as how fish are using the structure (cover, flow refugia, feeding, etc.). Video footage of areas of particularly high numbers

Snorkel survey near a replaced culvert

of fish can help inform the design process with respect to habitat fish are likely to selectively utilize. Alternatively, video footage can provide information about areas fish are *not selecting*, which can be evaluated to further inform engineers about what to avoid in future projects.

Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) are guided by specific elements in a program that help to ensure precision, accuracy, representativeness, completeness, and comparability. Quality assurance is the review of data in the field, or as part of the data management process, that ensures that the values collected and calculated have been reviewed for these five elements. Quality control is the system of management that ensures that those steps are completed. The Project Effectiveness Monitoring Program has both elements included.

Precision in the program is supported by using specific written protocols that help ensure consistent collection of field data using standardized methods and equipment. The protocols used in this study have been evaluated through peer review and in other studies, and refinements have been made to ensure a high level of precision for the methods used (Peck et al. 2003). Field equipment is calibrated and precision targets are enforced through electronic warnings in digital data collectors and precision limits on measurements (e.g., total station survey error).

Accuracy of field samples is ensured by testing using a field comparison from 2007 and through the use of experienced field staff and standardized protocols and equipment. The difference between field measurements using these methods and through highly accurate survey methods (professional survey grade mapping) was also quantified as part of the 2012 and 2013 re-survey programs as part of the Columbia Habitat Monitoring Program. These studies supported the repeatability of these field methods in terms of providing accurate results. In addition, staff follow written protocols, and the condition of the equipment is evaluated prior to field sampling to ensure it is in proper working condition.

Representativeness is ensured by randomly selecting projects to be sampled from the pool of potential projects funded in that category. A sample size of 10 projects was determined, using a power analysis, to have an 80 percent probability of detecting results for a large number of the metrics tested. In addition, at each sample site, systematic sampling at transects helps to ensure that data collected is representative of the reach and unbiased.

Completeness is ensured both during data collection and as part of the data uploading process. Portions of the digital data sheet requiring an entry will display a warning if left blank, prompting the surveyor to complete the form before proceeding to the next form. In addition, warnings are provided if values are outside of the expected range of sample values. Finally, a data manager reviews all of the data submitted, and identifies any issues with data that are then sent back to the field crew to address during the field season.

Comparability of this program with other programs in the region is high. Our participation in the Pacific Northwest Aquatic Monitoring Partnership has helped leverage the protocols from this and other programs to bring together data collection methods across the region. Programs in Oregon, the Upper Columbia Region in Washington, and across the Columbia Basin use similar protocols that have been adapted from the Washington Project Effectiveness Monitoring Program. Data from these programs have been combined for a more effective analysis.

Data Analysis Methods

Data analysis methods include standard procedures that are used across all project categories. These procedures detect change in metrics over time as compared to a control, as well as fish-specific analysis methods, that support further investigation into how fish are utilizing restoration projects in relation to various habitat elements.

Data from each restoration category are the summary of projects sampled within that category and are intended to provide a look at the "average" effectiveness of a given project type. They provide a basis for some comparison between project types. Each project category has several metrics and those metrics change at different rates through time. Three different analysis methods were used to accommodate different rates of change in order to detect differences between the pre- and post-project conditions, as well as to examine the trend, or slope, of those changes through time.

The evaluation of results at each site was conducted to compare (subtract) the change at the control reach from change in the impact reach. By removing the control reach, Tetra Tech hopes to reduce the effect of inter-annual variability that could affect the analysis. The following three measures of change or trend for each site were used:

1. The most recently sampled post-project year minus the baseline (pre-project) Year 0 was used as a measure of the current status.
2. The average of post-project differences minus the average of pre-project differences was used as a measure of the average project impacts over controls if the change occurs quickly.
3. The linear regression slope of the impact-control differences through time was used as a measure of total change at each site, specifically targeting changes that take place gradually through time.

The average of each summary statistic across sites were then assessed for differences from zero using a t-test or the nonparametric equivalent Wilcoxon test, depending on the distribution of the data. The non-parametric test was used if the data from a category were not normally distributed. The first test was a straightforward paired t-test, while the

Methow River juvenile Chinook parr

other two comparisons can be viewed as an extension of the paired t-test, using the slope or average difference between the pre-treatment and post treatment condition rather than the absolute difference between two years.

For each variable within each monitoring category, linear slopes and average changes for each project were estimated and evaluated for approximate normality. If the slopes differed significantly from a normal distribution (Shapiro-Wilks p-value < 0.05), a two-tailed nonparametric t-test (Wilcoxon test; alpha = 0.10) was used to assess significant trends. Otherwise, a two-tailed t-test was used. The assumptions for the t-test are that the sites represent an independent random sample from all possible sites, and that the slope estimates are approximately normally distributed. Trends are not evaluated for endpoints with data from fewer than three sites. Note that for habitat protection projects, there was no "pre-project" Year 0 sampling, so only the regression slope is estimated and tested.

Results

Results from each of the category analysis are presented below. Additional analyses across categories are also presented at the end of the section.

Fish Passage

Fish passage projects were found to remain functional for two years after project implementation, and over 80 percent of the projects met the structural design criteria that were originally set out over that two-year timeframe. Both juvenile and adult fish were observed above all barriers monitored, although the numbers of fish at some sites were minimal. Due to these low numbers, only coho juveniles were observed to have a significant increase using the slope method, indicating a gradual increase through time above the repaired barriers (Figure 2). Spawning data were collected for a single species at each project due to the length of time over which multiple species spawn. Of the nine projects sampled, two to three projects were sampled for each species. Although adults were observed above the fish passage projects in all cases, the difference between the treated reaches before and after treatment was not significant (Table 2).

Table 2. Analysis results for fish passage projects

Analysis Method	Significant Metrics
Current minus baseline	None
Average difference	None
Slope difference	Juvenile coho density

Instream Structures

Instream habitat projects have been consistently effective at improving aquatic habitat in rivers and streams. Most projects are targeted at increasing pool habitat, channel

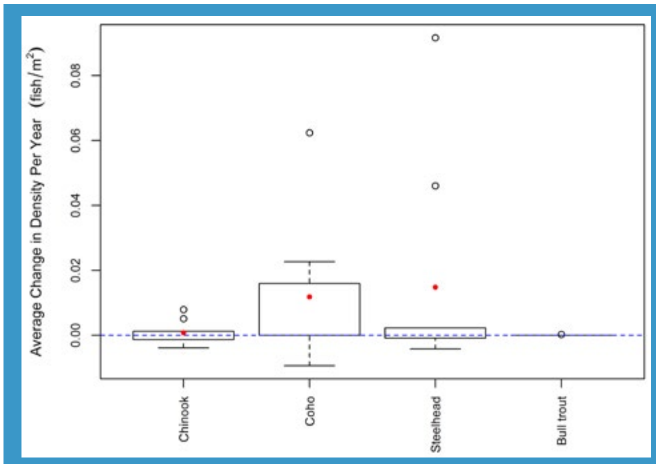


Figure 2. Juvenile densities at fish passage projects compared to controls

complexity, and cover elements in active channels and floodplain areas. Pool area, pool depth, and the amount of wood in rivers and streams significantly increased as a direct result of projects (see Figures 3 through 6 and Table 3, next page). Structures placed as part of instream habitat projects have largely remained in place and functional over a five-year monitoring period. After five years, 13 of 15 projects retained over 80 percent of placed pieces in a functional position. Two projects did not remain functional over that time period. One project was built in a depositional side channel, and although the structures remained in place, they were buried by extensive deposits of sand (see Figure 7). At the other project, a major channel avulsion redirected flow to the other side of the river, leaving a third of the placed structures segregated from the flow of the river. Although the area is occasionally activated during extremely high flows, fish are unable to access the structures during the majority of flows.

Even though physical habitat improved at instream habitat projects, no significant responses for fish species were detected. Positive trends were seen for coho and steelhead; however, Chinook showed a negative response over five years of monitoring (Figure 8). Chinook also showed a negative trend when compared to volume of LWD at restoration sites. As such, the following additional questions naturally arise:

- Are we building the right habitat for fish (specifically for juvenile Chinook)?
- Are we monitoring the right habitat metrics?
- Are we building habitat of sufficient quality—meeting cover, complexity, velocity, and depth requirements?
- Are we restoring enough habitat to make a difference?

Additional monitoring of instream habitat projects funded through the SRFB as well as through BPA and the UCSRB will help contribute toward answering these questions.

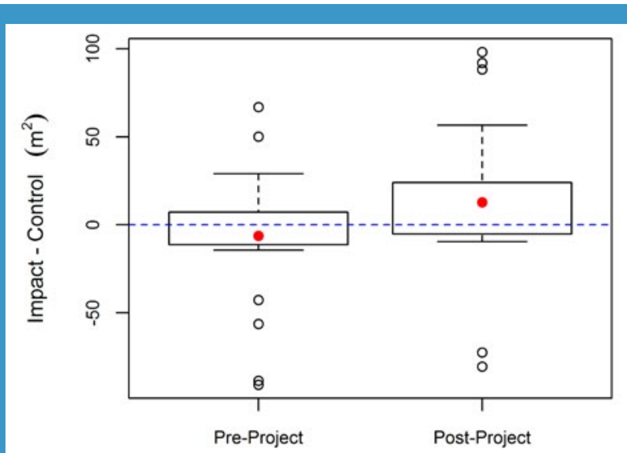


Figure 3. Linear cross-sectional pool area

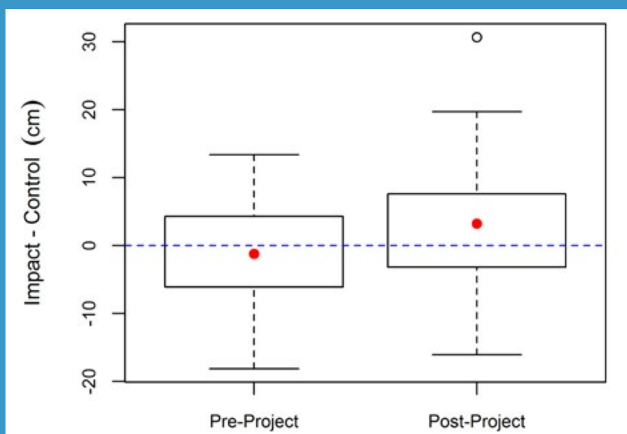


Figure 4. Residual pool depth

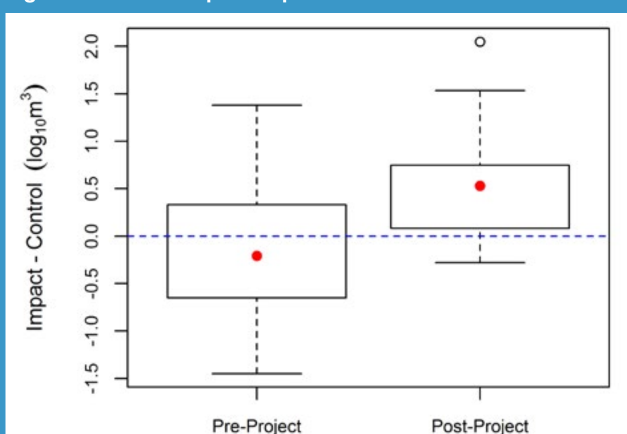


Figure 5. Large wood volume

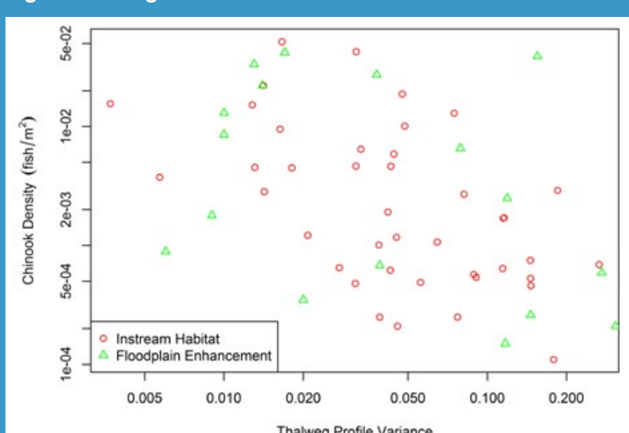


Figure 8. Floodplain enhancement and instream habitat projects: Thalweg Variance vs. Chinook Density

Table 3. Summary of significant results for instream structure projects

Analysis Method	Significant Metrics
Current minus baseline	Areasum, RP100, Logv10
Average difference	Areasum, RP100, Logv10
Slope difference	Areasum, RP100, Logv10

Figure 6. Large woody debris jam and pool at Cedar Rapids prior to channel avulsion

Figure 7. Edgewater Park looking down dry channel in Year 10 (2014). This side channel and wood placement project was buried in sediment deposited by the Skagit River.

Riparian Planting

Riparian planting projects implemented by the SRFB have effectively increased the percent of woody cover, and over 90 percent of the projects have met the 50-percent survival target over a five-year monitoring period. One project did not meet the survival target due to the fact plantings were mowed down after installation (see photo below). Another project did not meet the survival target due to challenging planting conditions (planting in cobble substrate). Stream shading and riparian structure have not been shown to increase significantly, but are showing positive trends. Bank erosion has also not decreased significantly in the projects monitored.

Riparian vegetation structure requires three layers of vegetative canopy, one of which is overstory, defined as being taller than 15 meters. The 10-year time frame for monitoring may not be long enough for most species to grow more than 15 meters tall. Growth rates of species as documented by the Conservation Reserve Enhancement Program (CREP) program show annual growth rates from 10.6 inches to 29.3 inches per year. The 2012 CREP monitoring report included growth rates for 6 years of monitoring. On the east side of Washington, average deciduous and conifer tree growth was 0.8 feet per year, while on the west side, average deciduous tree growth was around 2.3 feet per year and average conifer growth was around 1 foot per year (Smith 2012). At these growth rates, it would take around 45 years, on average, for trees to reach 15 meters in eastern Washington and around 20 years on the west side.

However, this monitoring was of very young plantings and therefore, one should probably look at some older sites for average height after 15 or 20 years. The forest service estimates that red alder can grow to 30 feet in five years, and 52 feet in 10 years (Burns and Honkala 1990). Another approach would be to set up an extensive post treatment study with planted areas of various ages to see what type of results are achieved. That would help better target the return interval using empirical data.

Even with the highest growth rates, the 15-meter target would be difficult to achieve in 10 years. Figure 9 shows photos of the 5-year time span showing tree growth. Additional evaluation of riparian planting sites is planned through the BPA monitoring program. These projects will be monitored over a range of time periods after implementation and will help to address the questions of time required to meet those minimum height requirements. In 2015, five additional projects in the SRFB program will be monitored for 10 years after implementation which may also help address these questions. The means and distributions for values for each metric are illustrated in Figure 10. Table 4 lists the responses from riparian planting projects.

Table 4. Summary of responses from riparian planting projects

Analysis Method	Significant Metrics
Current minus baseline	Woody cover
Average difference	None, woody cover not tested
Slope method	Woody cover

Centralia riparian, showing field where plantings were mowed down

Figure 9. Salmon/Snow Creek riparian planting in Year 1 (2006) (left) and Year 5 (2010) (right) showing tree growth over that period

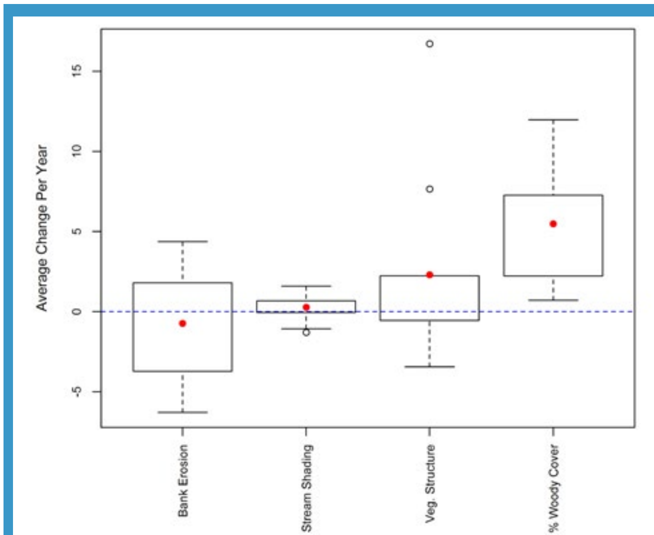


Figure 10. Metric responses at riparian planting projects relative to controls

Livestock Exclusion Projects

Livestock exclusion projects have proven to be highly effective at reducing bank erosion and have shown significant increases over five years in canopy cover using two of the three analysis methods. Reduction of bank erosion is generally seen in the first two years after implementation as herbaceous plants recolonize trampled banks. Figure 11 shows photos of the five-year growth of herbaceous plants. There have been instances, however, where fence maintenance has been an issue, or where downcutting in the stream continued to erode the banks. Of 12 projects monitored over five years, eight (67 percent) maintained all levels of function – no breaks in fences, no need for additional maintenance, and no sign of livestock entry. This result is below the target of 80 percent of projects remaining functional over 10 years. Since those projects that remain intact are highly successful in achieving improvements to habitat, this is more an issue of correct project implementation and maintenance versus that of effectiveness. Riparian vegetation structure is one of the measured metrics that has not shown change for this category. This result is likely due to insufficient monitoring time for canopy heights to be achieved – a similar result to that seen for riparian planting projects. Table 5 lists the responses from livestock exclusion projects.

Figure 11. Johnson Creek at bottom of site looking upstream in Year 0 (left) and Year 5 (right) showing reduction of erosion due to plant growth

Table 5. Summary of responses from livestock exclusion projects

Analysis Method	Significant Metrics
Current minus baseline	Bank erosion, canopy cover
Average difference	Bank erosion
Slope method	Bank erosion, canopy cover

Floodplain Enhancement Projects

Floodplain enhancement projects have shown a high level of promise in delivering not just physical changes in habitat, but a measurable biological response to project actions as well. Physical responses in canopy cover, channel dimension, and available off-channel habitat have been documented, as well as notable increases in use by both juvenile Chinook and coho salmon. This result is in contrast to the lack of positive results detected in the instream habitat projects. Five of 10 metrics in the category have shown improvement by five years after implementation when baseline conditions are subtracted out. The study period for this project type is planned to be 10 years to allow adequate time for high flows to engage with the new projects. Floodplain and instream habitat projects have comparable outcomes in terms of increasing pool area and depth, yet the fish response is much greater for Chinook juveniles in floodplain projects (see Figures 12a and 12b). This result indicates that the amount of pool habitat may not be the best predictor of fish response, especially for Chinook salmon juveniles. Other metrics such as the availability of edge habitat may be more likely to show a correlation with juvenile Chinook densities and level of use. Table 6 lists the responses from floodplain enhancement projects.

Table 6. Summary of responses from floodplain enhancement projects

Analysis Method	Significant Metrics
Current minus baseline	Canopy cover, bankfull width, floodprone width, juvenile Chinook, juvenile coho
Average difference	Canopy cover, floodprone width, juvenile Chinook, juvenile coho
Slope method	Bankfull width, floodprone width, juvenile Chinook

Connectivity through time is another element that is measured in the evaluation of floodplain enhancement projects. Of nine projects that included creation of, or reconnection with, off-channel habitat, three did not remain connected through time and were substantially disconnected within the first two years after construction. In all of these projects, deposition of fine sediment in the first two years led to disconnection and reduced flow during the low flow season (see photo at right). Two projects go dry during the summer season despite being designed for year-round use by juvenile salmon. Better understanding of sediment transport velocities necessary to keep channels open should therefore be included in project design.

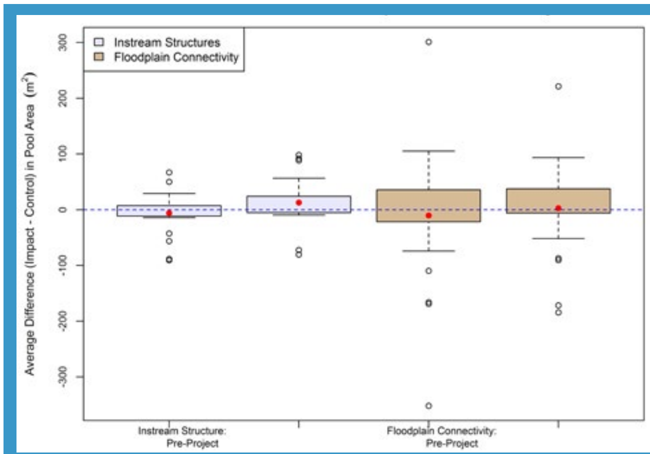


Figure 12a. Change in pool area for instream structure and floodplain enhancement projects

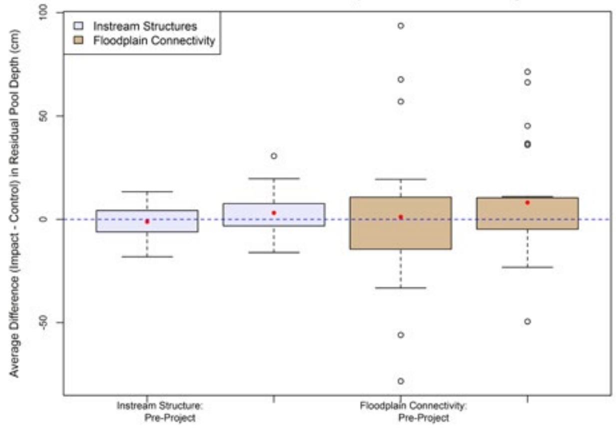


Figure 12b. Change in residual pool depth for instream structure and floodplain enhancement projects

Riverview Park dry channel in July 2014 showing disconnection of off-channel habitat following construction

Additionally, reconnection of side channels and creation of new side channels should be re-evaluated in terms of the overall expected life span of these projects and the fact many become disconnected within five years of construction.

Sediment transport in off-channel areas is governed by a balance of flow and the sediment load in the system (illustrated in Lane's Relationship balance, Figure 13). Understanding the dynamics at high flows that lead to deposition of sediment in off channel areas is critical to implementation of side channel creation projects. Integration of natural processes of erosion and deposition in design should include a sediment budget and careful hydraulic analysis to evaluate the capacity of the system for deposition in these areas. Monitoring of changes in elevation provides feedback as to whether systems are depositing material in off-channel habitats, and the expected life span of these areas.

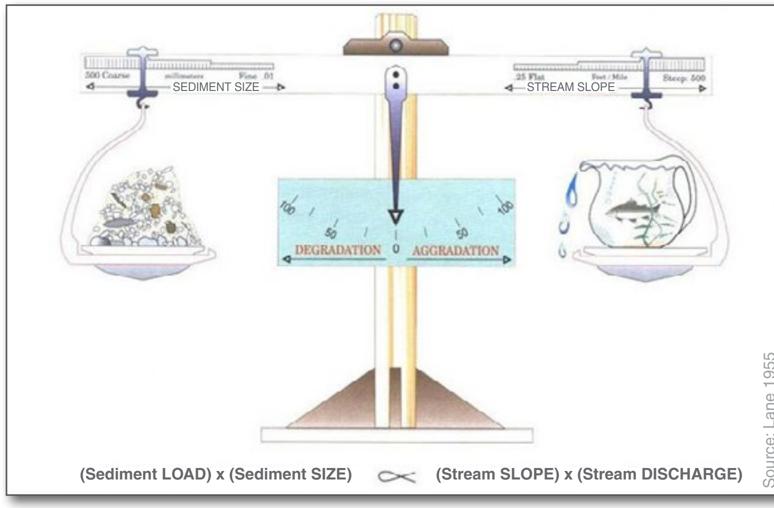


Figure 13. Lane's Relationship

Habitat Protection Projects

Habitat protection projects are monitored to measure changes in ecological health through time, and as a result, involve more metrics than other types of projects. Protection projects often include both riparian and upland habitat, and as such, include protocols for measuring terrestrial vegetation health as well as riparian and instream conditions. Questions being posed include "Does the habitat quality at this parcel rate highly as compared to standard indices of ecological health?" and "Is the habitat quality at this parcel maintaining or improving through time?" Most metrics have shown little change during the monitoring period from 2004 through 2014. A significant decrease in the basal area of deciduous vegetation has been observed, indicating maturation of forests due to the fact that conifers are the dominant species in mature PNW forests (Waring 1979). In addition, conifer basal area is increasing and stem count is decreasing, indicating an increase in the maturity of the surrounding forests at these sites. Invasive species are also decreasing as measured by both the relative and absolute cover of herbaceous species (Table 7).

Table 7. Summary of significant responses to habitat protection metrics

Analysis Method	Significant Metrics
Slope method	Basal area of conifers (increase) Conifer stem count (decrease) Basal area of deciduous (decrease) Absolute area of herbaceous non-native veg (decrease) Relative area of herbaceous non-native (decrease) IBI (decrease) Mebane index (decrease)

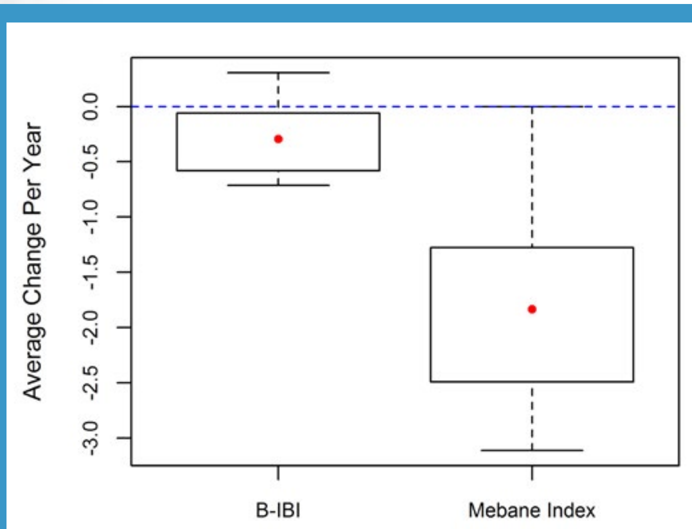


Figure 14. Average annual change in Index of Biotic integrity (IBI) and Mebane Fish Index over monitoring period. Y-axis shows annual decreases in index values indicating gradual reduction in aquatic ecological health.

Results from habitat protection monitoring indicate that while terrestrial habitat is improving in terms of tree growth and reductions in invasive species, the condition of aquatic communities in these areas is slowly decreasing. Decreases over time for both the macroinvertebrate index and the fish index designed to measure ecological health identify a disturbing trend in habitats identified as the highest quality and worthy of protection (see Figure 14). For the majority of instream habitat metrics, there has been no change over an eight-year study, indicating that the decrease in biological health indicators may be a more widespread problem in the watershed. Comparison with trends in watershed-scale status and trends monitoring programs should shed some light on this observation. For example, if status and trends data in the watersheds where habitat protection projects are located are showing a watershed wide decline in Benthic Index of Biotic Integrity values, then we would have evidence of a larger systemic issue in biological condition.

Similar Metrics Across Monitoring Categories

Metrics that are common across monitoring categories can also be used to test for differences in effectiveness across categories. Some of the more successful project categories we have evaluated based on significant results are livestock exclusions and floodplain enhancement projects. Both of these projects remove constraints to natural processes (e.g., levees and intense cattle grazing) and help to restore natural processes in project areas. Although at opposite ends of the scale in terms of implementation costs, both projects have been effective at achieving project goals and show a high level of promise in terms of project results and cost effectiveness. Both restoration techniques are process based. They restore watershed process rather than make direct instream habitat modifications. These results support the restoration strategy presented in the 2008 Global Review of the Physical and Biological Effectiveness of Stream Habitat Rehabilitation Techniques (Roni et al. 2008), where processes should be prioritized before instream habitat projects. The restoration strategy is presented as a flow diagram in Figure 15.

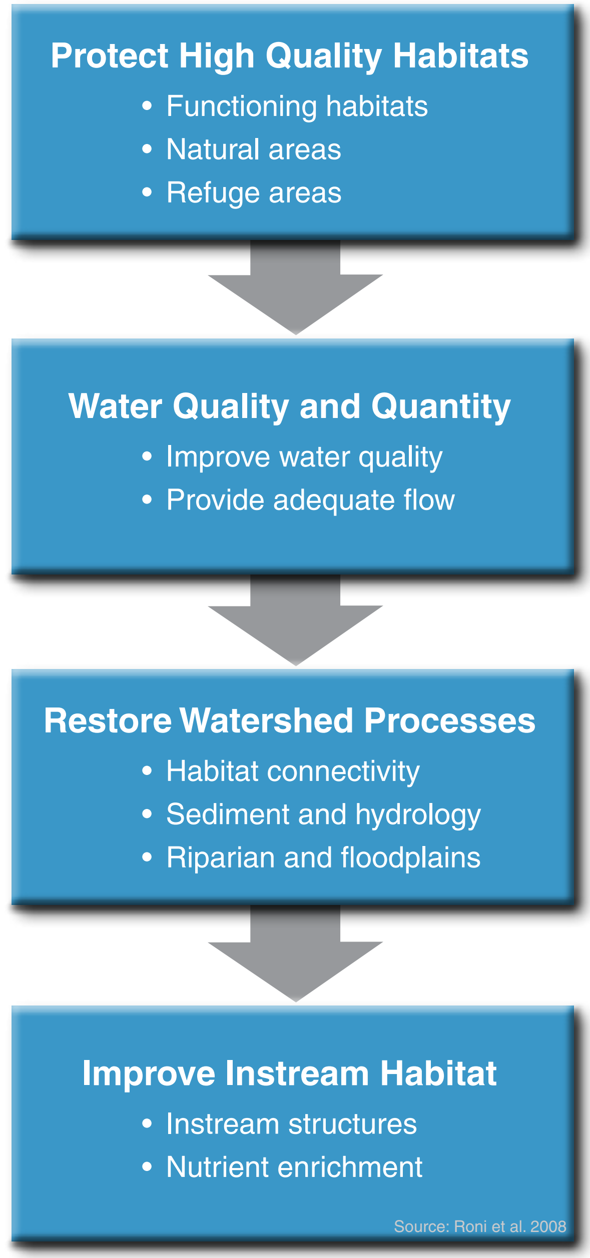


Figure 15. Proposed interim strategy for sequencing stream rehabilitation techniques prior to considering other factors (e.g., project cost, species of interest, cost-benefit ratio, economic, social, and political)

Within categories, specific construction approaches can also be compared (see Figure 16). Several construction approaches have been used in instream structure projects with varying levels of success for coho and steelhead, but very low levels of success for Chinook. Conversely, the change in Chinook use due to floodplain projects is a significant increase when compared to a control reach. A better understanding of the species-specific fish responses to changes in physical habitat can help in project selection, design, and implementation.

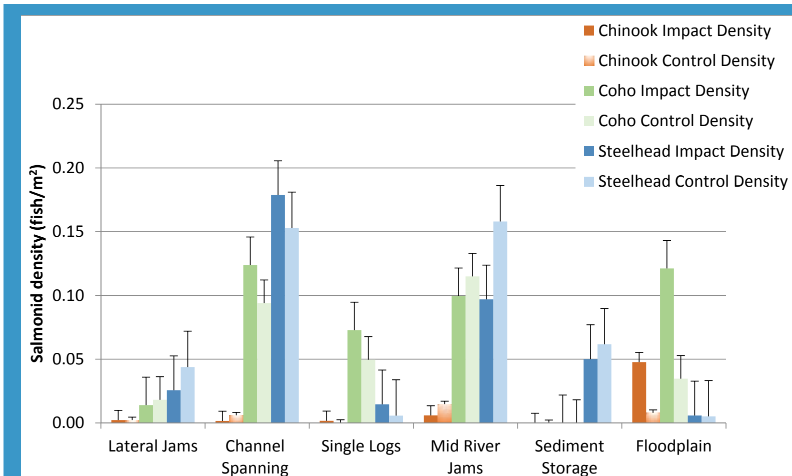


Figure 16. Post-implementation salmonid mean density by UCSRB and SRFB project type

Similarly, floodplain enhancement projects that set back levees and allow natural processes to occur are showing improved responses for

Table 8. Summary of cost effectiveness for metrics shared across monitoring categories

Metric	Average Cost	Mean Change in Metric
Canopy cover (% cover)	Riparian planting: $250,363	Riparian Planting: – 0.43
	Livestock Exclusion: $ 51,025	Livestock Exclusion: 1.36
	Floodplain Enhancement: $413,325	Floodplain Enhancement: – 3.17
Pool area (m^2)	Instream Structure: $387,944	Instream Structure: 19.04
	Floodplain Enhancement: $413,325	Floodplain Enhancement: 13.09
Pool depth (cm)	Instream Structure: $387,944	Instream Structure: 4.42
	Floodplain Enhancement: $413,325	Floodplain Enhancement: 6.90
Chinook density (fish/m^2)	Instream Structure: $387,944	Instream Structure: – 0.0025
	Floodplain Enhancement: $413,325	Floodplain Enhancement: 0.1990
Coho density (fish/m^2)	Instream Structure: $387,944	Instream Structure: – 0.0186
	Floodplain Enhancement: $413,325	Floodplain Enhancement: 0.2610

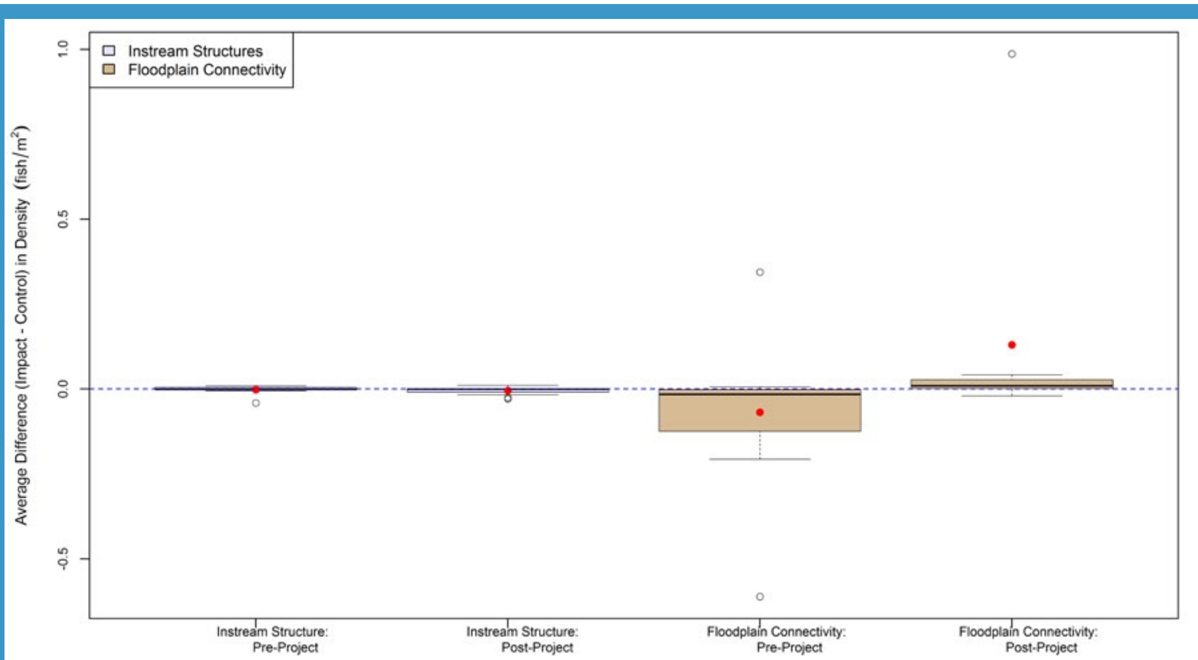


Figure 17. Change in Chinook Densities for Instream Structure and Floodplain Enhancement Projects

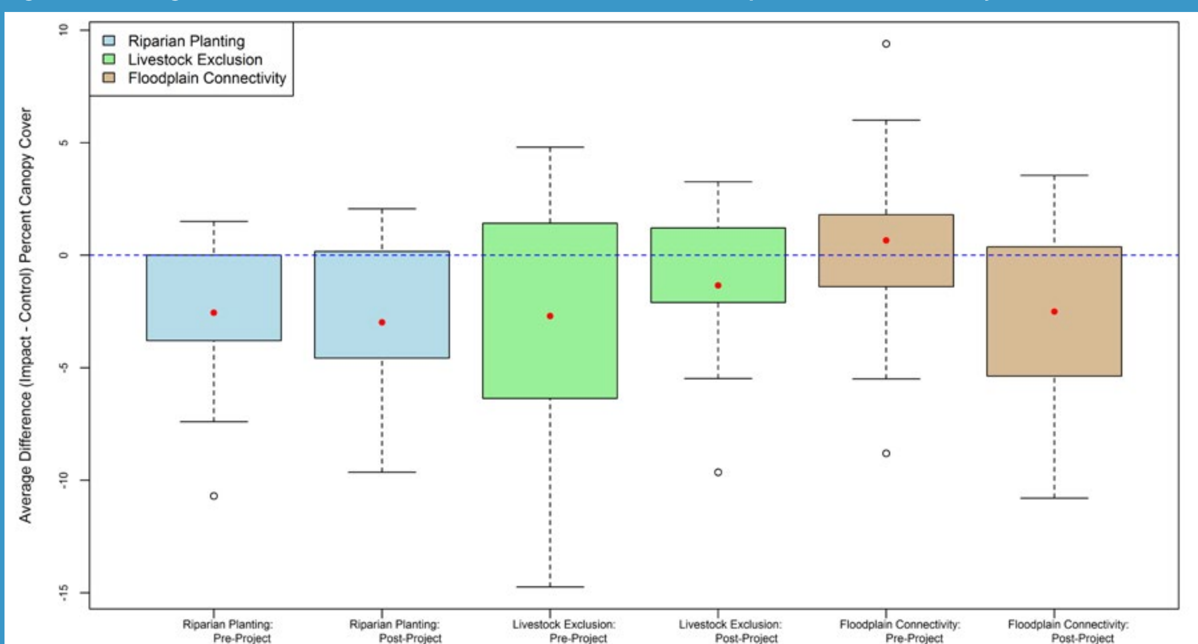


Figure 18. Change in Canopy Cover Across Project Categories

fish species, specifically for Chinook juveniles (Figure 17). A better understanding of the species specific fish responses to changes in physical habitat can help in project selection, design, and implementation.

Cost Effectiveness

Changes in metrics that are monitored using the same methods across categories can be compared to the average cost of projects in those categories to assess cost effectiveness of project efforts. The average cost of projects in each monitoring category was compared to the mean change in a given metric due to the project actions (see Table 8 and Figures 19 and 20).

Livestock exclusion projects are more cost effective at improving canopy cover than either riparian plantings or floodplain enhancement projects (Figure 18). They are also better approaches for reducing bank erosion at a lower cost. These projects are applicable only in areas where the source of riparian degradation is due to livestock use, but in those situations, the method has been found to be effective. However, maintenance of the fencing is critical to project success. These projects have a 67 percent functional rating after five years, whereas the rating for riparian plantings was over 90 percent functional for survival after three years. Lack of maintenance in fencing or livestock management practices can reduce the effectiveness of livestock exclusion projects, and these issues should be considered as part of the project funding approval in terms of project sponsor and landowner track records for follow-up maintenance.

Floodplain enhancement projects are marginally (6.5 percent) more expensive than instream structure projects, but they deliver greater results in terms of pool area, pool depth, and use by juvenile Chinook and coho. Significant increases were detected at floodplain projects for both of these species. Resource managers and decision makers can use this information in funding allocations.

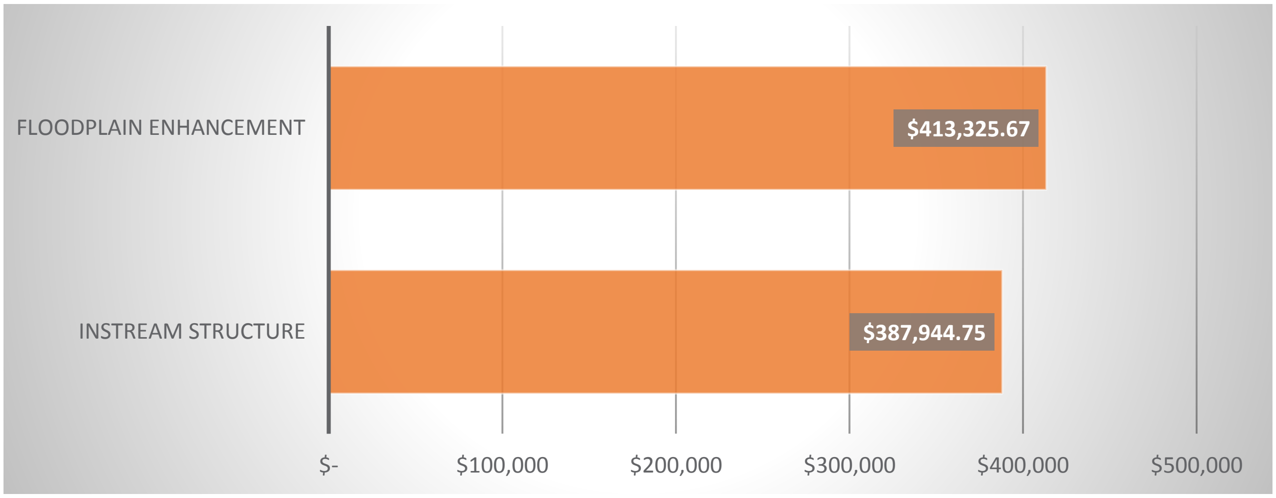


Figure 19. Average cost

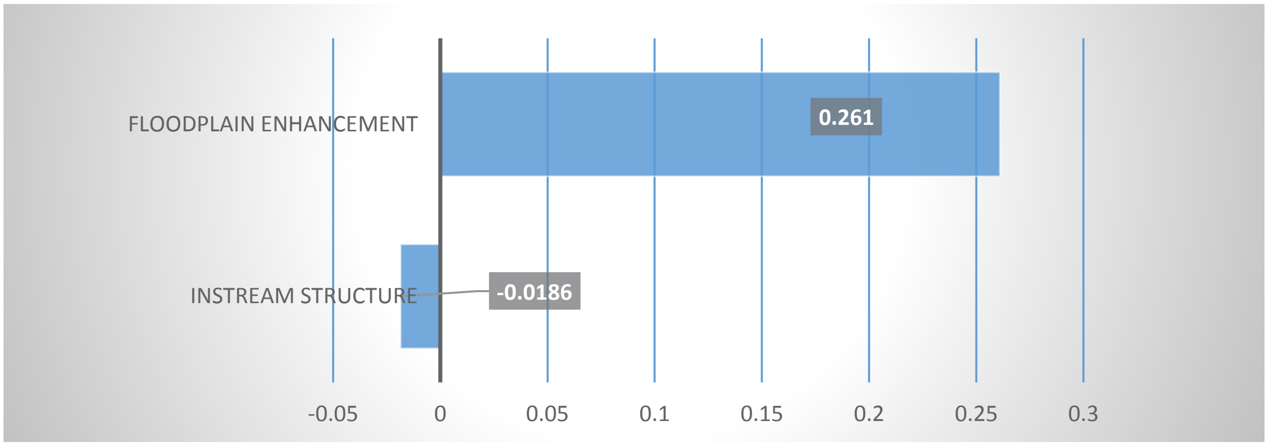
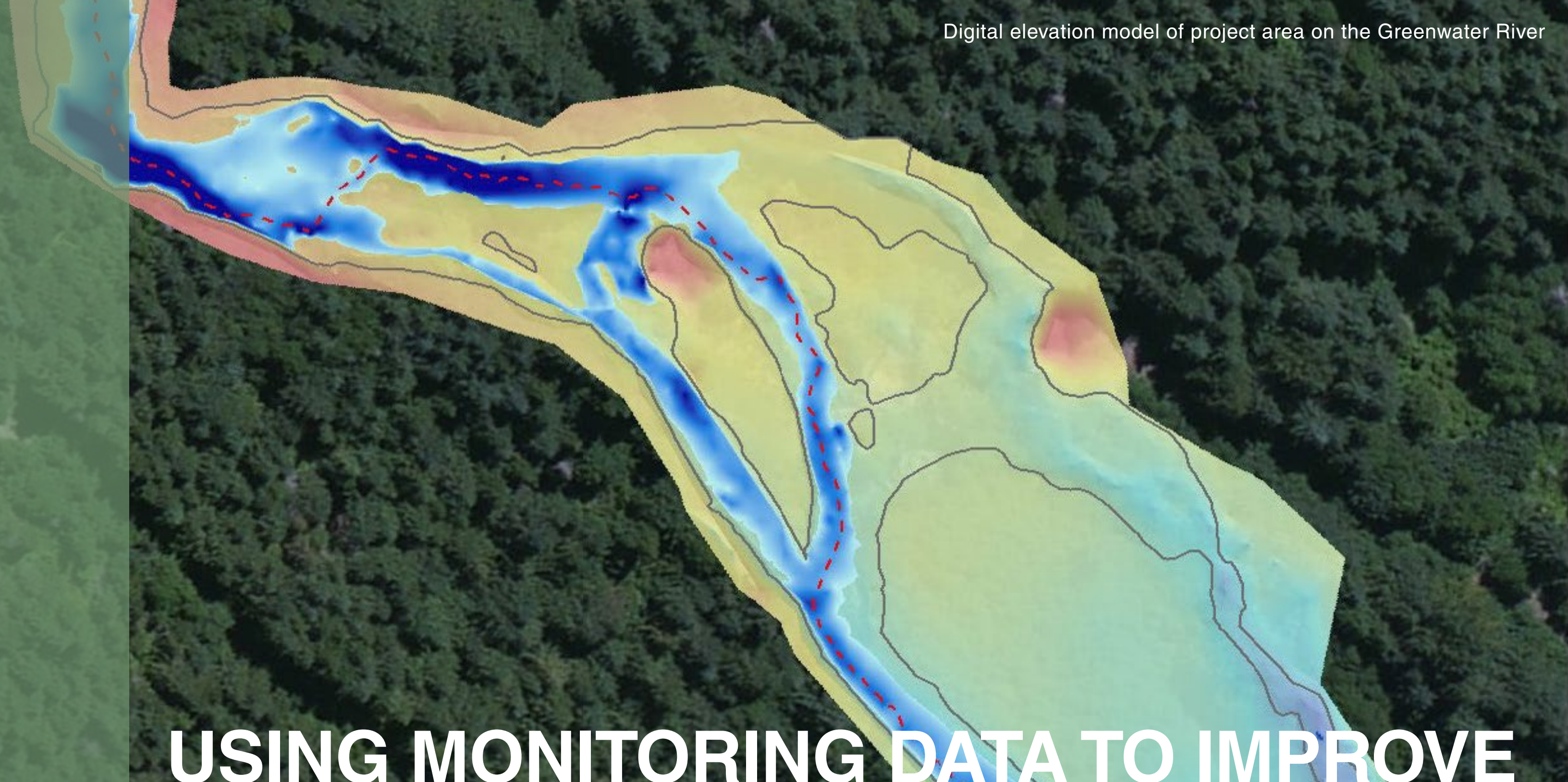


Figure 20. Change in mean density of juvenile Chinook salmon


Digital elevation model of project area on the Greenwater River

USING MONITORING DATA TO IMPROVE PROJECT DESIGN CRITERIA:

GEOMORPHIC CHANGE DETECTION AND HABITAT SUITABILITY MONITORING

Monitoring data and design input information have historically been collected at different times by different groups. Availability and use of site-specific monitoring data in project design processes has been limited at best. Improvements in monitoring technology as part of the Washington Project Effectiveness Program have resulted in a coalescing of methods used for both monitoring and flow analysis for design, whereby data can be shared across efforts and across disciplines. Information gained through monitoring can be fed back into design criteria to improve the performance of current designs and future projects.

Project monitoring for instream habitat and floodplain enhancement projects includes a method adopted from the Columbia Habitat Monitoring Program (CHaMP) for conducting a topographic survey to measure changes in channel topography and geomorphology. Using the topographic survey data, a digital elevation model (DEM) is developed using geographic information system (GIS) software. The DEM is then used to track the changes in channel and floodplain topography over time.

By comparing DEMs, across–years, changes in available habitat can be quantified, allowing the levels of floodplain reconnection and channel scour to be measured. The topographic survey also allows the calculation of channel and habitat conditions such as pool area and depth, areas of off-channel habitat, and ratio of side channel to mainstem channel length that can be tracked over time. Under this method, the DEM is uploaded into the River Bathymetry Toolkit (RBT), a software package used to analyze the data, produce summary statistics, and automate calculations of summary statistics from the DEM.

Using the DEM from the topographic survey and the RBT, category-specific response variables for both instream habitat and floodplain enhancement categories can be evaluated. The RBT has been designed to calculate pool metrics shared by both monitoring categories—the *mean residual pool vertical profile area* and the *mean residual pool depth*, as well as the floodplain metric—the *average bankfull channel capacity*.

web:
Detailed descriptions of how the RBT calculates the response variables can be found at:
https://sites.google.com/a/northarrowresearch.com/rbt-for-emap/documentation/metric-calculations

Beyond the RBT analysis, the topographic surface of the channel and surrounding floodplain of the DEM allow more flexibility in data analysis and information output. The DEM can serve as input into various models, such as hydraulic models, to determine channel response under different flow conditions. Geomorphic change across the entire monitoring reach through time can also be calculated, which is particularly useful for assessing project-specific goals.

By comparing the elevation differences in the DEMs, both localized geomorphic response, such as pool scour that may be expected from the installation of an engineered log jam (ELJ), and reach scale response, such as the response of removing a levee, can be explicitly quantified and evaluated. The next section provides a description of the geomorphic change methodology.

Geomorphic Change Detection

Geomorphic Change Detection (GCD) is based on DEMs from the topographic survey and tracks erosion and deposition at monitoring sites by comparing successive surveys through time. To perform GCD, the DEM from one year is subtracted from the DEM of the previous year's survey to assess changes in the topography in terms of area, location, and amount of deposition or erosion. The resulting DEM, which shows the elevation changes between surveys, is called the DEM of Difference (DoD). The DoD is analyzed to calculate the total area and volume of erosion and deposition at a site, providing an overall sediment budget indicating whether the site has a net gain or loss of sediment. The changes are also geospatially linked, so the DoD also provides a visual representation of where the erosion and deposition are occurring. The locations of erosion and deposition at a site can help inform how a site is changing in response to restoration actions. For example, the local response of LWD placement can be tracked to determine if erosion is occurring around the wood placement. The efficacy of the restoration treatment through time can also be evaluated to determine whether the pool caused by scour of the LWD (for example) remains over a span of years, or if it fills in with sediment. Performing GCD is also an effective tool for monitoring floodplain restoration, such as reconnecting or creating side channels. Monitoring the sediment dynamics of the reconnected or created side channel is a way to determine if the side channel remains connected or if it becomes blocked or filled with sediment and, in the latter case, the length of time of the filling.

Specific feedback on the geomorphic function of a restoration project is useful for informing project implementers and designers on how their project or restoration design held up through time. An as-built survey is often performed immediately after restoration has been completed, but it only informs how the project was built compared to the restoration design and the level of function immediately after construction. By performing successive topographic surveys throughout the 10-year monitoring cycle prescribed by the SRFB, the performance of the project can be tracked over a longer time period. This longer surveying of a stream's response to a restoration action through GCD analyses provides valuable information on the duration and degree of benefit from restoration actions. For example, the results of GCD can inform a practitioner if the LWD placement actually resulted in the pool development it was designed for, as well as the length of time that pool was maintained.

web: **More information on the GCD software can be found at:**
http://gcd.joewheaton.org

The GCD process is facilitated using GCD software developed by Utah State University and North Arrow Research. The GCD software performs the DEM subtractions and automatically calculates the quantities of erosion and deposition. An elevation threshold can be applied to the DoDs which filters out all the elevation changes below a set threshold. The threshold enables us to account for the level of precision in the data collection methodology and filter out results that are beyond the resolution and accuracy of the methods, thereby reducing error in interpretations of the data. The threshold is customizable and can be set from something as simple as a constant elevation, such as 0.1 meter, or a more complex threshold that utilizes topographic point density, slope, and the accuracy of the instrument used to collect the data. GCD results for George, Reecer, and South Fork Asotin creeks, the Pioneer side channel, and Riverview Park (Figure 21) are shown on the following pages. These figures identify the locations of erosion and deposition between survey years.

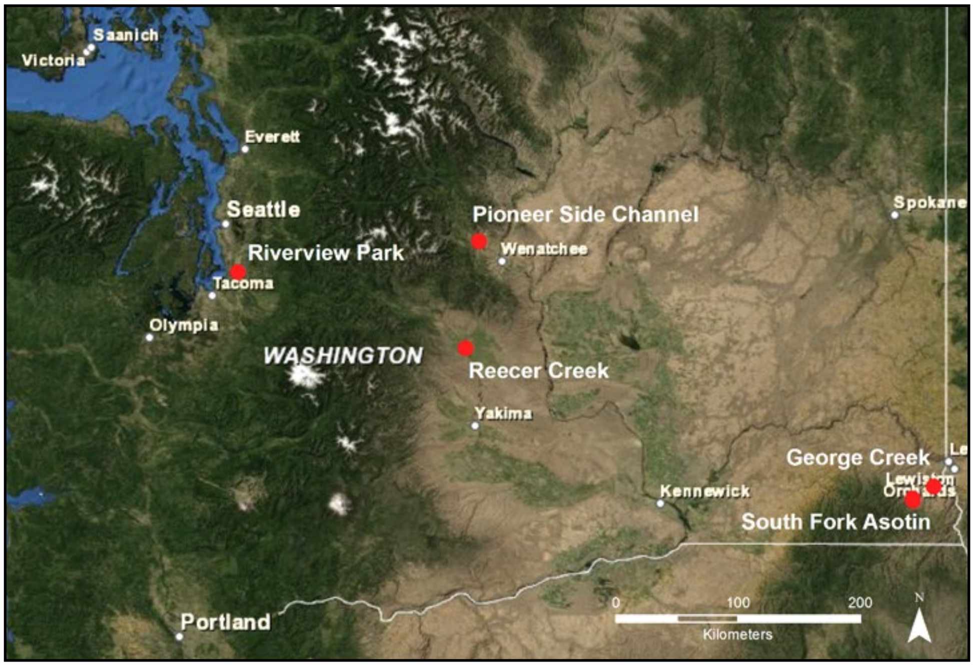


Figure 21. Location map of project sites selected for habitat modeling

Total Volume of Erosion (m^3)	462
Total Volume of Deposition (m^3)	379
Total Volume of Difference (m^3)	841
Total **Net** Volume Difference (m^3)	**-82**

GEORGE CREEK

CHANGE DETECTION

George Creek is a channel remeander and LWD placement project in the Snake River Recovery region in Asotin County, WA.

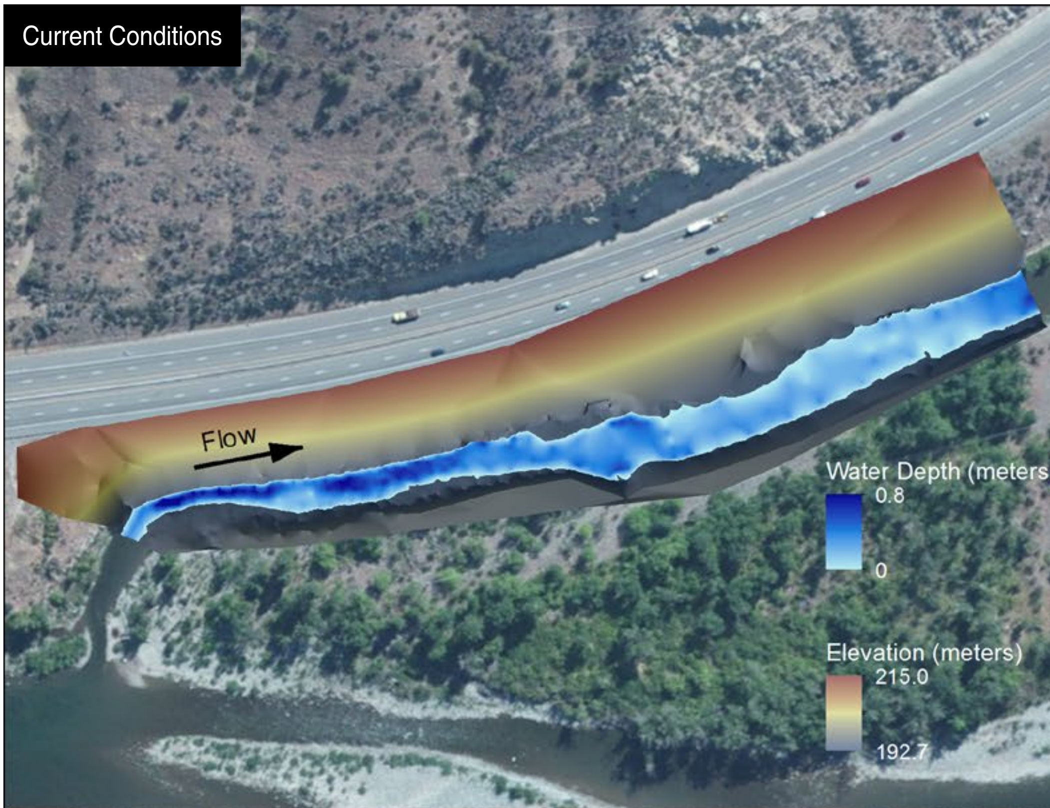
Project goals include increasing pool habitat, sinuosity, floodplain connectivity and LWD density, and improving riparian vegetation cover and flows at the downstream end of the project to reduce dewatering during summer.

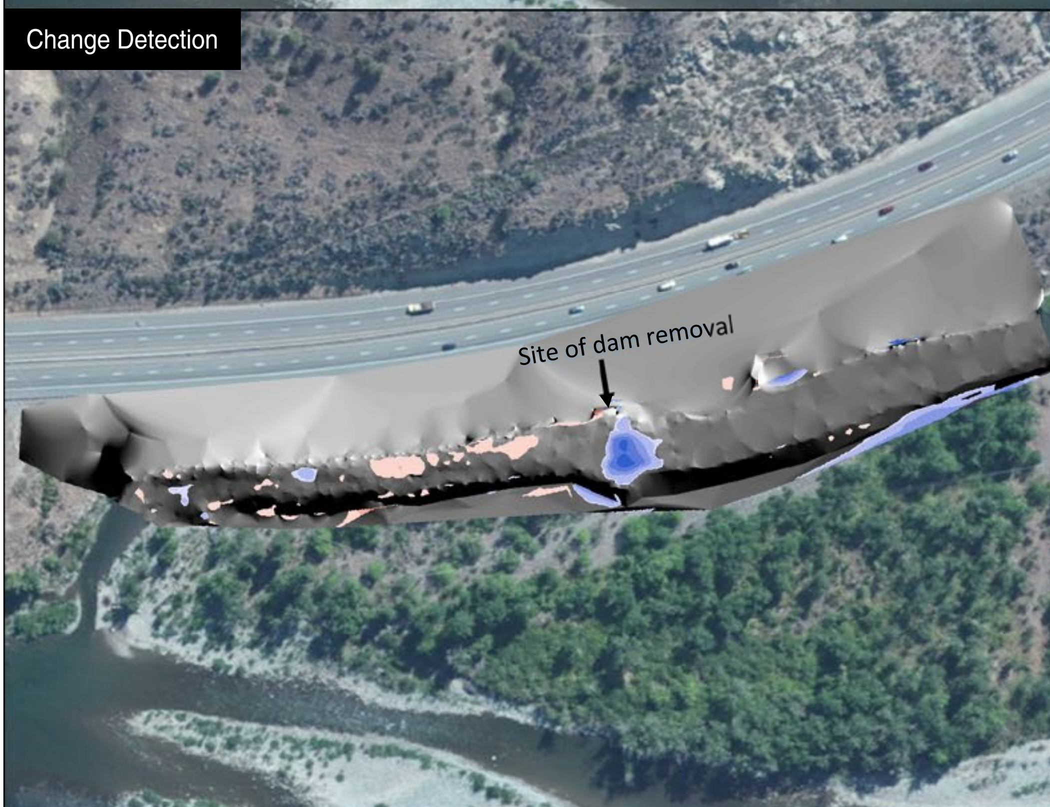
Results from one year after restoration show a large area of erosion where the new channel was created. Deposition occurred where LWD jams were placed in the old channel, near the inlet and outlet of the new channel.

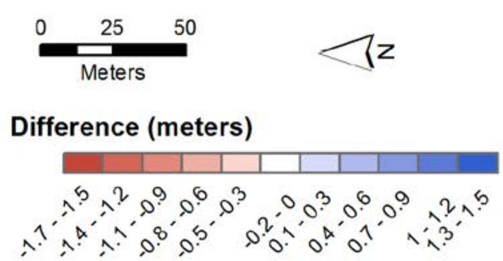
The source of erosion north of the channel is unknown, but was probably related to earth moving during the restoration work.

The LWD were placed near the inlet and the outlet to maintain the connection with the new channel.

Monitoring the new channel and LWD placements will track how well the new channel is maintained, and how the LWD functions through time.







Total Volume of Erosion (m^3)	145
Total Volume of Deposition (m^3)	457
Total Volume of Difference (m^3)	602
Total **Net** Volume Difference (m^3)	**312**

PIONEER SIDE CHANNEL

CHANGE DETECTION

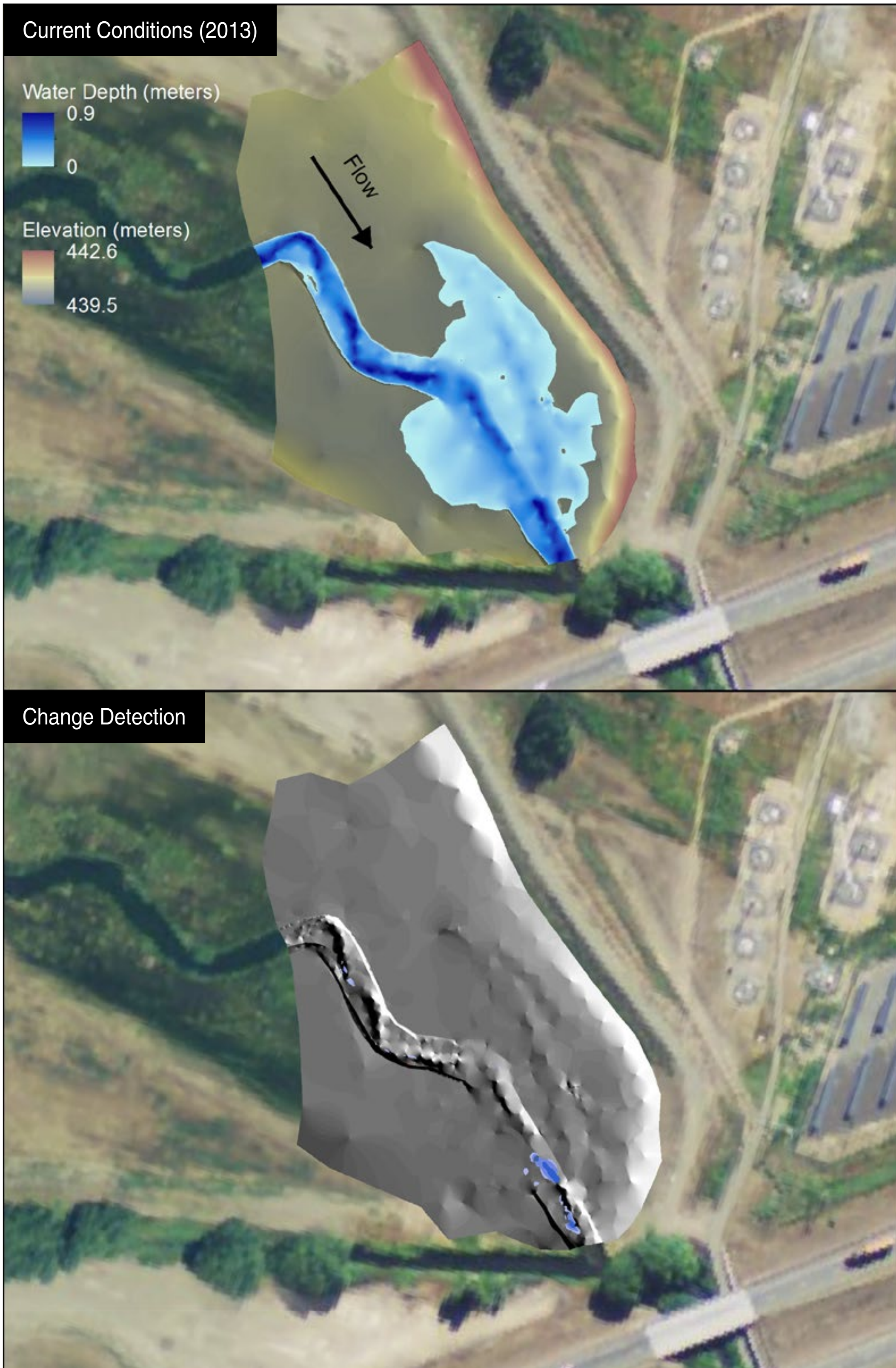
Pioneer Side Channel is a dam removal project in the Upper Columbia Recovery Region on a side channel of the Wenatchee River near Cashmere, WA.

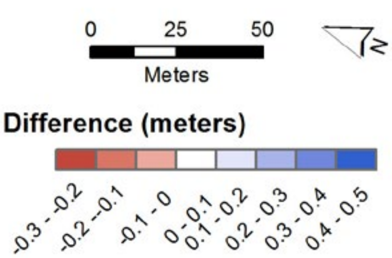
Project goals are to increase stream flow back to the Wenatchee River, and improve fish access and movement through the side channel.

Results from two years after restoration compared to right after dam removal show geomorphic changes that are likely the direct result of the dam being removed. Juvenile salmonid densities are higher both one and two years after restoration than before restoration.

The pool area below the dam is filling in. The pool filling was expected, since the pool was originally created by the flow of water over the dam. The scouring action of water flowing over the dam is stopped, the pool is no longer maintained, and will fill in from the sediment formally stored behind the dam.

There are also areas of erosion upstream of dam, likely the result of reworking of sediment that was trapped in reservoir behind dam.





Total Volume of Erosion (m^3)	0.1
Total Volume of Deposition (m^3)	30.5
Total Volume of Difference (m^3)	30.6
Total **Net** Volume Difference (m^3)	**30.4**

REECER CREEK

CHANGE DETECTION

Reecer Creek is a channel relocation and remeander project in the Middle Columbia Recovery Region in the town of Ellensburg, WA.

Project goals include reconnecting the floodplain and dissipating flood energy, increasing channel length and complexity, and installation of log structures to add fish habitat and aid in channel stabilization.

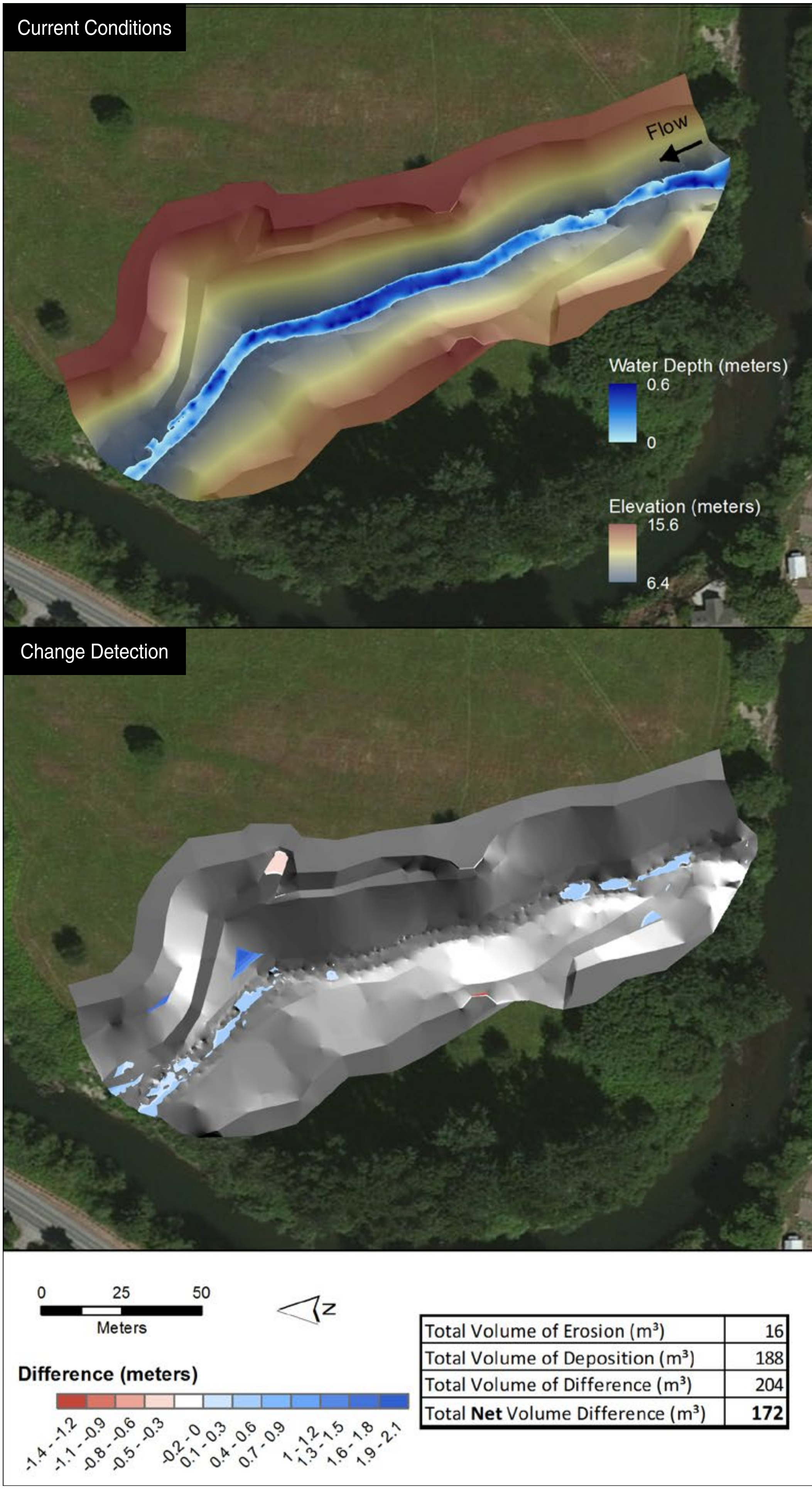
Results from three years after restoration compared to right after construction show a mostly stable channel, with deposition along the thalweg in channel in the bottom 1/3 of the site, a small area of deposition along the thalweg near the top of the site, and virtually no erosion.

The deposition led to flood flows beyond the banks of the channel. The stream can now easily engage the floodplain, as illustrated by the water spread out in the middle of the site.

The project is in a low gradient (0.22% water surface slope) section before the confluence with Yakima River, so continued deposition would not be surprising.

RIVERVIEW PARK

CHANGE DETECTION



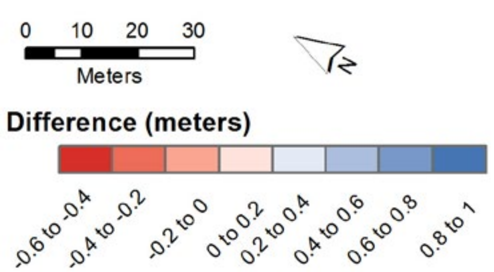
Total Volume of Erosion (m^3)	16
Total Volume of Deposition (m^3)	188
Total Volume of Difference (m^3)	204
Total **Net** Volume Difference (m^3)	**172**

Riverview Park is a side channel creation project in the Puget Sound Recovery Region on the Green River in Kent, WA.

Project goals included creating off-channel habitat for summer rearing, high flow refuge, and channel connection 90% of the year.

Results from two years after restoration compared to just after construction show there was deposition throughout the channel, especially near the inlet and outlet of the channel. Deposition throughout the channel indicates the side channel is filling and losing connection to the mainstem of river, thereby reducing the functionality of the side channel.

If the depositional trend continues, the side channel will eventually become disconnected from the river, no longer providing off channel habitat for salmonids. The U.S. Army Corps of Engineers re-excavated the inlet of the side channel in September 2014. Without the re-excavation, the inlet would have more deposition, and the channel would be less connected.



Total Volume of Erosion (^{3})	9
Total Volume of Deposition (^{3})	39
Total Volume of Difference (^{3})	48
Total Net Volume Difference (^{3})	**30**

SOUTH FORK ASOTIN CREEK

CHANGE DETECTION

South Fork Asotin Creek is a site from an Intensively Monitored Watershed (IMW) in the Snake River Recovery Region on Asotin Creek in Asotin County, WA.

The IMW restoration placed numerous low cost wood structures (50 structures per kilometer) designed to constrict streamflow and encourage pool and bar development.

Results from one year after restoration show little change thus far, and the change occurred mostly along the banks, not in the stream channel. Low levels of change indicate minimal engagement of wood structures thus far, although peak stream flows between Year 1 and Year 0 were lower than normal in Asotin Creek, so a lack significant change is not surprising.

The change between Year 3 and Year 1 will be more telling of how well the log structures work, and hopefully higher stream flows will occur as well.

Hydraulic Modeling

To relate topographic data directly to design considerations, hydraulic models were constructed to analyze flow depths and velocities for 10 projects. The topographic data used for modeling was created by combining field survey topographic data and light detection and ranging (LiDAR) data (in the floodplain) whenever possible. Topographic data were generated in ArcGIS and brought into AutoCAD Civil 3D software to extract cross-sections for modeling in HEC-RAS (the Hydrologic Engineering Center river analysis system), a one-dimensional hydraulic model developed by the U.S. Army Corps of Engineers (USACE 2010). Field survey data including the location of features such as the thalweg, bankfull stage, and the edge of water at the time of survey were used to develop and calibrate the model.

Three flow levels—the flow at the time of survey, the bankfull flow, and the two-year flood event flow—were modeled at each project. At certain projects, the two-year flow was not included if model flows were not contained within the available topographic surface. Where available, discharge measurements at the time of survey were used as the survey flow. When discharge estimates were not available, the hydraulic model was run iteratively to estimate the survey flow based on observed water surface elevations. The hydraulic model was also run iteratively to estimate bankfull flow utilizing the bankfull locations identified in the field. The two-year flow was estimated using the regression equations developed by the U.S. Geological Survey (USGS) for estimating peak discharges in ungauged basins in Washington (Sumioka et al. 1998; Knowles and Sumioka 2001).

The hydraulic models utilized split-flow models for side channels, as needed. Spilt flows, the alignment of the cross-sections, and roughness values were optimized for the survey flow. Reach roughness (Manning's "n") values were determined by applying the USGS methodology as described in Arcement (1989), that uses site-specific conditions (e.g., vegetation, obstructions, degree of meandering, etc.) to estimate roughness. One roughness value was estimated for in-channel locations, and another roughness value was estimated for the floodplain areas. These roughness values were then fed into the hydraulic model to determine velocity and depth at different targeted discharges.

HEC-RAS model results for depth and velocity were exported to HEC-GeoRAS, a custom interface between HEC-RAS and GIS, for mapping the spatial distribution of hydraulic model outputs. These mapped outputs could then be compared to habitat suitability curves for specific species and life stages by geographic area. This comparison is used to provide visual representations of habitat quality.

Hydraulic fish habitat suitability models have been used for decades to evaluate the relationship between physical characteristics and habitat suitability (also referred to as preference). This relationship is determined by suitability functions, or curves, that relate relevant physical stream characteristics such as depth, velocity, and substrate to biological characteristics, or habitat suitability. This set of parameters (e.g., depth, velocity, substrate) are combined into a single index of habitat suitability. Several software programs have incorporated fish habitat modeling capabilities (e.g., PHABSIM, River 2D, CASiMiR). For this project-scale monitoring application, a habitat suitability model was constructed to allow for more control and flexibility of model parameters and to produce habitat suitability mapping that allows for the convenient display and visualization of habitat suitability data. The conceptual diagram in Figure 22 shows the process for developing

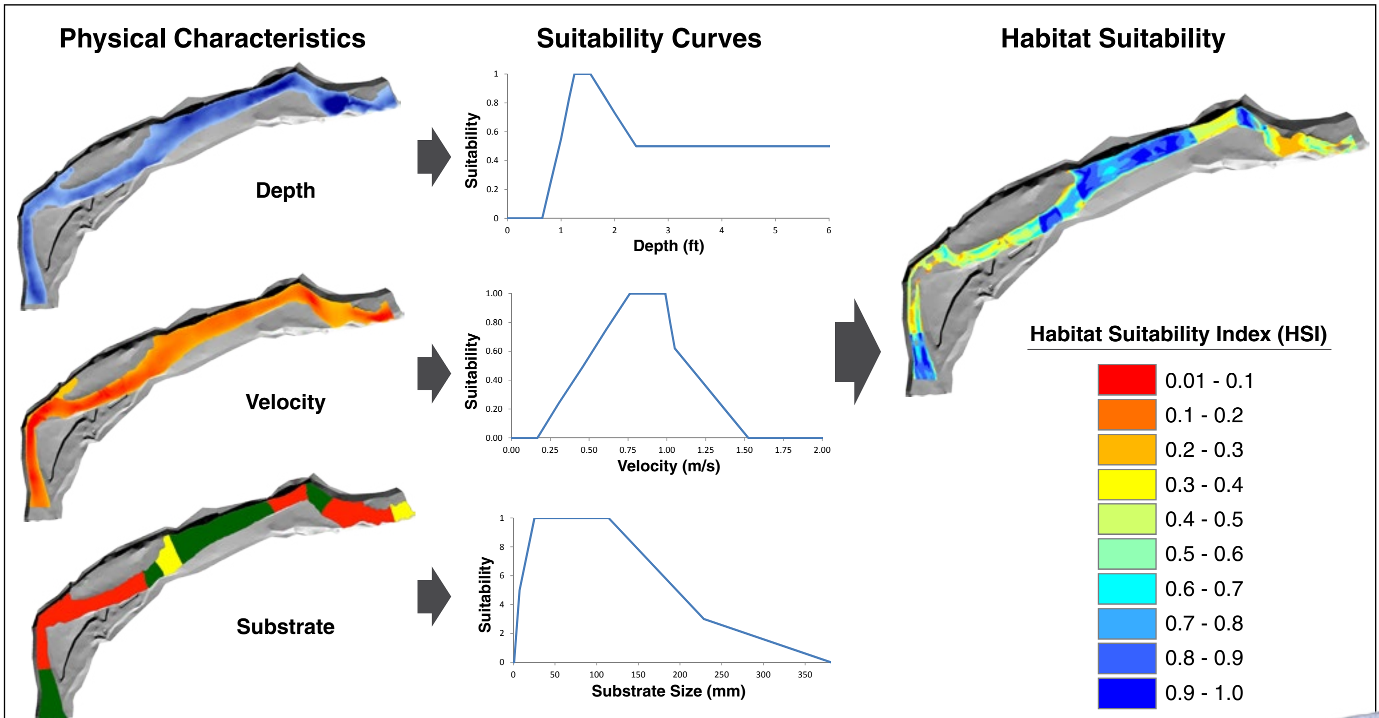


Figure 22. Habitat suitability model process diagram

habitat suitability model results from physical parameters using established habitat suitability curves.

Additional fish habitat suitability and edge habitat modeling and analyses were conducted in 2014 to evaluate fish habitat quality at projects. These results may be used to measure project effectiveness and improve project designs in the future. The fish habitat suitability modeling combined empirically-derived habitat suitability curves developed from Instream Flow Incremental Methodology (IFIM) studies with field survey data and flow characteristics (depth and velocity) derived from hydraulic modeling to create indices of habitat quality. The habitat suitability modeling quantified the quality of spawning and rearing habitat for Chinook and steelhead at a range of flow conditions. Habitat quality was represented by a spatially explicit Habitat Suitability Index (HSI) that combined model parameters to evaluate the relative habitat quality at projects.

The habitat suitability model was used to evaluate the quality and quantity of spawning and rearing for Chinook and steelhead at specified flow levels. Spawning and rearing habitat suitability were quantified and mapped with the habitat model resulting in HSI values scaled from 0.01 to 1.0 for Chinook and steelhead throughout each project. An HSI value of 1.0 indicates optimal habitat conditions (e.g., depth, velocity, and substrate) for the specific life stage (spawning or rearing) and flow level.

The habitat suitability model combined hydraulic modeling and field survey data with the spawning and rearing suitability curves for depth, velocity, and substrate developed for the Washington State Department of Ecology (Ecology) and Washington Department of Fish and Wildlife (WDFW) Instream Flow Study Guidelines (Ecology and WDFW 2004) and basin-specific IFIM studies. Spawning and rearing suitability curves developed for IFIM studies on the Washougal River (Ecology and WDFW 1999), Entiat and Mad Rivers (Ecology and WDFW 1995), Tucannon River (Ecology 1995, Watershed Sciences 2010), and the Green River (Ecology 1989) were reviewed and incorporated, where applicable.

Non-zero suitability curve values were required for both depth and velocity to be included in the HSI calculation. Substrate data, when available, were incorporated for the survey flow habitat model only because substrate data were not collected outside of the wetted channel at the time of survey. Fish cover data were not incorporated in the habitat model because the data collected were percentages for cover in channel units rather than specific areas where fish cover existed.

The area of edge habitat was also calculated for each flow level using the depth and velocity from hydraulic modeling. The area of edge habitat included areas where the modeled depth was less than 0.6 meter and the velocity was less than 0.15 meter per second.

Project-scale habitat modeling of monitoring sites address the monitoring questions and objectives described above by providing a means to quantify changes in habitat suitability in order to provide near-term feedback on project performance and evaluate whether changes in habitat are suitable for target species and life stages. A total of 10 project sites were chosen for habitat modeling. These sites were chosen for habitat suitability modeling because there was potential to establish baseline data and provide valuable feedback to project sponsors before implementation, or there was a specific interest in the site, or there was an opportunity for informative post-implementation results. The sites modeled and their respective survey length in years are as follows:

- Upper Elochoman River Treatment Reach (1 year pre-project)
- Upper White Pine River Treatment Reach (2 years pre-project)
- Upper White Pine River Control Reach (2 years pre-project)


Topo survey along the Wenatchee River

- Tucannon River Project Area 3 Treatment Reach (1 year post-project)
- Tucannon River Project Area 24 Treatment Reach (2 years pre-project)
- Tucannon River Project Area 24 Control Reach (2 years pre-project)
- Entiat Stormy #3 Treatment (2 years pre-project)
- Entiat Stormy #3 Control Reach (2 years pre-project)
- Greenwater River Treatment Reach (3 years post-project)
- Riverview Park Treatment Reach (2 years post-project)

The location of each of these project sites modeled is shown in Figure 23.

web: **Figures showing the HSI distributions for each site can be found at:**
http://www.rco.wa.gov/doc_pages/other_pubs.shtml#effectiveness

Results

Results from hydraulic modeling allow for the mapping of habitat suitability and edge habitat that may serve as indicators of use for specific species and life stages. Habitat suitability indices are targeted at predicting the highest quality habitat for specific life stages in geographically specific settings. Indices for Chinook and steelhead rearing and spawning have been developed for several areas in Washington. Additionally, edge habitat has been found to correlate with Chinook rearing habitat.

Habitat Suitability

Modeling of Chinook and steelhead spawning and rearing suitability was completed for all 10 monitoring sites. The results provide a spatially explicit index of habitat suitability (i.e., HSI) ranging from 0.01 to 1.0 for each species and life stage at all sites. Where possible, three flow levels where modeled—the survey flow, the bankfull flow, and the two-year flow. The two-year flow was not modeled for the Upper White Pine Control Reach, Entiat Stormy #3 Control Reach, Greenwater Treatment Reach, or Riverview Park Treatment Reach because these flows were not contained within the available topographic surface. Field survey substrate data were incorporated into the spawning model at the survey flow at all sites except the Greenwater Treatment Reach because the data were not available.

The amount of modeled spawning habitat and the distribution of HSI values varied considerably by site and flow level. A preliminary review of the spawning model results indicate that the model is likely over-estimating the amount of spawning habitat quantity and quality at some locations.

With the current data collected, it is not possible to determine where the model is over-estimating spawning habitat specifically, but over-estimates could be as large as 50 percent. Improving the specificity of the suitability curves would help address this issue. Specific mapping of substrate by channel unit would also improve the estimates. The HSI results are at the flow-cell level, reflecting the heterogeneity of the channel depicted in the topographic survey. One way

Figure 23. Location map of project sites selected for habitat modeling

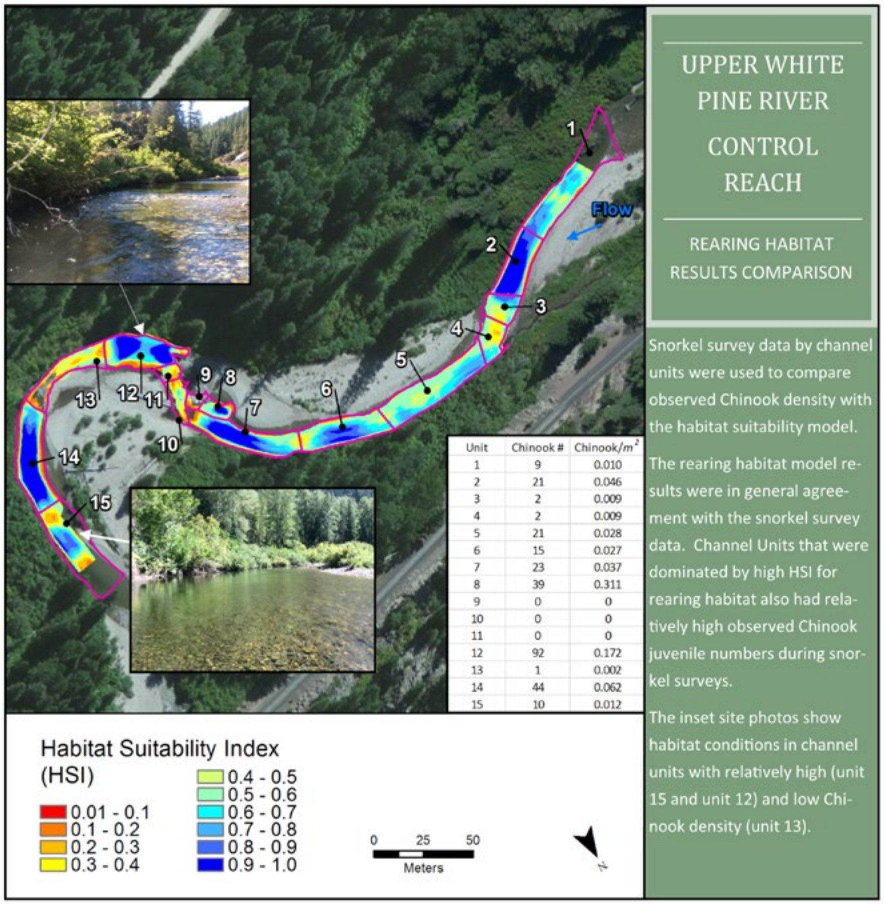


Figure 24. Comparison of HSI results and observed juvenile Chinook observations for the Upper White Pine Control Reach. High levels of agreement are shown between HSI values and observed fish densities.

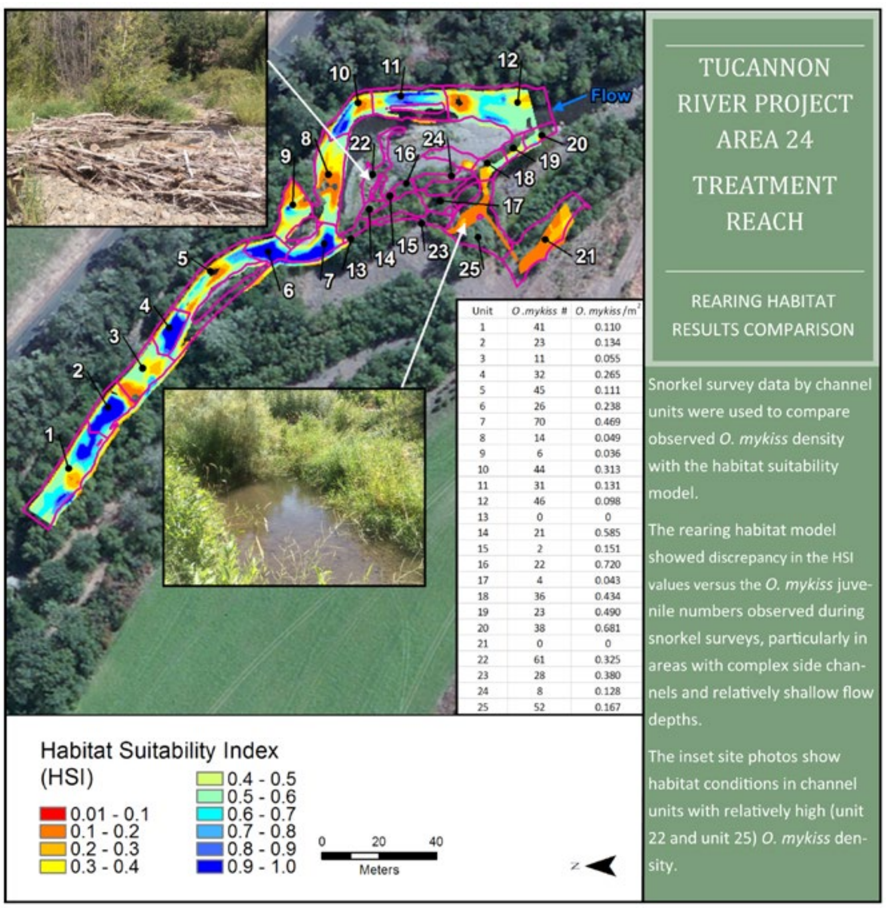


Figure 25. Comparison of HSI results and observed juvenile Chinook observations for the Tucannon River Project Area 24 Treatment Reach. Note low levels of agreement between fish densities and HIS scores.

to obtain substrate data that could more accurately reflect this precision would be to map out changes in substrate, similar to how channel units are mapped. This would result in partially overlapping layers but would take the variability of flow within a channel unit into account, similar to the HSI method. A less precise but more practical way would be to create a separate reach map to document areas of suitable spawning substrate and fish cover. These would be sub-channel unit maps that would likely result in "spawning area" and "fish habitat" polygons crossing the channel unit boundary lines. While not exact, these data, in conjunction with photographs and field notes, would allow the modelers to delineate areas of identified spawning-sized substrates.

The main reasons for the overestimate of spawning habitat are likely 1) the substrate data were collected at the channel unit scale which does not account for substrate variability within channel units, and 2) the spawning suitability curves reflect that spawning has been observed over a relatively wide range of hydraulic conditions. To improve the predictive capabilities of the spawning habitat model, future efforts should attempt to incorporate more detailed substrate data and refine spawning suitability curves using field observations of redds, or salmon spawning locations, where available.

The amount of modeled rearing habitat and the distribution of HSI values also varied considerably by site and flow level. Rearing model results were compared with juvenile abundance data collected during snorkel surveys. Preliminary results of the comparisons indicate that the rearing model is a good predictor of juvenile abundance at some project sites, but not all. For example, while there tended to be a positive correlation between high HSI values and relatively high juvenile abundance at the Upper White Pine Control Reach (Figure 24), this did not hold true at other project sites such as

Table 9. Area of edge habitat for by project site

Project Site	Area of Edge Habitat (m^2)			Observed Fish Count	
	Survey Flow	Bankfull Flow	2-Year Flow	Chinook	*O. mykiss*
Upper Elochoman Treatment Reach	227	185	85	13	11
Upper White Pine Treatment Reach	851	109	367	168	381
Upper White Pine Control Reach	669	544	--	279	66
Tucannon Project Area 3 Treatment Reach	155	435	499	52	202
Tucannon Project Area 24 Treatment Reach	274	259	343	84	684
Tucannon Project Area 24 Control Reach	19	123	184	45	478
Entiat Stormy #3 Treatment Reach	753	222	1,306	3	0
Entiat Stormy #3 Control Reach	894	824	--	2	5
Greenwater Treatment Reach	268	427	--	--	--
Riverview Park Treatment Reach	952	115	--	0	0

the Tucannon River Project Area 24 Treatment Reach (Figure 25). The main reasons for the discrepancy are likely related to the ability of the model to accurately depict complex side channels and the meso- to micro-habitat scale features within channel units. The lack of spatially explicit cover data may also detract from the quality of the results. Future efforts to refine the predictive capabilities of the rearing habitat model should attempt to incorporate cover data and refine rearing suitability curves using field observations.

Edge Habitat

The area of edge habitat was calculated for each site at the survey flow based on the hydraulic modeling results for depth and velocity. Edge habitat is defined as areas with the following two characteristics: 1) < 0.15 m/s velocity, and 2) < 0.6 meter in depth (Beechie et al. 2005). Table 9 contains the area of edge habitat and the observed fish counts for Chinook and steelhead, where available, for each project site.

The area of edge habitat available at the survey flow ranged from 19 square meters (Tucannon Project Area 24 Control Reach) to 952 square meters (Riverview Park Treatment Reach). The magnitude and direction of change in edge habitat area with increasing flow varied considerably by site depending on channel conditions. Four of the sites had low fish abundance (five or fewer of each species observed) or no surveys conducted (Entiat Stormy #3 Treatment and Control Reach, Greenwater Treatment Reach, and Riverview Park Treatment Reach). Figure 26 shows, at sites having more than five fish, the relationship of the observed fish count for Chinook and steelhead and the area of edge habitat. The number of observed Chinook exhibits an increasing trend with the area of edge habitat as shown by the dashed blue line in Figure 26, although there are relatively few data points (n=6). The number of steelhead does not appear to be strongly correlated with the area of edge habitat at these sites.

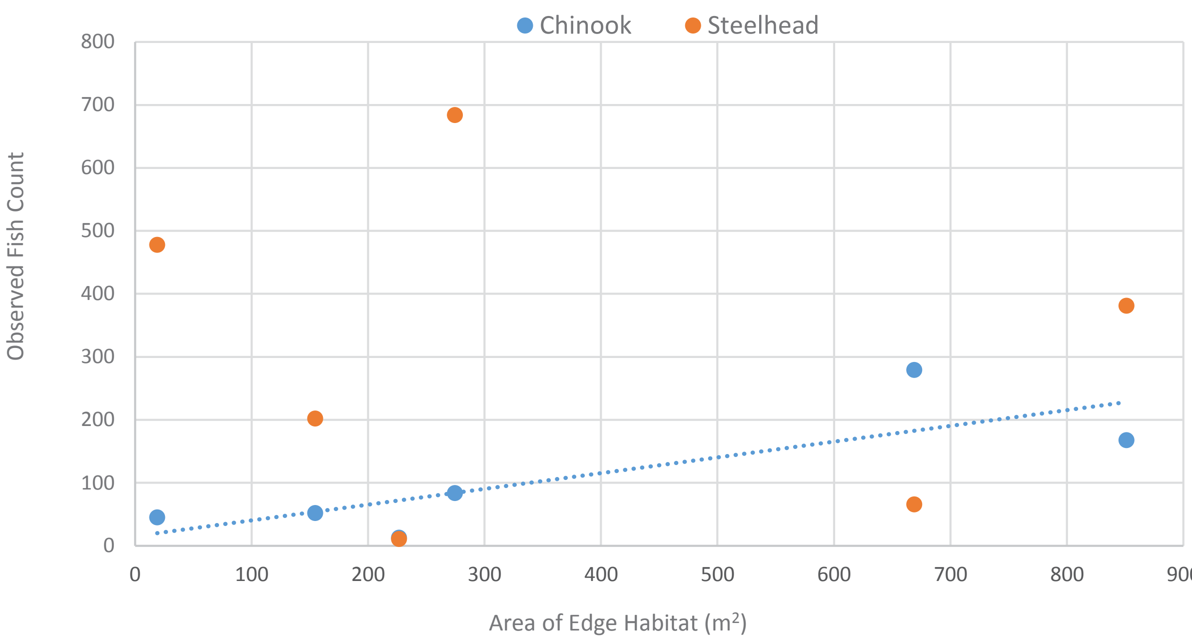


Figure 26. The relationship of observed Chinook and steelhead and area of edge habitat at sites with more than five fish

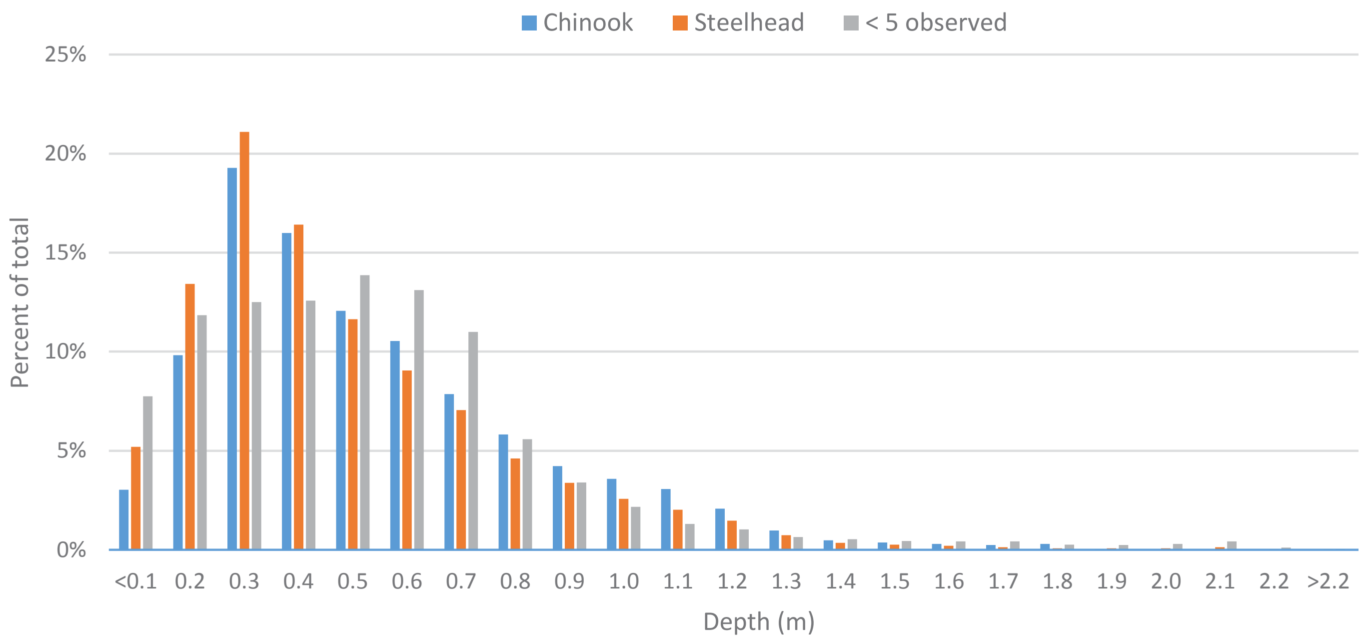


Figure 27. Depth distribution comparisons for channel units containing Chinook (more than five observed), steelhead (more than five observed), and less than five of either species

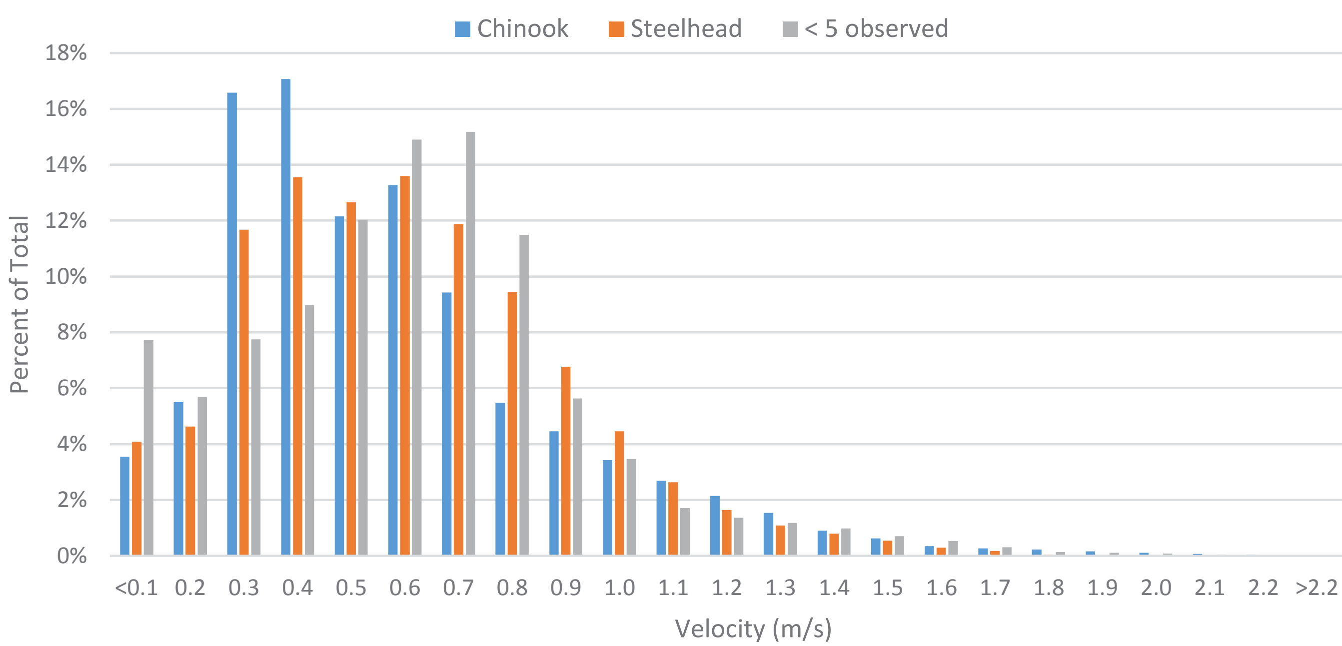


Figure 28. Velocity distribution comparisons for channel units containing Chinook (more than five observed), steelhead (more than five observed), and less than five of either species observed

Depth and Velocity Distributions

Depth and velocity distributions were evaluated to identify potential differences in observed rearing conditions based on project site or species presence. The evaluation was done by comparing depth and velocity distributions in channel units based on juvenile abundance by species. The categories for comparison were channel units with more than five observed Chinook, channel units with more than five observed steelhead, and channel units with less than five observations of either species. The depth and velocity distributions at each site show a high degree of variability and no clear trend. This differentiation was designed to characterize habitat that is more desirable for Chinook and steelhead as compared to channel units with less desirable habitat. The depth and velocity distributions were combined for all sites as shown in Figure 27 and Figure 28, respectively. The depth distribution shows a higher proportion of depths from 0.2 to 0.4 meter for both Chinook and steelhead when compared to the channel units with less than five fish observed, which is somewhat contrary to the suitability curves that have relatively low HSI values in that range. In contrast, the velocity distribution also shows a higher proportion of velocities from 0.2 meter per second to 0.4 meter per second for both Chinook and steelhead when compared to the channel units with less than five fish observed, which is in agreement with the suitability curves that have high HSI values for that range.

The habitat modeling provides a robust set of baseline data quantifying spawning and rearing habitat suitability and provides additional measures to evaluate whether desired changes in habitat are occurring and if those areas are likely to be used by the target species and life stages. With multiple years of monitoring data, changes in habitat quality and quantity can be compared by evaluating the habitat outcomes that result from restoration actions. These results can be applied to quantify habitat gains at the project scale and evaluate which project types are effective at achieving localized changes in habitat; they can also be used to address specific limiting factors or ecological concerns.

The habitat modeling results can be fed back into the salmon recovery process to guide future restoration actions and decision making. Habitat suitability mapping has much potential to be an effective tool for communicating the effectiveness of design alternatives with the community of river restoration practitioners including scientists, engineers, and project sponsors. Future development of habitat modeling efforts will be focused on improving design criteria in order to create habitat outcomes that specifically address limiting factors, or ecological concerns for target species and life stages. Developing the tools to effectively communicate design effectiveness is an important step in the continuous improvement of river restoration science.

UNDERSTANDING THE CUSTOMERS IN SALMON RECOVERY:

FISH RESPONSE TO PROJECT ELEMENTS

Salmon recovery restoration is carried out to achieve one purpose: the recovery of salmon species in the Pacific Northwest to reduce the risk of extinction and create viable salmon populations. There are many steps in achieving this purpose, but the major focus should remain achieving a salmon response to the restoration efforts. It is not uncommon, however, for a clear understanding of the salmon response to restoration efforts to be unknown and unmeasured. Capturing physical changes in geomorphic process has become an accepted surrogate for improving the response from salmon. While creating geomorphically healthy watersheds is an important element in salmon recovery, the actual fish response to those changes is the ultimate barometer of the success of restoration efforts.

The ultimate goal of these habitat improvement projects is to increase fish abundance and survival, as well as enhancing diversity and productivity at the population scale. Multiple years of related habitat and fish data allow for some investigative analyses into what might be driving fish use at sites and provide a platform to test general assumptions of fish responses to proposed actions. This may help shed light on why one project succeeds and another doesn't.

Additional analyses were carried out to determine relationships between fish and habitat characteristics at restoration projects. Data was transformed, where needed, to meet normality requirements of the tests. Differences between categories were tested for significance with Student's t-tests while linear models were used to assess regression relationships between fish values and habitat values.

Both instream structure and floodplain enhancement monitoring sites contain habitat and fish abundance data. This information was used to calculate fish utilization of habitat types and identify which habitat types had higher utilization. Both treatment and control sites were used in this assessment. Each analysis was conducted only for those sites containing the species of interest.

Thalweg Profile Variance

Habitat complexity is often cited as one of the goals of habitat restoration. One aspect of habitat complexity is variability in channel or thalweg depth as measured by the longitudinal profile. Tetra Tech compared thalweg profile variance against fish abundance and density. Density values were $\log_{10}$-transformed to meet normality requirements of the statistical test. A linear regression model was then fit to the data to test for any significant relationship between density and thalweg profile variance.

Chinook density appears to be negatively correlated with increased Thalweg Profile Variance (see Figure 29), with a p-value of 0.07. The slope of the $\log_{10}$ (Density) is -0.37. It should be noted, however, that the adjusted r-squared value for this relationship is low, at 0.04.

Steelhead density also appears to be negatively correlated to thalweg profile variance (Figure 30). The negative correlation between the $\log_{10}$-transformed density and thalweg profile variance is significant for instream habitat projects (p=0.02, adjusted r-squared=0.02), but not for floodplain enhancement projects (p=0.18, adjusted r-squared=0.03). Understanding fish responses to high variance in the thalweg profile warrants additional investigation in terms of understanding these results. The relationship of thalweg

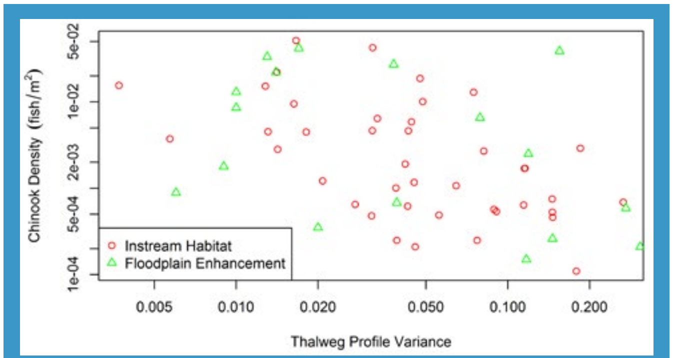


Figure 29. Floodplain enhancement and instream habitat projects: thalweg variance vs. Chinook density

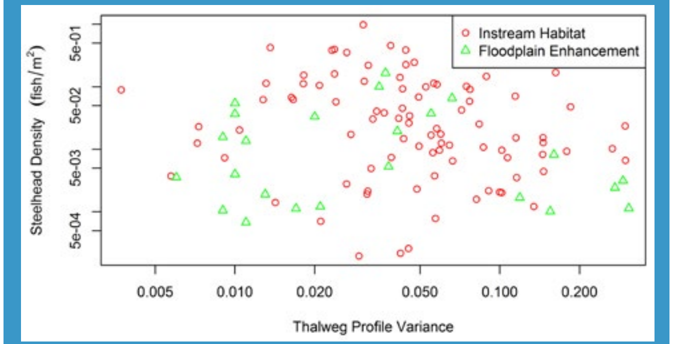


Figure 30. Floodplain enhancement and instream habitat projects: thalweg variance vs. steelhead density

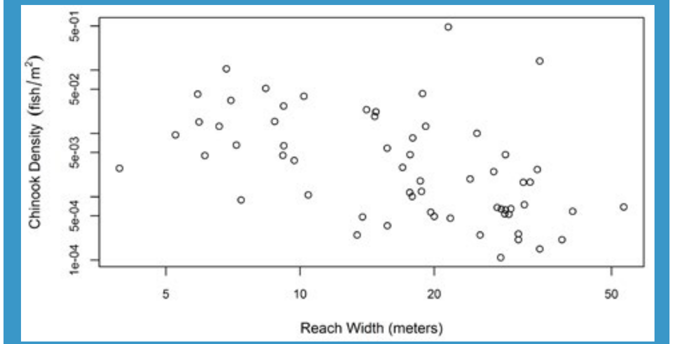


Figure 31. Chinook density vs. reach width

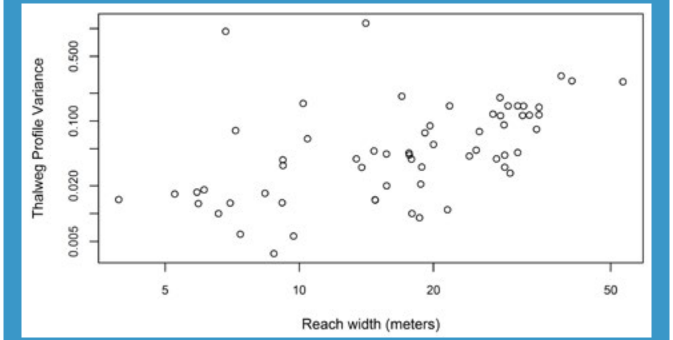


Figure 32. Thalweg profile variance vs. reach width

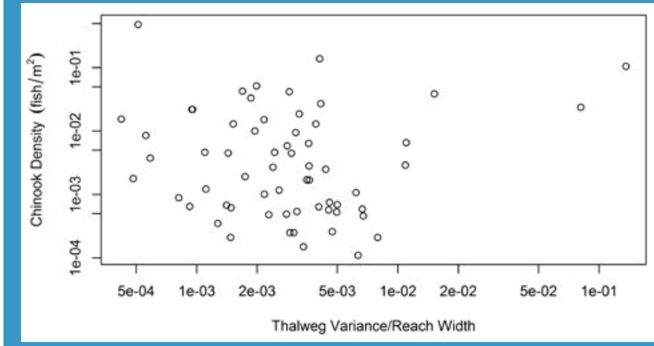


Figure 33. Chinook density vs. adjusted thalweg variance

profile variance to stream width shows that larger streams, have higher variance (Figure 31). When Chinook density is plotted against reach width (Figure 32), it becomes clear that the density/variance relationship is driven by reach width; demonstrating that larger streams have lower densities. Normalizing variance by reach width results in no significant relationship with either density or abundance (Figure 33). Thalweg profile variance is a convenient measure of channel complexity, but may not be the best suited to matching with favorable response by salmonids.

Channel Unit Analysis

In 2013, Tetra Tech began the transition from collecting fish data by transects to collecting them by channel unit. In 2014, all fish data was collected by channel unit. This shift was made to compliment the shift from the original SRFB protocols based on EMAP surveys to physical survey protocols more similar to CHaMP, which mapped channel units in a digital elevation model. Recording fish by channel unit allows us to associate fish numbers with restoration actions aimed at increasing habitat complexity components such as LWD, pools, and fish cover. Channel units are also used for the auxiliary habitat data collected during physical habitat surveys. Having comparable spatial categories allows for a cleaner relationship between fish and physical factors. We can directly relate fish to habitat data at the sub-reach scale and determine whether the physical metrics being used show any relationship to fish abundance, diversity, and density. If so, we can then start to examine the specific characteristics or areas that appear to be favorable for fish use and whether these preferences are similar for all species and size classes. The original SRFB protocols provided calculation methods for determining channel unit differentiation and percentages of each type within a transect; however, fish counts in a particular pool could only be inferred. As we move toward the goals of informing practitioners on which actions appear to have the most associated use and which do not, knowledge of where fish are relative to the channel unit formation can be very useful.

Results of the channel unit analysis showed that Chinook had a higher density in pools, relative to other channel-unit types (Figure 34). This result was significant for comparisons with fast-turbulent (p=0.01) and small side channels (p=0.12), but not for fast-nonturbulent/glide (p=0.38). Use of pools by Chinook and other salmon species is fairly well documented and is the reason that pool area and depth are identified as the prominent physical habitat variables for improvement.

Steelhead were less strongly affiliated with pools when compared to other channel units (Figure 35). Mean steelhead density in slow/pool habitats does not differ from fast-nonturbulent/glide habitats (p=0.67) or small side channels (p=0.75), but is significantly greater than in fast-turbulent channel units (p=0.02). Densities in fast-turbulent channel units were similar to fast-nonturbulent/glides (p=0.13) and small side channels (p=0.22). Steelhead species are

often found in higher velocity habitats than Chinook juveniles, and have a more broad preference for habitat types.

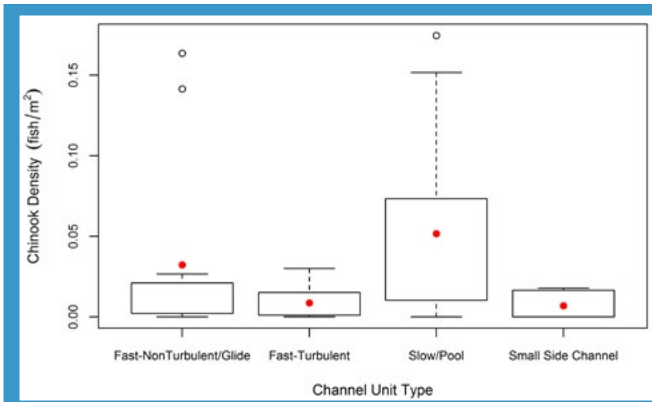


Figure 34. Chinook density by channel unit type

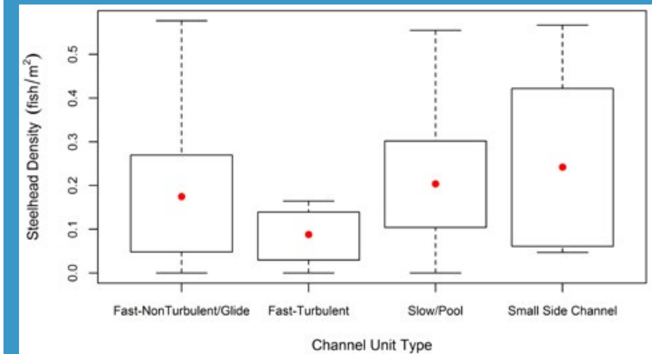


Figure 35. Steelhead density by channel unit type

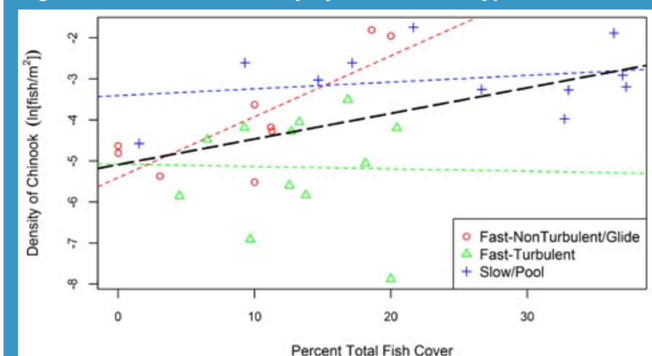


Figure 36. Chinook density by channel unit type relative to fish cover

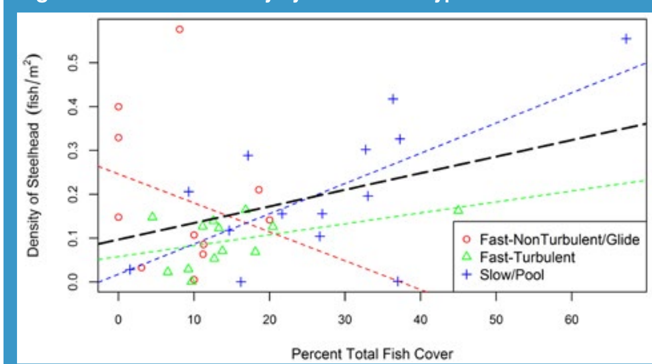


Figure 37. Steelhead density by channel unit type relative to fish cover

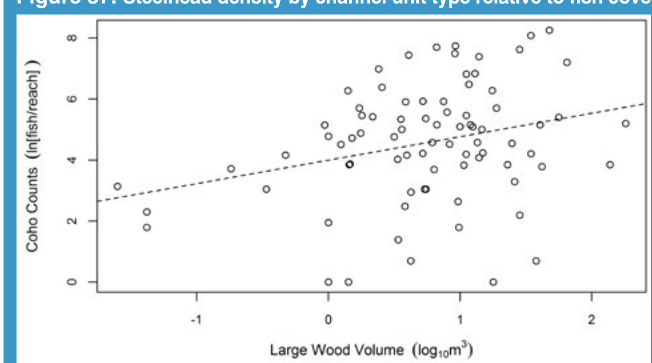


Figure 38. Coho counts vs. large woody debris volume

Influence of Fish Cover

Fish cover is frequently mentioned as a limiting factor or target for restoration improvement. The importance of this habitat feature may also be influenced by habitat type. The presence of large wood or fish cover is also often used as a surrogate for complexity of habitat. A better understanding of the definition of habitat complexity would improve communication between project proponents and project funders.

There was a significant positive relationship (p=0.009, r-squared=0.2) between the normalized densities (using the natural log) and percent total fish cover (see black dashed line, Figure 36). There was a highly significant relationship between cover and densities within fast-nonturbulent glide channel unit types (p=0.009, r-squared=0.6), but not for the other three channel unit types. This suggests that cover is an important driver in determining fish use in fast-nonturbulent/glide channel units.

There was a significant relationship between steelhead density and percent total cover (p=0,01, R=0.1); however, the relationship was not as strong as it was for Chinook. In contrast to Chinook, there was a significant positive relationship between fish cover in pools and steelhead density (p=0.006, adjusted r-squared = 0.43) (Figure 37), while there was no such significant relationship for glides. These results highlight some of the differences between Chinook and steelhead habitat use. Data collected as part of the Upper Columbia Regional Project Effectiveness Monitoring Program (Tetra Tech 2015) showed that steelhead and coho use wood placement projects at much higher levels than Chinook, which could be contributing to this response.

Large Woody Debris and Fish Occurrence

Wood placement is a common restoration technique aimed at improving instream habitat conditions by providing cover and structural elements that can change the geomorphology of the stream channel toward what is considered more suitable habitat conditions for salmonids. Chinook, steelhead, and coho counts and densities were compared to wood volume in project reaches to investigate the relationship between fish occurrence and volume of LWD. Chinook and steelhead did not have significant relationships with LWD volume; trends were negative for Chinook and positive for steelhead. However, there was a significant (p=0.009) positive relationship (slope = 0.768) between coho counts and wood volume (Figure 38). This trend is discussed in the section on instream structures (page 9).

Summary of Fish-Habitat Relationships

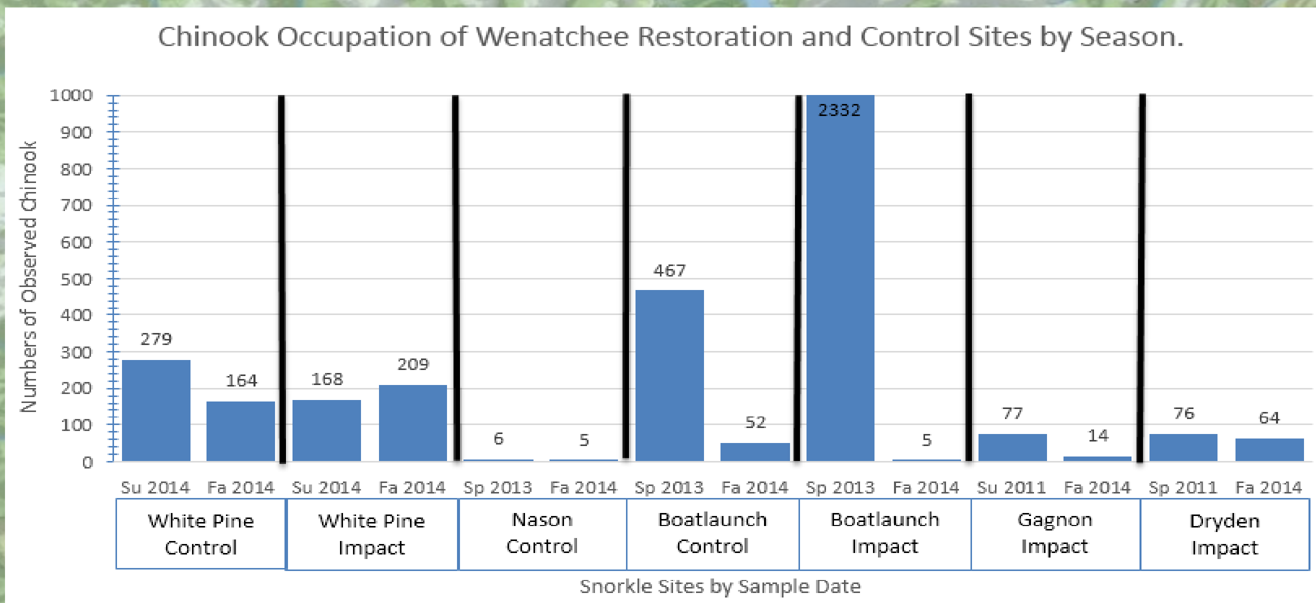
Information on species and life stage-specific preferences can be used to help understand responses to restoration projects, and may help in restructuring the goals with respect to these efforts. For example, many project sponsors targeting

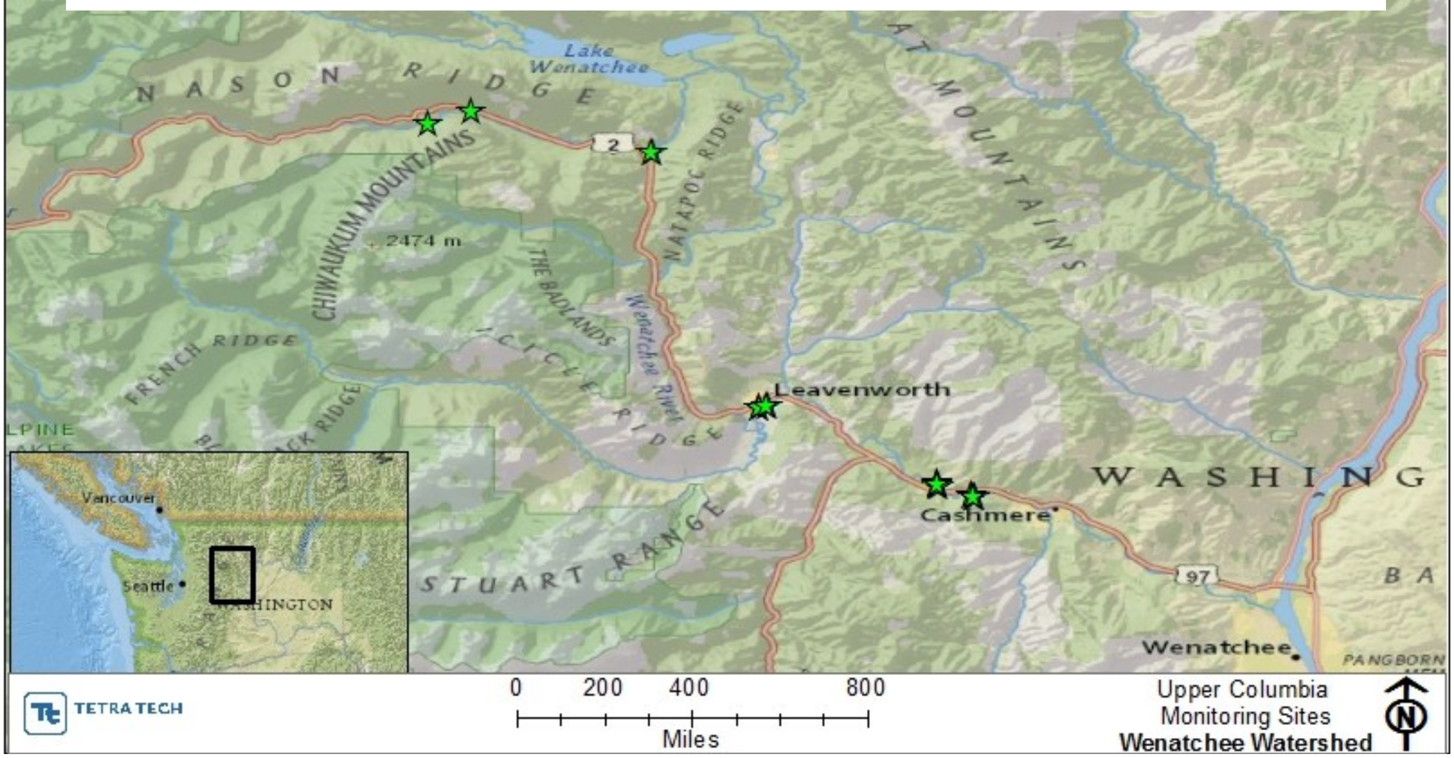
Chinook Occupation of Restoration Sites in the Wenatchee Watershed.

The UCSRB Project Effectiveness Monitoring Program has been evaluating restoration efforts in the Wenatchee watershed since 2011. But most of the survey efforts occur between late spring and early fall, with the expectation that most of the local Chinook start their out-migration by the end of this time frame. This leaves a gap in available information regarding Chinook use of restoration sites during the rest of the year. Tetra Tech undertook a rapid assessment (night snorkeling) of some Wenatchee restoration sites in late October 2014 to assess the relative timing and distribution of Chinook throughout the watershed.

The results from this effort are presented in the figure below and match with the marked sites along State Route 2 on the under laying map. The results on the chart match up with furthest west site (left side) to furthest east site (right side).

Data from spring and summer surveys were collected in three different years and could be affected by flow levels. Off-channel habitat at the Boat Launch site in the Leavenworth area had the highest level of use during those seasons in all years measured. Fall 2014 surveys show a higher level of use in Nason Creek as compared to the mainstem Wenatchee.

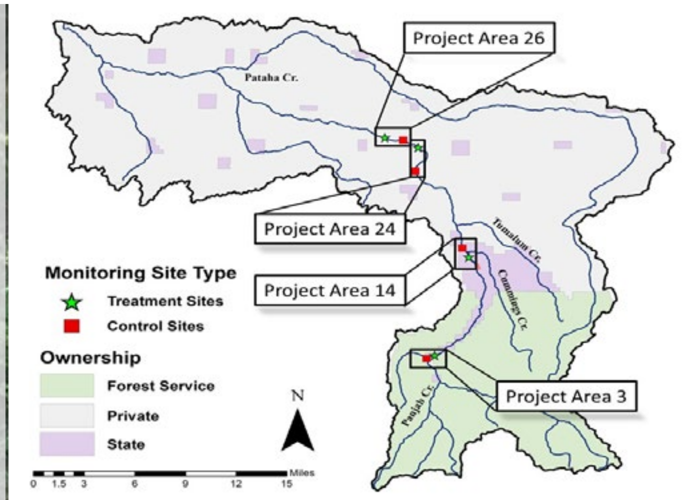




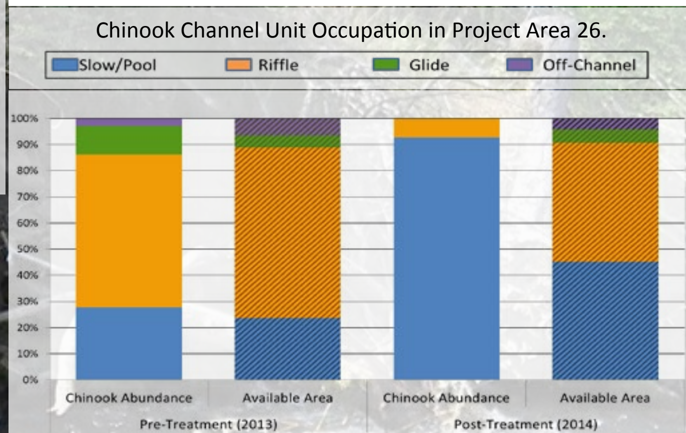
Tucannon River Effectiveness Monitoring

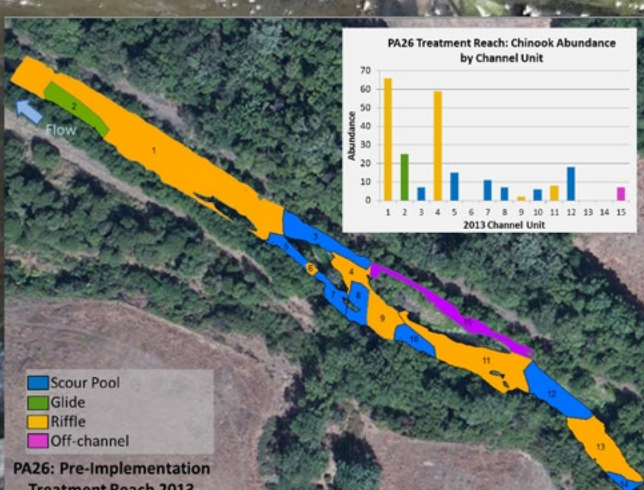
Tucannon River flows 62 miles from the Blue Mountains to the Snake River in south-east Washington and is an important contributor to salmon production. There are four new project areas (PA) currently targeted for effectiveness monitoring. Three of these sites (PA -3, -14, -26) have pre- and post- project monitoring information, while PA-24 just has pre-project information available.

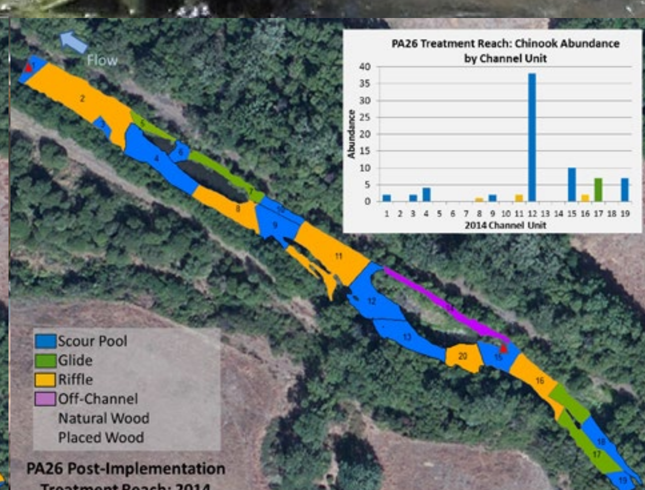
Below are the results of the pre- and post-project Chinook abundance of PA-26 when matched with the mapped channel habitat units. There is a noticeable increase in overall pool area from the pre-project (22%) to the post-project (45%) survey. And while general Chinook numbers were less in 2014, there was a clear preference of the 2014 Chinook to occupy pools (93%) versus pool occupation in 2013 (28%). Additionally, low Chinook numbers between years could be attributed to variances in annual runs (all surveyed sites in the Tucannon showed less fish in 2014 than 2013), lower flows or in-water work that was occurring upstream at the time of surveys.



Chinook Channel Unit Occupation in Project Area 26.







Chinook salmon rearing habitat identify channel complexity as an element they are trying to improve. Measurement of variation of the thalweg has been identified as an indicator of channel complexity; however, there appears to be little association with juvenile Chinook use when corrected for channel size. Data obtained by Tetra Tech and from other studies (Beechie et al. 2005) suggest that perhaps using edge habitat would be a better predictor of juvenile Chinook use and a better target for projects sponsors to focus on larger river systems. Further, wood placement projects are also commonly implemented to benefit Chinook juveniles in both Puget Sound and the Columbia Basin. Tetra Tech's data show a negative relationship between Chinook salmon and wood placement, although there are positive responses for coho and steelhead. Chinook response to floodplain enhancement projects has been strong, suggesting that these projects may be a better choice for benefits to this species.

Video Assessment of Fish Use and Behavior

While video documentation was not conducted for quantitative analysis, review of the footage provides some indications of fish utilization for different structures and placements. At some sites, it was clear that fish were using logs that provided minimal velocity refuge as cover. These structures provided overhead cover away from the banks of the stream, and fish aligned themselves underneath. This may result in improving forage areas, as it expands the area where fish can forage while still being under, or near, overhead cover. In areas where large wood was added to high-velocity river segments without creating low-velocity areas, fish use was more difficult to tie to wood placement. This type of placement should be evaluated for fish benefits. Fish often congregated around root wads that created flow-breaks in fast sections, but were less likely to use cover elements where high velocities remain un-attenuated. While LWD enhancement generally focuses on placement of large structures, fish use was not always associated with the size of wood. For example, in one site, 15 Chinook and steelhead parr were present within a section of riffle, all associated with a 9-millimeter diameter beaver-chewed branch that was snagged on a large cobble. While the affected area was less than half a square meter and temporary, it was highly utilized by the juvenile salmonids.

Summary and Recommendations for Fish Use and Behavior Monitoring

Project level fish metrics are often directed toward reach-scale effectiveness monitoring for category analysis. These metrics are also useful at the site level, as far as reporting overall success of the projects relative to their control reaches over time. However, the surveys provide opportunities to report on many other metrics regarding fish utilization of natural and created habitats. Over time, the auxiliary data that documents preference of flow habitats, cover, and how fish use the stream channel and habitats (supported by video documentation) may shed additional light on fish behavior and response to habitat modifications from restoration actions. Variability in responses relative to habitat metrics requires further analysis. As we investigate mechanistic results, the analysis methods need to be expanded. For example, when Chinook density is plotted against thalweg profile variance, we saw a negative trend, however, this trend is dominated by the fact that thalweg profile variance increases with channel width and Chinook density decreases with channel width. When compared using total counts, there was no discernable trend—an indication that the decreasing trend was a result of lower densities in larger systems.

Data collection methodology has changed over the course of the 10-year period, as the focus of the monitoring has changed. The analysis for the overall reach-scale questions was not affected; however, the shift in methodology for channel unit delineation and fish use of channel units has made it impossible to do a direct comparison of this type of data from the beginning of the survey to recent years. A reason for this is that earlier data did not have the same resolution. It is, however, still possible to compare data at the reach-level resolution targeted in the earlier study design. Additional analyses such as multivariate statistics and additional ways of looking at the data may provide opportunities for us to include older data sets in some of the more detailed studies of trends at the sub-reach level (channel units). Adapting analyses to allow more of the earlier survey data to be included will provide a larger dataset and time series for addressing questions and informing the direction for future monitoring.

Additional monitoring methodologies are being implemented at certain sites to gain further understanding of site use. While large-scale monitoring programs often standardize sampling periods to minimize seasonal effects on results, this may artificially skew results for projects that are designed to provide habitat advantages during portions of the year other than the sampling period. Examples include sites designed for high-flow refugia or to aid in migration. Surveying during fall and winter would allow us to evaluate how projects designed for overwintering are functioning at the reach level. Additionally, sampling throughout the year allows opportunities to coordinate reach and sub-reach level fish use with overall migration timing. Another focus that may warrant additional effort as we proceed into future monitoring designs is looking specifically at how fish are spatially distributed throughout a reach, at the sub-channel unit level. This may involve additional GPS data collection for both habitat features and fish occurrence. Such detailed data collection may translate to fewer sites and/or a shift from the census-type of fish survey to a more targeted location-based survey. The advantage of such surveys would be to allow for better training of habitat use prediction models (such as HSI) and more direct feedback to practitioners on how fish are using specific structure placements and designs. Such methodology shifts will need to be evaluated against the overall program goals for fish use monitoring.

Spawning Chinook in the Nooksack River

SUMMARY

Years of data monitoring have provided insight into the measures of success of restoration project implementation. In addition to enabling evaluation of restoration method effectiveness, increased interactions with project practitioners has led to an evolution of monitoring methods and reporting formats.

The original directive to compare shared metrics within and across project categories is useful for basic management and funding decisions; however, it does not provide adequate detail for adaptive management of restoration. Detailed recommendations for project improvement require a deep understanding of project design criteria and effects as well as concrete, useable information for those designing and building projects. As a result of feedback received from project sponsors and designers, the two considerations outlined in this report that attempt to address those needs are: 1) a need for information that can be directly incorporated into designs, and 2) a need for more information on fish use of habitats that is life stage-specific, species-specific, and geographically relevant. Providing data that can be used in design criteria (e.g., specific depth and velocity targets) addresses the first need, and developing a better understanding of the preferences for rearing species (e.g., Chinook) addresses the second.

These first 10 years of project effectiveness monitoring have provided insight into how projects are functioning as a whole and the type of monitoring information proving valuable to restoration practitioners. This dataset and other similar datasets are now being evaluated for the results of their target metrics. They are also being used to determine whether the monitoring approach and desired metrics are appropriate. Determining the target for restoration prior to implementation, and incorporating those restoration goals and objectives into a monitoring program, will help refine the data, determine project success, and help determine how “success” should be defined.

In cases where a project does not function as expected, it should be determined whether it is a result of project failure or a result of the system merely adjusting as natural systems tend to do. If cases where the system is adjusting, the next step is determining whether the altered implementation plan or the implementation plan initially employed is more suitable for crucial salmonid life-history needs. Examination of use specificity and whether restoration actions are functioning as desired may also point to the need to revise the monitoring methodology. A key component in this determination is the use of projects throughout the year. When analyzing the effectiveness of a project based on number of fish utilizing the structure, sampling throughout

the year will likely provide a more accurate picture of project success. This is because year-long sampling would include high-flow events and account for projects designed to provide refugia habitat during high flows and overwintering periods.

While the full census survey method has many benefits, it is time consuming and restricts the amount of specific use data that can be collected without adversely affecting data quality and breadth of coverage. It may therefore be necessary, in future monitoring programs, to reduce census coverage in favor of specific use surveys (such as video or specific structure use surveys) to determine how structures or built environments are functioning relative to fish use.

While these are reach-scale effectiveness projects, taking into account larger scale conditions will also be useful in improving understanding of the results. Coordinating with other monitoring groups and agencies can provide information on general population trends throughout a drainage and the context of the restoration action regarding site conditions and limiting factors. Some of these factors are issues that should be taken into account during funding review, and closer alignment between the grant requirements and project objectives can help drive future monitoring programs.

Looking forward, seasonal evaluations of fish use and additional refinement of habitat suitability modeling are the top two priorities for the program. These investigations will help refine monitoring results and take into account factors that are not fully evaluated under the current methodology. As we complete the first programmatic effort for monitoring project effectiveness, there may be unexpected results that challenge the current beliefs regarding interactions between fish and habitat. By welcoming these challenges as opportunities to improve the practice of restoration and adaptively manage our efforts, we stand to gain the most.


Diversion dam on the Middle Fork Nooksack River

Chewuch River Mainstem – upstream from control site

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