ASOTIN CREEK
INTENSIVELY MONITORED WATERSHED:

UPDATED STUDY PLAN

JULY 10, 2015

Prepared For:

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and

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EXECUTIVE SUMMARY

- Asotin Creek in southeast Washington was chosen as a site to develop an Intensively Monitored Watershed Project (IMW). The goal of the IMW is to implement stream restoration actions in an experimental framework to determine the effectiveness of restoration at increasing salmon and steelhead production and to identify casual mechanisms of the fish response to help guide restoration actions in other watersheds. Asotin Creek is designated a wild steelhead refuge and steelhead are the focus of the IMW.
- The Asotin Creek IMW has a hierarchical-staircase experimental design which includes the lower 12 km of three tributaries: Charley Creek, North Fork Asotin Creek, and South Fork Asotin Creek (hereafter the study creeks). Each study creek is divided in three 4 km long sections and one section of each creek has been treated (i.e., restoration applied) with the remaining sections acting as controls. Treatments were staggered over three years with one section treated each year starting in 2012.
- The study creeks consist primarily of highly homogenized and degraded habitats, which are thought to be limiting steelhead production. One of the primary limiting factors in these study creeks is riparian function which has led to a lack of pool habitat and cover for fish, and a relatively low abundance, density and mean size of large woody debris (LWD) compared to reference conditions and assumed historic recruitment levels.
- The addition of LWD to streams to improve habitat complexity and quality is not a new restoration strategy. However, we argue that most projects place undue focus on the size and stability of LWD with frequent attempts to anchor LWD in place. From a stream or watershed perspective, we think that the low density of LWD is a much bigger problem than the size, and streams with healthy rates of LWD recruitment see much more dynamic behavior in their LWD (i.e., it moves regularly). We seek to produce a population-level response in steelhead in the Asotin Creek Watershed by treating over 12 km of stream in three study creeks with 500 – 600 LWD structures. We expect this to fundamentally alter the complexity of habitat at three sections within the project area inducing an increase in steelhead production at the stream scale.
- To achieve the desired LWD densities with traditional treatment methods would be extremely expensive, highly disruptive to the existing riparian vegetation, and logistically infeasible to implement over the broad range of steelhead habitat in the Columbia Basin. We instead propose to test the effectiveness of a installing post-assisted log structures (PALS), which are constructed of wood posts, driven into the streambed, and augmented with LWD cut to lengths that can be moved by hand.
- Post-assisted log structures were installed with a hand-carried, hydraulic post-pounder by a crew of 2-4 people. Typical installation time is on the order of 1-2 hours per structure and material costs are < $100. Thus, if the treatment method proves effective, this is potentially cost-effective method to transfer to other streams.
- Post-assisted log structures, like naturally occurring LWD jams, are designed to produce an immediate hydraulic response by constricting the flow width. Like natural LWD accumulations, this alteration of the flow field creates more hydraulic heterogeneity, providing shear zones for energy conservation for fish next to swift areas with high rates of invertebrate drift. Moreover, the convergent flow produced by the constriction is likely to scour and/or maintain pools at high flows, and divergent flow downstream of the PALS where the stream width expands, may promote active bars that provide good spawning habitat.
- The fate of an individual structure is not as critical as the overall density of structures. A high density of PALS will increase the large-scale roughness of the stream section creating much more variability in flow

width and opportunities to build, alter, and maintain complex assemblages of active bar and pool habitat. Ultimately, we hope to use the PALS to initiate a more regular exchange of materials (sediment, water, LWD, etc.) with the adjacent riparian area.

- We have articulated these predicted responses into a series of explicit design hypotheses, which are guiding our monitoring efforts. The monitoring is part of an adaptive management plan and is nested within the hierarchal-staircase experimental design. A targeted blend of detailed, habitat monitoring and fish sampling nested within treatment and control sections is combined with coarser-grained rapid assessment inventories and remote sensing at the stream and watershed scale. This approach ensures that we can reliably detect and infer mechanisms of geomorphic changes and fish response at local scales, but we can then reasonably expand these understandings to the stream and population scales.
- The staggered implementation of the restoration (i.e., staircase design) provides explicit opportunities within the adaptive management plan to refine and adapt implementation and monitoring specifics as may be necessary.
- Preliminary results from the performance of over 400 structures installed in the summer of 2011-2013 suggest that the structures are able to withstand higher than average spring floods (the peak March 2012 discharge was the largest in 12 years at the confluence of North Fork and South Fork) and produce many of the intended hydraulic and geomorphic responses.
- We have collected a robust set of pre-treatment fish data including abundance, growth, movement, and survival across multiple spatial and temporal scales and are in the process of collecting post-treatment data to determine how effective the restoration has been at increasing steelhead production.
- Preliminary estimates indicate fish abundance has increased in treatment sections compared to control sections suggesting that the habitat changes we have observed are improving habitat for fish.
- We are developing methods to use PIT tag arrays to assess movement patterns and productivity at the stream and treatment section scales. We have not calculated measures of productivity yet but this will be the focus of the IMW from 2015-2019.
- There also is a robust set of fish data at the watershed scale (WDFW Fish In Fish Out), habitat data at various scales from individual restoration structures and geomorphic units to the watershed scale, as well as watershed wide stream temperature, and discharge data that will all be used to interpret fish responses to restoration and help extrapolate results from Asotin Creek to other similar watersheds.

ACKNOWLEDGEMENTS

The Asotin Intensively Monitored Watershed (IMW) is a collaborative multi-agency initiative sponsored by the Snake River Salmon Recovery Board (SRSRB). The SRSRB provides oversight and technical review of all the Asotin IMW activities through support from the Regional Technical Team (RTT), and National Oceanic and Atmospheric Administration (NOAA) staff. The majority of the IMW takes place on Washington Department of Fish and Wildlife (WDFW) and US Forest Service (USFS) land, and both agencies have supported the development and implementation of the project. Asotin County Conservation District (ACCD) also continues to support the project and is working on long-term riparian restoration and invasive plant species control within the IMW study area. Funding for the primary monitoring components of the IMW are provided by the NOAA Pacific Coastal Salmon Recovery Fund (PCSRF). Funding for the restoration activities have come from PCSRF through the State of Washington's Salmon Recovery Funding Board (SRFB) and Bonneville Power Corporation (BPA), and Washington State Conservation Commission. The USFS and WDFW have donated considerable amounts of equipment use and materials (e.g., large woody debris) to aid in both monitoring and restoration. The Clarkston WDFW field office has provided field staff to assist in all aspects of the IMW. WDFW also operates “fish in-fish out” monitoring on Asotin Creek funded by BPA which greatly enhances the IMW ability to understand population dynamics and structure in the watershed . Bob Dice, the manager of the Clarkston Wildlife Office, has also provided the IMW with accommodation, transportation, and access since the start of the project that is essential to success of our field activities. We also wish to thank the Koch and Thornton families for graciously providing us access to private property along Charley Creek to conduct monitoring and restoration. Brad Johnson, WRIA 35/Asotin County Public Utilities District (PUD) has also been an indispensable part of the IMW team working with the local landowners and agencies to help secure land access, operating permits, and local support and sponsorships for the IMW. Bruce Heiner, WDFW Habitat Engineer and Barry Sutherland, USDA Natural Resources Conservation Service (NRCS) Fluvial Geomorphologist provided comments of the earlier versions of the restoration plan. The following groups have provided direct support to the IMW in either goods or services and we wish to thank them for their help with this important fisheries conservation project: Avista Power, Clearwater Power, Collier Electric, Inland Metals Electric, TDS Telecom, Jim and Pat Thornton, Jim and Betty Koch, WDFW, and USFS.

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LIST OF ABBREVIATIONS

ACCD	- Asotin County Conservation District
CHaMP	- Columbia Habitat Monitoring Protocol
DEM	- Digital elevation model
DoD	- Geomorphic change detection using the difference between two DEMs
DOE	- Washington State Department of Ecology
PALS	- Dynamic woody structure (main restoration technique proposed)
ELR	- Eco Logical Research Inc.
IMW	- Intensively Monitored Watershed
ISEMP	- Integrated Status and Effectiveness Monitoring Program
LWD	- Large woody debris
NOAA	- National Oceanic and Atmospheric Administration's
NRCS	- Natural Resources Conservation Service
PCSRF	- Pacific Coastal Salmon Recovery Fund
PTAGIS	- PIT Tag Information System
PUD	- Public Utility District
RTT	- Regional Technical Committee
RCO	- Washington State Recreation and Conservation Office
SRSRB	- Snake River Salmon Recovery Board
USDA	- United States Department of Agriculture
USGS	- United States Geological Survey
WDFW	- Washington Department of Fish and Wildlife
WRIA	- Washington Water Resource Inventory Area

1. INTRODUCTION

1.1 Background

Restoration of the freshwater habitat of anadromous salmonids has been occurring for decades with little evidence that restored habitat has led to an increase in salmonid populations at the watershed scale (Bernhardt et al. 2005, Roni et al. 2008, Roni et al. 2010). Recently a series of Intensively Monitored Watersheds (IMWs) have been established in the Pacific Northwest to assess the effect of different restoration actions on populations of salmonids at the watershed scale (Bilby et al. 2005, Bennett et al. 2015). IMWs use an experimental framework to increase the probability of detecting a population level response to restoration actions, should one exist. A population level response can be defined as any increase in freshwater production or productivity of salmonids due directly or indirectly to a restoration action. Freshwater production can be measured by summation of salmonid abundance, growth, and survival over a defined period of time (Almodóvar et al. 2006, Horton et al. 2009) whereas freshwater productivity can be measured by calculating the recruits from one life stage to another such as smolts/spawner (Crawford and Rumsey 2011). For practical purposes, it is assumed a population level response will need to be large (i.e., $\geq$ 20%) to be detected by most monitoring efforts (Hinrichsen 2010, Roni et al. 2010). The main goals of IMWs are to assess how restoration actions alter stream habitat conditions, and to understand the casual mechanisms between stream habitat restoration and changes in salmonid production at the watershed scale. Asotin Creek was chosen as the site of an IMW in southeast Washington through a process coordinated by the Snake River Salmon Recovery Board (SRSRB). A detailed account of the process to select an IMW in southeast Washington can be found in Bennett and Bouwes (2009).

The intent of this document is to revise and synthesize the original study plan (Bennett and Bouwes 2009), restoration plan (Wheaton et al. 2012), summary of pre-treatment data (Bennett et al. 2012), and the most recent annual report (Bennett and Camp 2015) into one document. There was a need to revise the previous study plan and restoration design because of changes made to the experimental design based on a power analysis simulation, and changes to naming conventions for restoration actions during the pre-treatment phase of the IMW. This document will now act as the official study plan and supersede all other reports.

1.2 Adaptive Management Approach

Although adaptive management (Holling 1978) is frequently touted as an important part of the restoration process, it is very rarely fully integrated into the restoration plan (Walters 1997, Downs and Kondolf 2002). Adaptive management explicitly incorporates monitoring into the restoration process, thereby forming an iterative process of learning by doing, while providing opportunities for the information gleaned from the assessment and evaluation of monitoring activities to be explicitly incorporated into refining restoration actions. We have implemented the Asotin IMW using an adaptive management process and describe the steps we followed in developing and implementing an adaptive management plan for the Asotin Creek IMW in Bouwes et al. (2015). We focus on the adaptive management steps that involve development of conceptual models, testable hypotheses, evaluation, learning, and a structured approach to project adjustments because they are critical to maximize learning and these steps have not been implemented in many projects that purport to use adaptive management (Gregory et al. 2006, Allen and Gunderson 2011). Each year we evaluate our experimental and monitoring designs and the effectiveness of the restoration actions and use 'triggers' to decide if adjustments are necessary (Figure 1). For example, if the restoration structures were causing harm we would remove them or alter their design. We used pre-treatment monitoring and literature to develop conceptual models of system function and then used the conceptual models to develop restoration design hypotheses which in turn dictated the monitoring necessary to test those hypotheses and undertake the critical adaptive management learning loop through assessment and evaluation of this data. We have made several changes to the overall design of the Asotin IMW either because of events beyond our control (e.g., changes in access to private land) or incorporating new information during our annual evaluation loops (Appendix I).

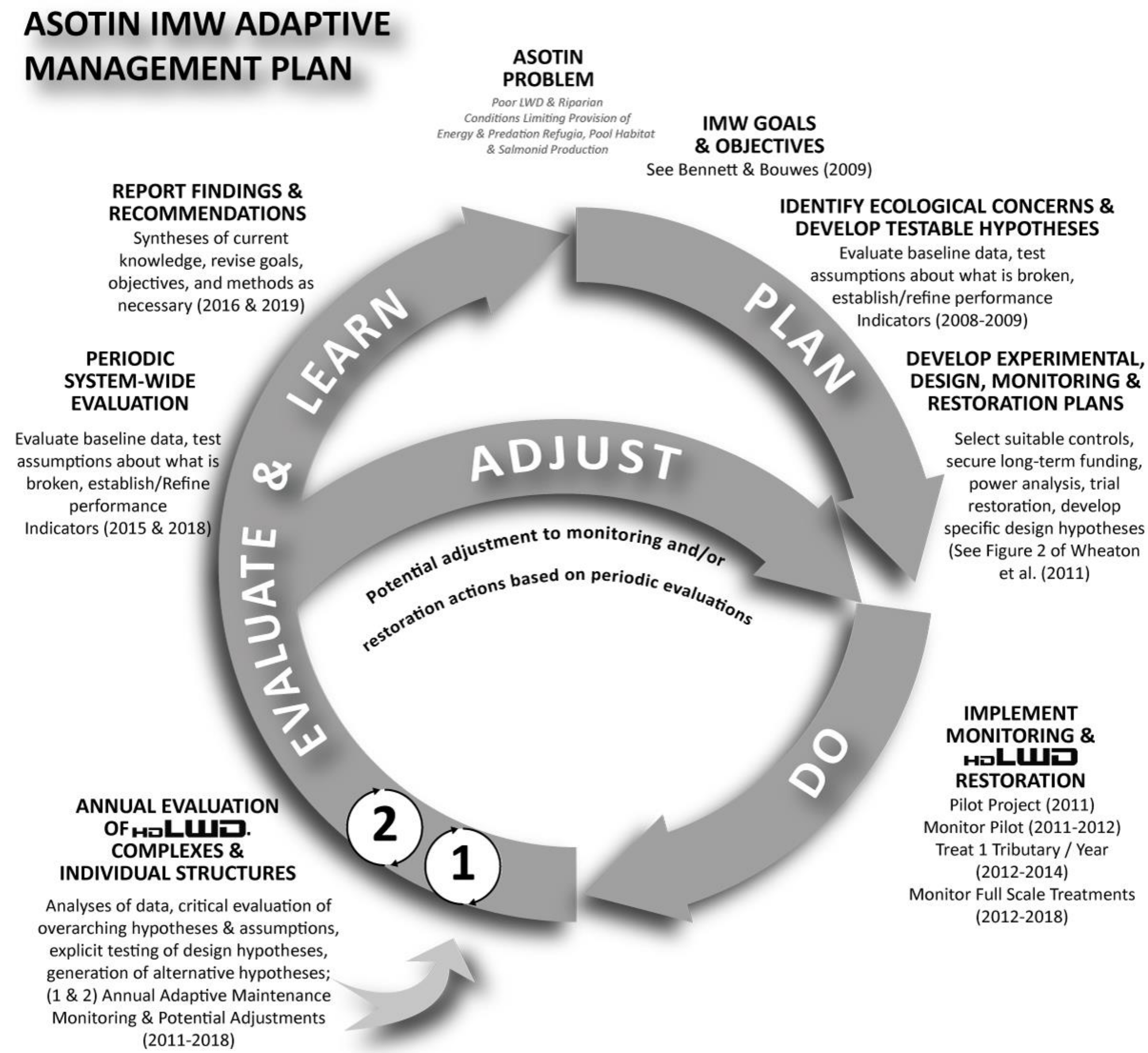


Figure 1. Asotin Creek Intensively Monitored Watershed adaptive management framework. Separate restoration structure and treatment section evaluation and learning loops (circles 1 & 2) are described further in Bouwes et al. (2015). $_{HD}$LWD = high density large woody debris restoration approach (see Section 8 for more details).

1.3 Selection of IMW Location

A set of candidate streams were selected for consideration as an IMW location based on two minimum criteria: the stream had to contain ESA listed salmonid species and there had to be some level of landowner support for the project. We then compiled existing information for each stream (i.e. average annual flow, average number of redds, years of historic fish and habitat data, etc.) to assess their potential as an IMW location. We then compiled a set of selection criteria to screen candidate streams based on past experience and published IMW literature (Table 1; Bilby et al. 2004, PNAMP 2005). The criteria were then ranked by each RTT member based on which was considered the most important for selecting an IMW location. These values were used to decide which streams best met the criteria for an IMW location (see Bennett and Bouwes 2009 for more detail on selection process).

Table 1. Criteria used to evaluate the best location for an Intensively Monitored Watershed in southeast Washington.

Criteria	Description
Potential for Response	EDT analysis of "restoration potential" (i.e. how likely is fish abundance to respond to restoration directed at limiting factors)
Seeding (# redds and redds/mile)	The number of redds/mile and total number of redds per subbasins; minimum criteria of 20 redds required to be considered for IMW
Controls	The number of subbasins with similar characteristics
Culture/ Social Significance	Did the basin have significant cultural and/or social significance (i.e. ESA listed species, recreational use, traditional use, etc.)?
Southeast Washington	Were the limiting factors representative of issues in southeast WA?
% Hatchery	Assumed that a lower % of hatchery fish would lead to fewer confounding factors
Fish Data	The number of years for all fish data collection summed by basin
Habitat/Water Quality Data	The number of years for all habitat or water quality data collection summed by year
Ongoing Monitoring	Summed all ongoing monitoring programs
PNW	Were the limiting factors representative of issues in southeast WA and across the Pacific Northwest
Past Restoration	Summed the number of restoration projects and divided them by the area (ha) of stream habitat in that reach/basin
Size	Used mean annual stream flow (cfs) to estimate size of basin and ability to restore function

Based on our IMW assessment and selection process outlined above, Asotin Creek watershed was selected as the location of the IMW. Asotin Creek and its tributaries are desirable as an IMW location in the SRSRR, in part, for the following reasons:

- There was strong agency and land owner support,
- Asotin Creek represents an area of significant concern for the region because of the presence of a wild steelhead population, and steelhead population seeding levels are relatively high compared to other candidate IMW watersheds in the region,

- A model watershed plan (ACCD 1995), subbasin plan (ACCD 2004), and recovery plan (SRSRB 2011) have been developed,
- Extensive restoration activities consistent with these plans have been implemented that reduced many limiting factors (e.g., high erosion rates of uplands mitigated in late 1990's),
- Low incidence of hatchery spawners (< 5%) as hatchery fish removed at lower adult weir (Crawford et al. 2015),
- Asotin Creek subbasin is a single MSA and as such has criteria and benchmarks against which to monitor progress (although includes multiple Snake River tributaries as part of the total Asotin population),
- WDFW has operated a smolt trap since 2004 and an adult weir since 2005, and collects an extensive suite of biological and trap efficiency data,
- WDFW has a long-term adult escapement and juvenile density/distribution abundance data set (1983 - present),
- Several stream habitat surveys have been conducted by the USFS and Natural Resources Conservation Service (NRCS) throughout the study area (NRCS 2001, Dowdy 2002),
- There are three active stream flow gauges in the Asotin Creek MSA, and
- Several years of water temperature and discharge data are also available (Bumgarner et al. 2003).

1.4 Coordination and Implementation of the IMW

Beginning in late 2007 ELR meet regularly with the SRSRB and RTT to introduce the IMW goals and objectives and to become familiar with state and federal fisheries and land management agencies, tribes, and conservation districts that are involved in salmon (*Oncorhyncus spp.*) and steelhead (*O. Mykiss*) conservation in southeast Washington. We used monthly RTT meetings led by the SRSRB to develop the IMW and coordinate with ongoing groups and programs. An important aspect of this coordination process was determining the types of ongoing and historic fish and habitat monitoring efforts and how these efforts could be used as part of the IMW monitoring design to reduce overall project costs and increase the overall efficiency of data collection in the study area. In addition, RTT and SRSRB members provided valuable institutional knowledge of the potential IMW areas that greatly aided in our understanding watershed conditions and potential difficulties in conducting a large scale stream restoration program.

Once Asotin Creek was chosen as the location of the IMW, several meetings with local landowners and the Asotin County Conservation District were conducted to discuss the details of the IMW project and ensure there was long-term commitment to the IMW. At this time two key landowners were contacted in Charley Creek to get permission to monitoring on their land (both landowners were in Charley Creek). However, since 2012 the WDFW has purchased land from these landowners and now all the IMW actions take place on WDFW or USFS land.

1.5 IMW Structure and Timeline

Eco Logical Research Inc. (ELR) was contracted in 2007 to coordinate the selection of an IMW site in southeast Washington, develop an experimental design, implement monitoring and restoration actions, and assess the effectiveness of the restoration at increasing steelhead productivity (Table 2). This is a relatively unique situation as other IMWs are generally designed and implemented by a large group of agency and private companies. However, there is still a great deal of support and assistance by other groups in implementing the IMW. As the two major landowners of the IMW study area, WDFW and USFS collect data on fish and habitat, control invasive species, and provide logistical and direct donations to the IMW project (Table 2).

Table 2. Roles/responsibilities related to the implementation and management of the Asotin Creek IMW.

Agency/Group	Actions and Roles
Eco Logical Research Inc.	Design, project management, IMW specific monitoring (mark-recapture, mobile surveys, habitat surveys, temperature and discharge gages), implementation of restoration actions, data analysis, QAQC, data storage, reporting, and presentation of IMW progress and results. A total of ~ $1,508,700 has been spent on IMW management, design, and monitoring over the eight years of the project (average ~ $188,000/year). This generally is allocated to four seasons of fish surveys (12 sites per survey), 18 summer habitat surveys, restoration effectiveness surveys, maintenance of PIT tag infrastructure (three arrays), and discharge (2 sites) and temperature monitoring (20-25 sites). We estimate that ~ $300,000/year is needed to properly implement this IMW.
WDFW	Fish in Fish monitoring at Asotin watershed scale (funded separately by BPA), redd surveys at watershed scale (funded by WDFW); assist in various aspects of IMW monitoring and restoration when staff and budget available (funded by IMW). Other ancillary studies such as mainstem tagging to assess movement on mainstem (funded by WDFW).
USFS	Donation of LWD to restoration efforts; provide data from past and ongoing habitat, water quality, and invertebrate sampling, weed control, and technical assistance.
Snake River Salmon Recovery Board	Coordinate IMW activities, funding, and presentation of IMW activities; facilitate technical review of IMW activities via Regional Technical Team; provided management of IMW funds from 2007-2013.
WA Recreation & Conservation Office	As of 2013 RCO provides management of IMW monitoring funds and coordinates Asotin IMW proposals with other ongoing IMWs in state of WA.
NOAA Fisheries	Provide design, project management, and monitoring funding via NOAA Pacific Coastal Salmon Recovery Fund (PCSRF); also significant technical support through CHaMP website (where we store habitat data) and ISEMP (provides data collection apps, databases, monitoring methods, equipment and materials (e.g., survey equipment and PIT tags), and analysis support (e.g., developing NREI, Barker model survival estimates).
Salmon Recovery Funding Board	All restoration actions to date have been funded by the SRFB (2012-2014). A total of $430,582 has been spent to date to treat 12 km of the 36 km study area.

The Asotin IMW began in 2008 with a summer fish capture and tagging and habitat survey at nine sites (Figure 2Figure 2). Monitoring infrastructure such as PIT tag arrays, water height gages, and temperature probes were installed by 2009. We conducted a trial of the restoration approach in 2011 and implemented full restoration between 2012-2014. We are proposing one last restoration treatment to increase the percent of the IMW study area treated from 33.3% to approximately 40%. We are also proposing the addition of more LWD in all treatments because our surveys indicate that wood density has not reached reference conditions. We expect ongoing effectiveness monitoring to continue until 2019 at a minimum.

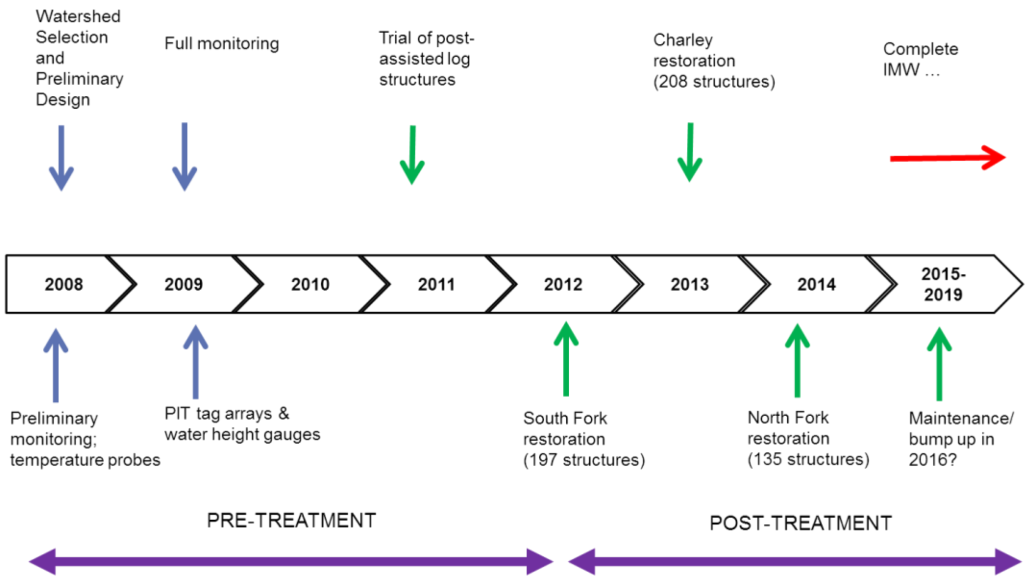


Figure 2. Timeline of Asotin Creek IMW design, monitoring, and restoration implementation. The initial restoration design of 12 km of wood treatments was completed from 2012-2014. A final restoration treatment and maintenance/increasing LWD density is proposed for 2016.

1.6 Focal Species

Asotin Creek supports three species currently listed as threatened under the Endangered Species Act (ESA): bull trout (*Salvelinus confluentus*), spring Chinook salmon (*O. thshawytcha*), and summer steelhead (ACCD 2004). Bull trout are mostly limited to the upper watershed apart from migrating adults and caught in very low numbers in the IMW study area (< 5 per year). Spring Chinook salmon are considered functionally extirpated in Asotin Creek but small numbers of spring and fall origin Chinook do spawn in Asotin Creek each year (Crawford et al. 2015). However, very few juvenile Chinook salmon are captured in the IMW study area (<100/year). Summer steelhead are the most abundant salmonid species in Asotin Creek and were selected as the target species for the IMW study. The Asotin steelhead are summer "A" run fish that generally migrate past Bonneville Dam before August 25 (ACCD 2004). An average of 657 wild adult steelhead return to spawn upstream of the WDFW adult weir trap on the mainstem of Asotin Creek each year based on 2005-2014 data (Crawford et al. 2015). Adult steelhead start entering Asotin Creek in December and peak spawning takes place in April and May. Asotin Creek was designated by WDFW as a natural production steelhead reserve area after the discontinuation of a hatchery supplementation program in 1997. Since 2009, stray hatchery adult steelhead are removed by WDFW at the adult weir near the mouth of Asotin Creek and it is estimated that fewer than 5% hatchery fish now spawn in Asotin Creek (Crawford et al. 2015).

2 WATERSHED SETTING AND IMW STUDY AREA

The Asotin Creek IMW is within the Snake River Salmon Recovery Region (SRSRR). The major river drainages in the region are the Asotin Creek, Tucannon River, Walla Walla and Touchet rivers and a portion of the Grande Ronde River Basin. The southeastern portion of the SRSRR is dominated by the forested Blue Mountains which rise to over 1940 m elevation. The remainder of the study area is a series of semi-arid rolling hills and ridge tops and deeply incised watersheds (SRSRB 2011). The majority of the land use in the region is dry land crops (55%), rangeland (21%), forest land (16%), and over 87% of all land in the region is privately owned (SRSRP 2006). Precipitation ranges from 30 cm per year in the lowlands to over 178 cm per year in the Blue Mountains.

The development history of southeast Washington was somewhat different than other areas (e.g. northeast Oregon) due to the relative isolation of the area from the traditional migration routes of early settlers (McIntosh et al. 1994). Grazing was the predominant form of landscape disturbance in the late 1800's and in many cases caused terraced hillslopes and high rates of erosion. After World War I the amount of grazing began to decline and forest harvesting and agriculture became the predominant forms of land use and causes of stream degradation. The combined effects of agriculture, forest harvesting, and grazing have contributed to further degradation of stream habitat, especially in the lower stream reaches (SCS 1984).

Asotin Creek is a tributary of the Snake River, flowing through the town of Asotin, in the southeast portion of Washington and the SRSRR (Figure 3Figure 3). The Asotin Creek watershed is within the Columbia Plateau and Blue Mountains level III ecoregions. These ecoregions are dominated by deep narrow canyons cut into underlying basalt lithology and surrounded by semi-arid sagebrush steppe and grasslands at lower elevations and open conifer dominated forests at higher elevations (Omernik 1987, Clarke 1995, Omernik 1995). The Asotin watershed is approximately 842 km^2 and the average annual precipitation ranges from 115 cm at higher elevations in the Blue Mountains to less than 30 cm at lower elevations (240 m) along the Snake River. Three study creeks make up the IMW study area: Charley Creek, North Fork Asotin Creek, and South Fork Asotin Creek (hereafter the study creeks; Figure 3).

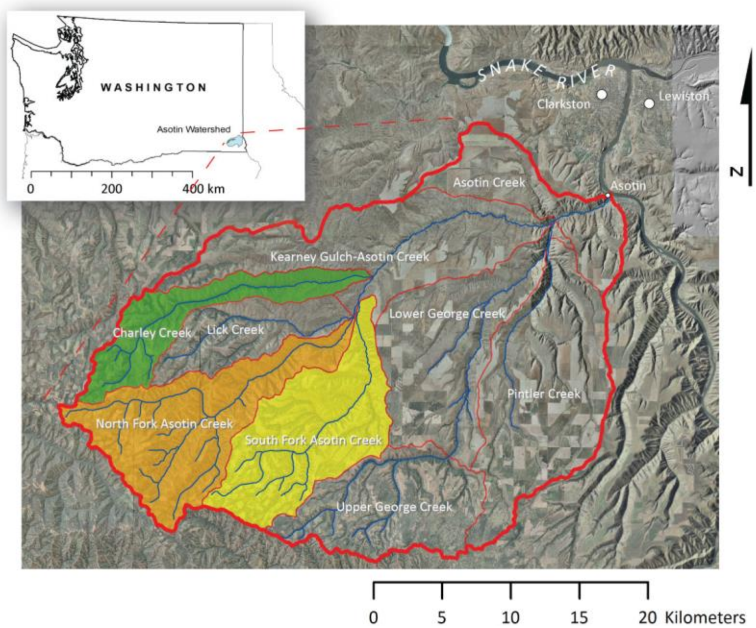


Figure 3. Location of Asotin Creek within Washington and the Asotin Creek Intensively Monitored Watershed study creek watersheds (i.e., three colored watersheds) within the Asotin Creek.

2.1 Geology

The Asotin Creek watershed typifies many of the tributaries to the Snake River in southeast Washington and northeast Oregon in terms of its basic physiographic setting. Three broad geologic attributes set the character of the watershed: 1) the underlying igneous bedrock sourced from lava flows (part of the Columbia River Basalt Group) that forms the broad plateau surfaces and uplands; 2) the Snake River Gorge, which sets the base-level control for tributaries like Asotin Creek, which 3) have dissected the lava flows with a network of streams draining to the Snake River that have carved steep canyons, the larger of which have filled small valley bottoms with alluvium. The Columbia River Basalt Group (CRBG) is a thick sequence of flood basalts that spread throughout northern Oregon, eastern Washington and western Idaho during the Miocene between 6 and 17 million years ago. During the Pliocene (5.4 to 2.4 million years ago) these CRBG flows were uplifted, allowing the antecedent streams to form steep-sided canyon walls and hillslopes and formation of high plateaus (Gentry 1991). Many of these high plateaus are mantled by loess (wind-blown sediment) deposits. The Snake River Canyon, at the mouth of Asotin Creek, was subjected to the cataclysmic Bonneville flood some 14,000 to 15,000 years ago, associated with the catastrophic drainage of Lake Bonneville. Deposits from the Bonneville flood are overlain by additional flood deposits associated with drainage of Glacial Lake Missoula. However, the majority of the IMW study area is not influenced by loess soils (Figure 4Figure 4).

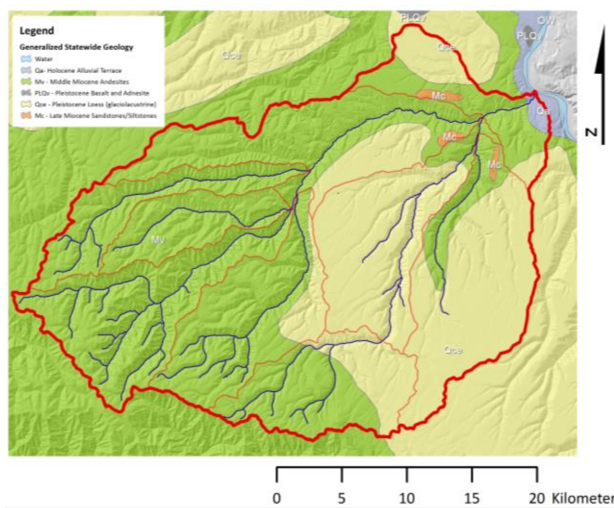


Figure 4. Asotin Creek Watershed bedrock and surficial geology; data obtained from WA State Geologic Map.

2.2 Hydrology and Watershed Characteristics

Mean annual precipitation in the Asotin watershed is 58 cm per year with the majority of this precipitation takes place in the winter months as snow in the upper elevations (Table 3). However, the biggest floods are associated with either rain-on-snow events or highly localized, high intensity convective summer thunderstorms that may form over a small portion of the watershed but produce a major flood downstream. Although the rock and soils are well drained, the soils and exposed bedrock are susceptible to runoff-driven erosion during such events via Hortonian overland flow (i.e., where rainfall rate exceeds infiltration rate). We have observed some of these events using trail cameras set to photograph sections of stream every hour (e.g., South Fork Asotin Creek, February 12, 2014 12:00pm: https://docs.google.com/file/d/0BwjA7Fk0-oqLYk1OUGdtbmNHcmc/edit).

Table 3. Basic watershed characteristics as summarized by the USGS Stream Stats tool for the three study creek watersheds, the Asotin watershed, and in contrast to the George Creek subwatershed in the eastern half of the Asotin Watershed (http://water.usgs.gov/osw/streamstats/index.html).

Parameter	Charley	North Fork	South Fork	Asotin	George
Basin Area- square km	58	165	104	841	332
Mean Basin Elevation in m	1,216	1,305	1,234	1,021	960
Min Basin Elevation in m	521	561	564	228	287
Max Basin Elevation in m	1,701	1,890	1,823	1,890	1,667
Max – Min elevation, in m	1,180	1,329	1,259	1,664	1,381
Mean basin slope in percent	34	40	29	24	15
% area slope > 30 percent	57	68	43	36	19
% area slope >30 percent and facing North	17	18	12	10	4
% area covered by forest	39	44	30	21	14
Mean annual precipitation, in cm	67	76	70	58	53

On average, Asotin Creek has a typical snow melt dominated flow pattern with the peak runoff usually happening in late May (Figure 5). Streamflow is monitored by the United States Geological Service (USGS), Washington Department of Ecology (DOE), and ELR. The earliest record of streamflows is available starting in 1928 (Headgate dam which is no longer active) and the longest record of continuous data is 35 years. ELR has maintained water level loggers on Charley and South Fork Creeks since fall 2009 and pressure transducers on the mainstem Asotin and North Fork Creeks since summer of 2011 (Figure 6Table 4). The water height data (hourly records) are combined with periodic field measurements (usually 1-2 times a month and during low and high flow periods) to develop stage discharge relationships for each logger.

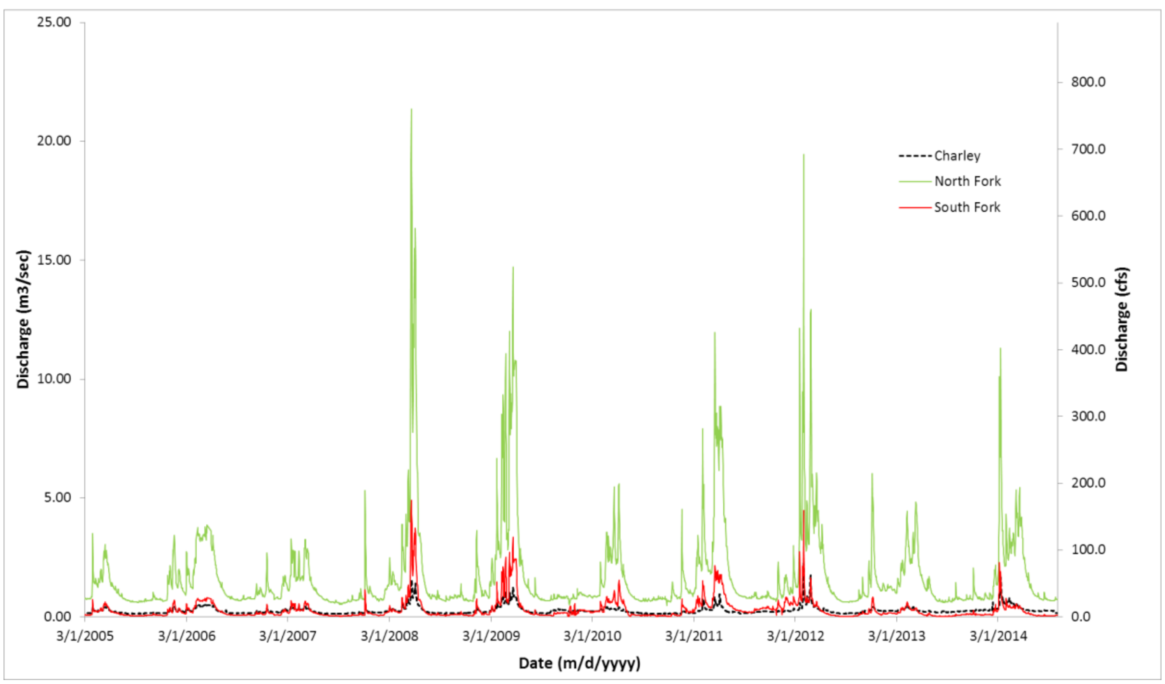


Figure 5. Estimated daily discharge in the three Asotin Creek IMW study creeks from March 1, 2005 through September 30, 2014. Estimates come from a combination of water height gages deployed in 2009 at the mouth of Charley Creek and South Fork and USGS gage data from the mainstem Asotin Creek.

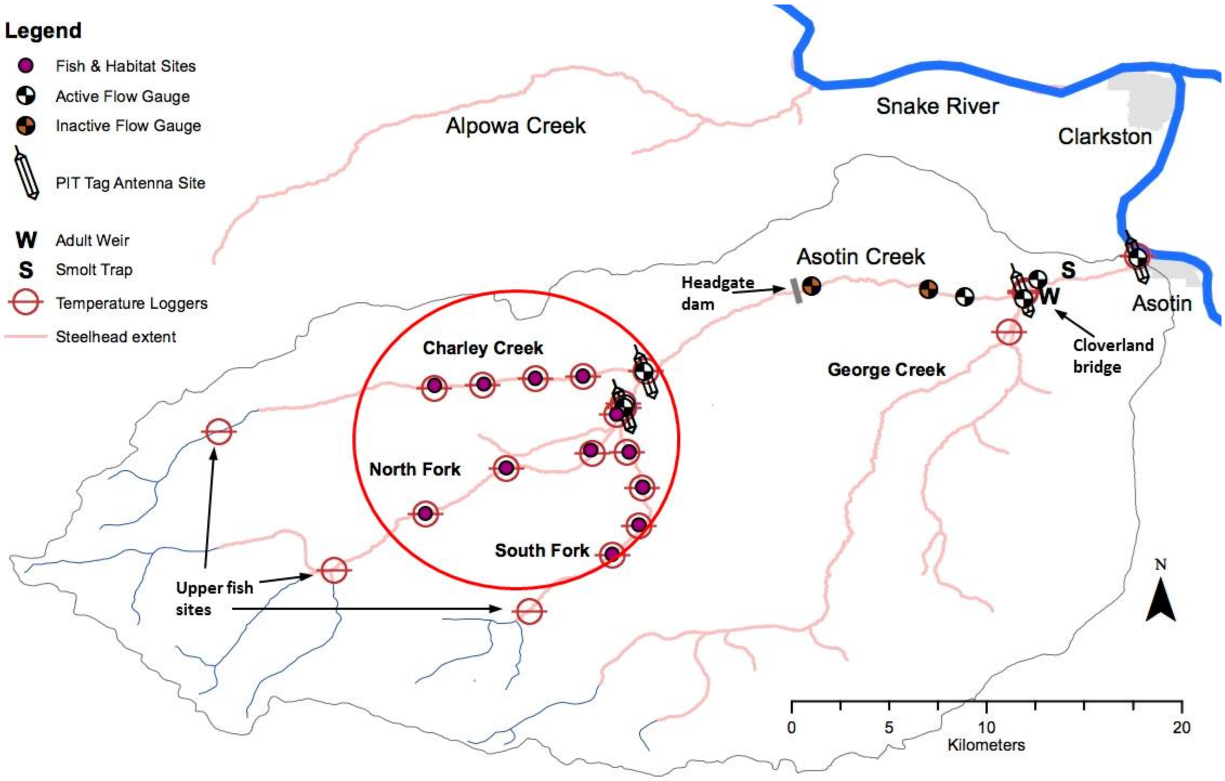


Figure 6. Monitoring infrastructure for the Asotin IMW. Eco Logical Research Inc. monitors IMW sites in study creeks (Charley, North Fork, and South Fork) for fish and habitat, stream temperature, discharge, and PIT tag arrays; WDFW monitors fish in fish out at lower mainstem smolt trap and adult weir; historic and current USGS and DOE gages are throughout the mainstem. Area within the red circle is the focus of IMW monitoring and will be referred to as the 'IMW study area' in the remainder of the report. Upper fish sites are sampled periodically to aid in determining proportion of anadromy versus residency of juvenile steelhead changes moving upstream.

The mean annual discharge of Asotin Creek is approximately 2.2 m^3/sec (78 cfs). During the period 2006-2013 using the existing DOE and USGS gages and the IMW gages we estimated the mean annual discharge of the study creeks to be: North Fork 1.7 m^3/sec (60 cfs), South Fork 0.33 m^3/sec (11.5 cfs), and Charley 0.27 m^3/sec (9.5 cfs). The study creek discharges track each other closely based on a relatively predictable pattern of snow melt in the spring; however, the discharge from Charley Creek is dominated by spring-fed flows that give it a more consistent base flow (Figure 5Figure 5). The peak flows do scale roughly to drainage area. Although the South Fork is a larger stream and has a larger basin area, during the summer months Charley Creek can have greater flows than the South Fork due to the more consistent spring-fed dominated flows (Figure 5).

The largest flow on record in the Asotin Creek was 143 m^3/sec (5,050 cfs) during the winter of 1996/97 resulting from a rain on snow event. Although the flood was documented to have reduced the amount of riparian vegetation and pools along large sections of the mainstem (NRCS 2001), these floods present major opportunities to work with fluvial processes to reshape a more dynamic stream channel. A flood the size of the 1996/97 flood has a predicted return interval of approximately 25 years based on the USGS Stream Stats tool (Table 4).

Table 4. Predicted flows (cfs) based on gauge data and basin characteristics for the main basins within Asotin Creek watershed based on USGS Stream Stats tool.

Recurrence Interval (years)	Charley	North Fork	South Fork	Asotin
2	292	674	448	1490
10	866	1740	1250	3880
25	1280	2460	1810	5460
50	1660	3100	2310	6820
100	2080	3790	2870	8320
500	3300	5730	4450	12400

2.3 Stream Morphology and Classification

We used data from 2011-2013 collected using the Columbia Habitat Monitoring protocol to describe the stream morphology of the study creeks (CHaMP 2014). The study creeks are small to medium sized with relatively simple channel form and have low sinuosity and bankfull widths that range from 4.8 – 9.8 m (Table 5). The study creeks have coarse substrates dominated by cobble. Charley Creek has the most fine sediment of the three study creeks and smallest average substrate size. All of the study creeks have low frequencies of LWD and pools and average residual pool depth of $\leq$ 0.30 m.

Table 5. Summary of stream characteristics 2011-2014 for Charley Creek, North Fork, and South Fork in the Asotin Creek IMW project*.

Stream	Sinuosity	Gradient (%)	D50 (mm)	% fines <2 (mm)	% fines <6 (mm)	BFW (m)	Pools/ 100 m	RPD (m)	LWD/ 100 m	Solar Access
Charley	1.20	3.01	53.2	11.1	19.1	4.8	2.1	0.26	15.3	65.5
North Fork	1.17	1.65	76.3	5.3	12.9	9.8	1.5	0.30	16.7	73.8
South Fork	1.15	2.63	72.2	6.3	12.8	6.4	2.3	0.20	10.6	65.9

* All data summarized from sampling at a minimum of three habitat sites per stream using the Columbia Habitat Monitoring Protocol (CHaMP 2014). Grad = % slope; D50 based on Wolman pebble counts; % fines = pool tail fines; BFW = bankfull width; W:D = width to depth ratio; Pool Freq = number of pools/100 m; RPD = average residual pool depth; LWD/100 m = number of large woody debris pieces >= 1.0 m long and >= 0.1 m in diameter/ 100 m; Solar Access = average available solar radiation from July-September.

2.4 Geomorphic Assessment

Considerations of fish and habitat responses to restoration activities will be most informative if appraised within the appropriate spatio-temporal context (e.g., Wohl et al. 2005, Hemstad and Newman 2006). This requires the collection, analysis and presentation of geospatial data describing baseline and changed environmental conditions as well as some conceptual model within which biological and physical relationships are appraised. To support this end, we are in the process of developing the geomorphic assessment of Asotin Creek based on the River Styles framework (Brierley and Fryirs 2005). There are four basic stages we are using to conduct a geomorphic assessment: determining 1) river character and behavior, 2) current condition, 3) recovery potential, and 4) priority management actions. We have completed the first two stages of the geomorphic assessment (Camp 2015).

2.4.1 River Character and Behavior

Using the River Styles framework (Brierley and Fryirs 2005) we have described the landscape units and reach types (e.g., river styles) as well as the geomorphic and fluvial processes that shape river channels and ultimately constrain the types of fish habitat that can be present. This procedure will provide us with the context in which to interpret and understand the habitat responses to restoration actions and enable better transfer of the lessons learned in the Asotin Creek IMW to other watersheds. There are four landscape units and nine distinct river styles in the Asotin Creek watershed (Figure 7). The majority of the river network with defined channels in the Asotin Creek drainage is either confined or partly confined. The long segments of confined valleys are common because the basin is dominated by multiple layers of ancient basalt flows, topped by Palouse loess soils on some ridge tops. The only instances of laterally unconfined streams are found in the very bottom of the catchment where the valley is uncharacteristically wide. See Camp (2015) for detailed description of the methods and results of the assessment of Asotin Creek.

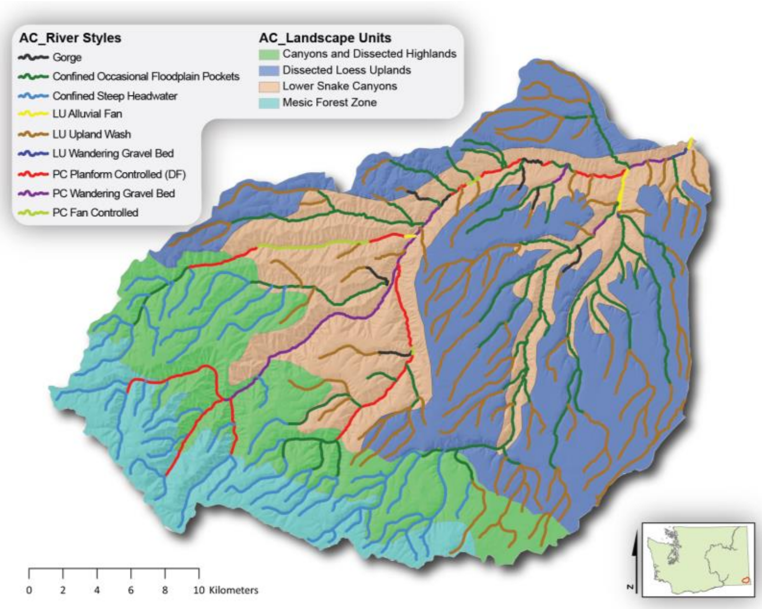


Figure 7. Landscape units and River Styles of 2nd order and higher streams in the Asotin Creek watershed (Camp 2015).

2.4.2 Condition Assessment

We found reaches in *good, moderate, and poor* condition during our condition assessment. We did not identify any *intact* reaches based on the effects of historic land use that has occurred throughout the watershed. However, we designated the majority of the North Fork of Asotin Creek and the headwaters of the South Fork of Asotin Creek as *good* condition variants of the associated River Styles. The rest of the South Fork of Asotin Creek is in *moderate* geomorphic condition with a short reach of *poor* condition near the mouth of Warner Gulch. Nearly the entire length of Charley Creek is in *moderate* or *poor* geomorphic condition. Similarly, most of George Creek and its tributaries are in *moderate* or *poor* condition. We recognize, however, that much of the IMW study streams are currently in recovery, and there is no indication that geomorphic condition is deteriorating at most of the reaches. See Camp (2015) for details of geomorphic assessment.

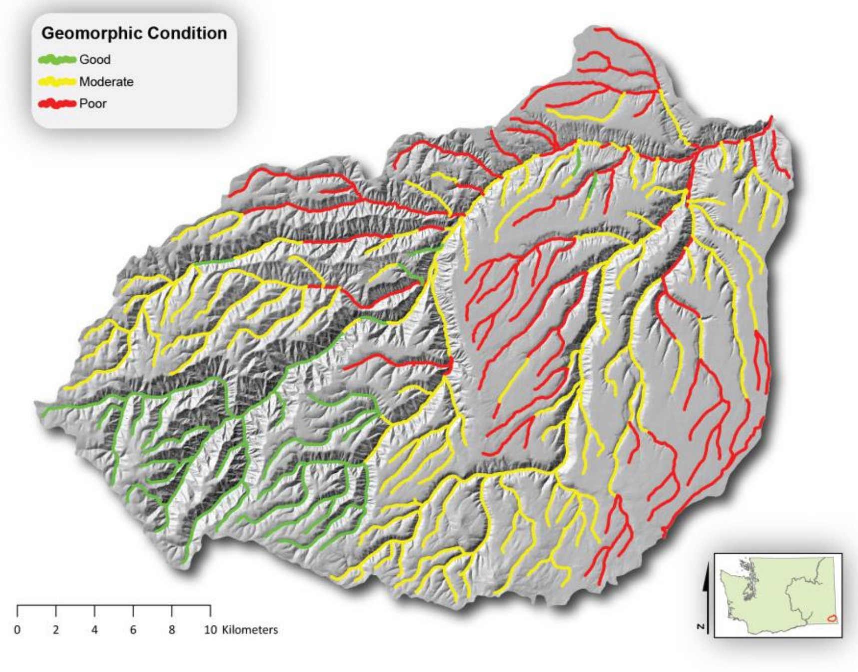


Figure 8. River Styles geomorphic condition assessment of 2nd order and higher streams in the Asotin Creek watershed (Camp 2015).

3 LIMITING FACTORS

3.1 Historic Disturbance, Limiting Factors, and Past Restoration

Grazing, forestry, and upland farming practices starting in the 1800s and early 1900s led to accelerated levels of soil erosion throughout southeast Washington (SCS 1984, ACCD 1995). Soil erosion rates were highest from croplands with moderate rainfall, averaging an estimated 8 tons/acre (SCS 1984). This created a fine-sediment and water quality problem for many of the creeks in the region. Loss of riparian habitat from over grazing exacerbated erosion rates and delivery of fine sediments to stream throughout the Asotin watershed. Stream habitat continued to be impaired by road and levee construction, logging, large woody debris removal, and flooding, all of which tended to decrease the sinuosity and habitat complexity of streams (ACCD 1995, NRCS 2001). Two recent flood events have been identified as causing further simplification of stream habitat in Asotin Creek and its tributaries: 1) Charley Creek was impacted in the 1960's by a flood resulting from the failure of two man-made fish ponds which are suspected of causing much of the channel incision observed in recent surveys (NRCS 2001), and 2) the largest flood on record occurred in the winter of 1996/97 (see summaries in Bennett and Bouwes 2009).

In 1995 a watershed plan was developed for Asotin Creek by a land owner steering committee with support from state agencies (ACCD 1995). The plan was one of the first attempts in Washington State to develop a watershed-scale plan to restore stream function and salmonid populations. The plan highlighted four key limiting factors for salmonid production in the watershed: i) high stream temperature, ii) lack of resting and rearing pools containing LWD, iii) sediment deposition in spawning gravels, and iv) high fecal coliform counts. The model watershed plan called for a series of restoration efforts to improve fish habitat and water quality including riparian fencing (26,400 linear feet), riparian planting (36,000 linear feet), instream habitat structures (144), tree planting (30 acres), and changes to upland farming practices including over 1,400 ha reserved in permanent grass cover. Since 1996, 581 fish habitat related projects have been implemented in the Asotin Creek watershed with the majority of projects focused on upland issues (60%) and riparian restoration (24%). Most of these projects were implemented in George Creek and its tributaries and in upper Asotin Creek between Headgate Dam and the confluence of North Fork and South Fork Creeks. It was speculated that implementation of the plan resulted in reductions of sediment from upland sources, stabilization of stream banks, and increased habitat complexity (NRCS 2001). While this is a reasonable assertion, a major learning opportunity was missed because adequate baseline monitoring and post project monitoring and assessment was not undertaken to definitively establish this.

Much of the riparian habitat along the mainstem of Asotin Creek has been recently fenced to prevent further degradation by cattle and large areas have been planted and or converted to Conservation Reserve Enhancement Program (CRP) land in an effort to restore riparian function (ACCD 2004). In the North Fork and South Fork, cattle grazing has been removed for several years as part of the WDFW and USFS management plans and planting of riparian areas has also been conducted. Riparian cover is well established along most of the North Fork and South Fork with lower reaches dominated by alder and willow and upper reaches becoming more conifer dominated. However, riparian function, channel, and bank conditions are still impaired in some areas, especially the lower reaches of Charley Creek on private land (NRCS 2001, Bennett and Bouwes 2009).

In 2013 WDFW negotiated the purchase of land from two private landowners bordering Charley Creek and this property is now in fenced and protected from cattle grazing. With this purchase, the entire IMW study area (Figure 6) is owned and managed by either WDFW or USFS except for a small parcel on South Fork Creek and the lower 200-300 m of Charley Creek (B. Dice, Personal Communications).

Prior to the initiation of the IMW study in Asotin Creek, EDT analysis was used to identify limiting factors for steelhead in Asotin Creek (SRSRB 2006). Common limiting factors that were identified in the Asotin Creek subbasin included increased sedimentation, substrate embeddedness, water temperature, decreased riparian function, floodplain connectivity, habitat diversity, low LWD, and low pool frequency and quality. Partial fish passage barriers were also identified at Headgate dam and Cloverdale Bridge on the Asotin mainstem, and Asotin Creek Road over lower Charley Creek.

3.2 Current Limiting Factors

To verify the historic assessments and determine which limiting factors to address with the IMW restoration we conducted numerous field investigations, summarized existing data, and compared our findings to the best possible reference conditions we could find (Bennett and Bouwes 2009, Bennett et al. 2010, Bennett et al. 2012, Wheaton et al. 2012). We concluded that riparian function is likely the most significant limiting factor in the IMW study area; however, many previously identified limiting factors are related to poor riparian function. The riparian conditions along the study streams appear relatively healthy and are providing adequate cover and shading to help regulate stream temperatures. However, a closer inspection reveals that most of Charley, large stretches of the South Fork, and portions of the North Fork are channelized, a fairly stable, young and small diameter (Figure 9), and rather homogenous riparian age and species structure (Bennett et al. 2012). This likely reflects a steady recovery following cessation and/or reduction in some of the previous land uses (e.g., logging, grazing) and large floods which caused most of the historic damage. Unfortunately, this recovery has taken place around a relatively homogenized channel and has acted to stabilize the degraded condition of the channel (Figure 10).

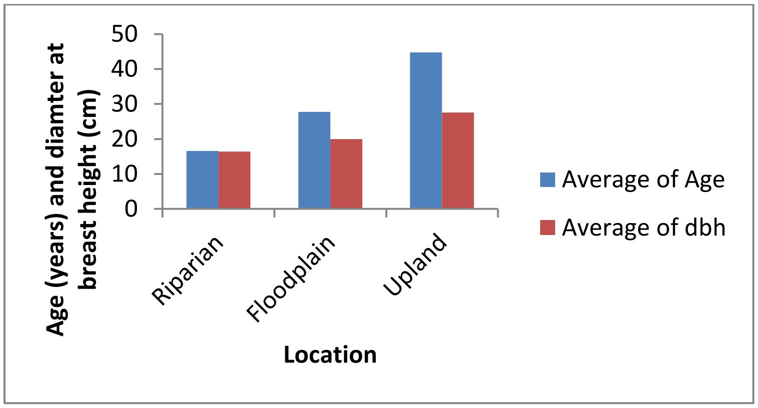


Figure 9. Average age (years) and diameter at breast height (cm) by distance from the creek of trees cored in the IMW study streams in 2009. Riparian and flood plain species are dominated by alder and water birch, and upland species dominated by ponderosa pine and Douglas fir.

Figure 10. Example of young riparian and upland vegetation along Charley Creek and a simplified channel with little geomorphic or hydraulic diversity, large woody debris, pools, or connection to the historic floodplain. Note the channelized nature of the stream limiting floodplain connectivity.

Our conceptual model for the current condition/limiting factors is that the majority of the study streams consist of homogenous instream habitat dominated by plane-bed runs and glides and characterized by a notable absence of large pools and large woody debris despite a riparian corridor that is well established and provides good cover. The current process regime supports the stability of this somewhat degraded state (Figure 11). The system is stuck in a state of low channel complexity, whereby the system parameters are fixed by a combination of a stable riparian corridor, an armored bed, and relatively modest mean annual floods that lack the capacity to shift the system into a different state and/or to modify the system parameters. Even when rare big floods do occur the system is quickly knocked back into its degraded condition. Despite this current condition, rapid habitat assessments of the lower 12 km of each study stream highlighted that the system is capable of promoting a higher degree of complexity (Wheaton et al. 2012). This seems largely related to the degree of hydraulic heterogeneity in flow width and flow patterns, which in turn are directly influenced by how much LWD is in this system.

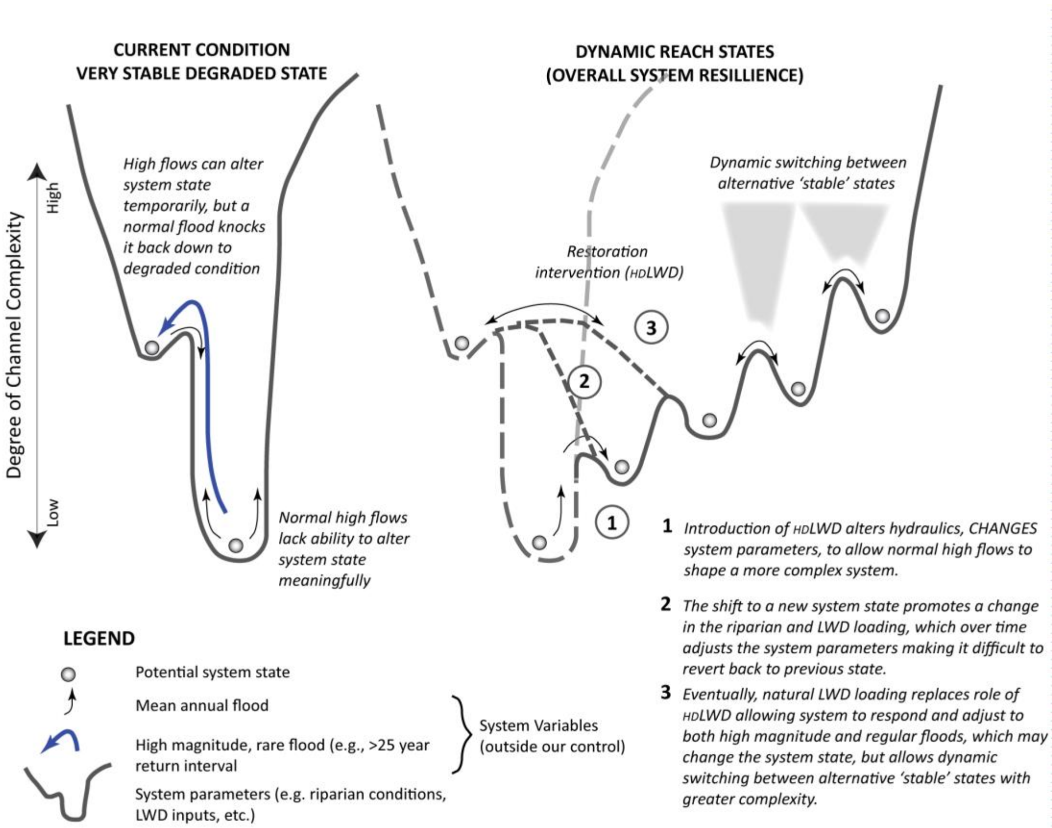


Figure 11. Conceptual models of current (left) and envisioned (right) conditions of IMW study streams (Wheaton et al. 2012). Current riparian vegetation is young, small diameter, and dominated by alder and provides limited large woody debris to the stream (degraded stable state). Addition of wood can create a more dynamic stable state with greater interaction between the stream and floodplain.

We compared the historic and current frequency of LWD and pools in the study streams to estimates of LWD frequency in managed and reference conditions from a variety stream surveys conducted in similar stream types. We define reference sites as sites (reaches or watersheds) with limited disturbance from human activities that represent the natural variation of conditions that would be found during pre-European settlement (Kershner et al. 2004). We compared 24 managed sites in the Asotin watershed surveyed by the USFS in the early 1990's (Asotin_1990s), 11 managed sites in the IMW study streams we surveyed in 2008 (Asotin_current), and 14 reference sites surveyed by Carlson et al. (1990) and Fox and Bolton (Fox and Bolton 2007) throughout Washington semi-arid sites east of the Cascade Mountains (Reference). The reference sites from semi-arid regions of Washington, Oregon, and Idaho had a wider range of stream characteristics and only matched our study streams at the ecoregion level. The mean frequency of LWD/100 m was higher in reference sites (45.9) compared to the managed sites (Asotin_1990s - 7.02, Asotin_current - 14.5; Figure 12). Although it appears that the amount of LWD has increased in Asotin Creek since the 1990's, this is likely due in part to the difference in LWD definitions between the 1990's and now (i.e., USFS used more restrictive definition of LWD).

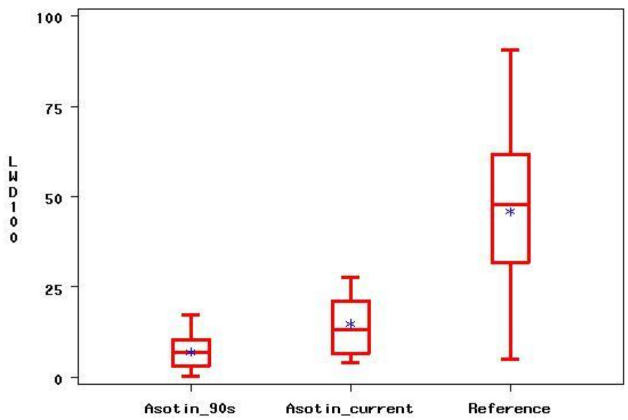


Figure 12. Comparison of the number of LWD/100 m in the Asotin Creek watershed for historic (1990's), current (2008), and reference conditions (see text for source). Box plot edges represent 25th and 75th percentiles, the horizontal line is the median, the star is the mean, and error bars are 5th and 95th percentiles.

We also compared the distribution of LWD and pools at 24 sites in both managed (20) and reference (4) areas across the Umatilla National Forest (UNF) determined by the USFS Fish and Aquatic Ecology Unit (2001-2006) to sites assessed using the same protocols in Asotin Creek between 2005 and 2008. We used only sites in the UNF with similar gradients (2-3.5%), elevation (< 1000 m), and geology (volcanic) as our study streams (Bennett and Bouwes 2009). We compared the Asotin sites to a mixture of reference and managed sites in UNF based on the assumption that the sites on the UNF would be less disturbed than the Asotin Creek sites that are on private land, or used to be privately owned (e.g. lower reaches in North Fork and South Fork).

It appears that not only is there less LWD and pool habitat lower in Asotin Creek compared to broad scale reference conditions, but the size distributions are different when compared to more local sites (i.e. UNF sites; Figure 13Figure 13; see Bennett and Bouwes 2009 for figure on pools). Managed and reference sites across the UNF consistently had more pieces of LWD ≥ 25 cm diameter in reference streams compared to Asotin Creek sites sampled in 2008. Of particular note was that pieces of LWD 30-75 cm diameter were 3-4 times more abundant in UNF sites than Asotin Creek sites. The same trend exists for residual pool depths with more pools with residual pool depths > 50 cm in UNF sites (Bennett and Bouwes 2009). Residual pool depths > 60 cm were absent from any of the Asotin Creek sites. These results suggest that the abundance of LWD and pools in Asotin Creek and its tributaries are likely well below reference conditions and that these are good indications that the habitat diversity is also lower in Asotin Creek than historically.

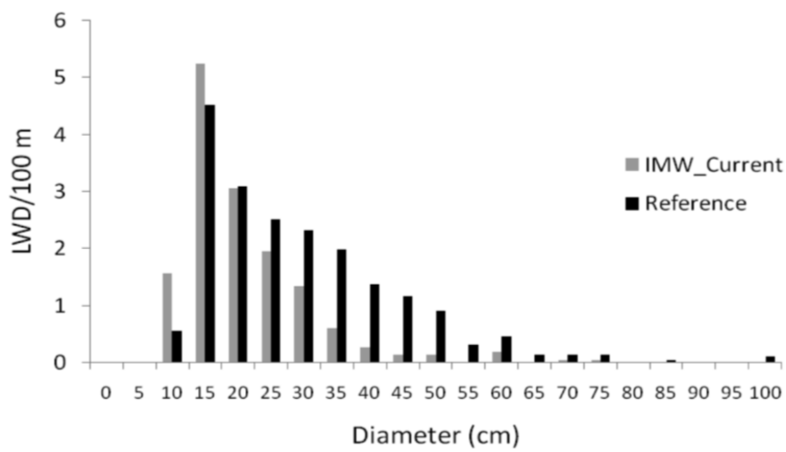
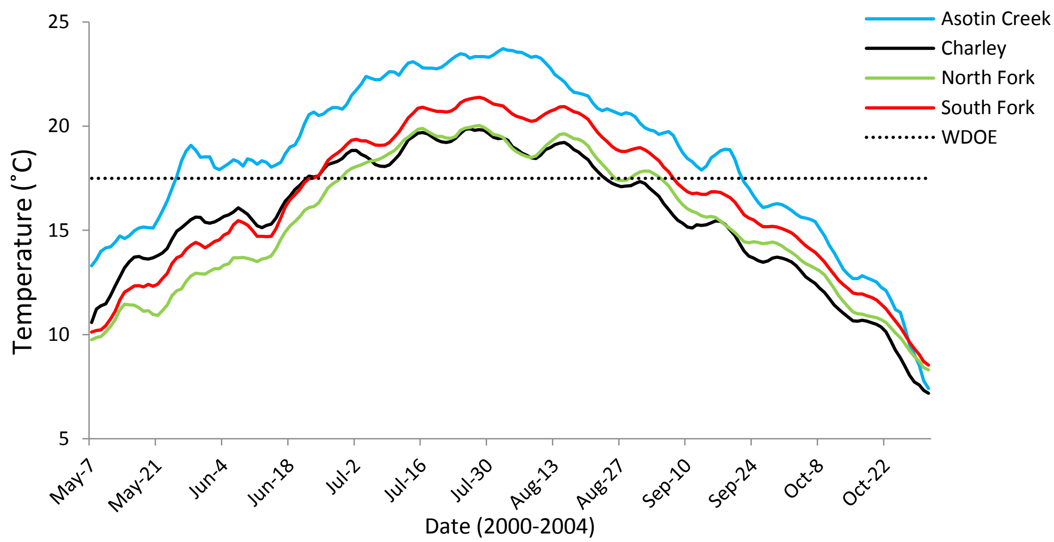


Figure 13. The size class distribution of LWD in Asotin Creek (Charley Creek, North Fork, and South Fork combined) based on sampling 2,153 m of stream habitat monitoring sites (n = 11) in July and August 2008 (total number of LWD counted = 314) versus Umatilla National Forest reference sites (n = 24) that sampled 4,284 m of habitat (total number of LWD counted = 853) .

We do not think that fish barriers, fecal coliform, sediment, or temperature are significant limiting factors in the IMW study area based on our recent assessments. We provide a brief rationale for these conclusions here and direct the reader to Bennett and Bouwes (2009) and Wheaton et al. (2012) for more detail. Of the three barriers identified in previous assessments only the Headgate dam continues to be a *potential* barrier to juvenile migration. Headgate dam is 10 km downstream from the IMW study area (Figure 6) and appears to be a potential barrier to juveniles (~ 0.5-0.8 m drop). It is scheduled to be removed in 2015 and we have PIT tag arrays in place to assess any changes in fish movement before and after its removal. There is no barrier of any kind at Cloverland Bridge on the mainstem Asotin and the potential barrier on the lower Charley Creek no longer exists because the partial gradient barrier at a culvert was eliminated due to sediment depositing downstream of the culvert in 2009.

Fecal coliforms are not a limiting factor in IMW study area because cattle are excluded from the majority of the area; the lower Asotin Creek mainstem still has fecal coliform issues due to private land owners wintering cattle along the stream. We have found no evidence of fine sediment being a problem, and in fact find that fine sediment is rare in the IMW study area (Wheaton et al. 2012). The lack of LWD and channelization is likely causing fine sediment and gravels to be quickly transported from the study reaches. These conclusions are supported by the lack of bar development and low levels of fine sediment measured in our CHaMP surveys (Wheaton et al. 2012).

Stream temperatures were likely a significant issue in the 1990's due to a lack of riparian vegetation (ACCD 1995). Temperature monitoring in the early 2000's indicated that temperatures were still above optimal temperatures for salmonid rearing and migration (Figure 14a; Bumgarner et al. 2003). However, temperatures appear to be significantly lower during the period of the IMW (Figure 14 b). Although we think temperatures are likely elevated compared to historic levels, we have noted that mean annual flows from during the IMW (2000-2009) were on average 25% larger than the period prior to the IMW (2000-2000). We have noticed a similar trend in the Tucannon River which suggests that winter snow pack is likely driving the current temperature regime more than riparian conditions. It is also worth noting that the criteria for optimal stream temperatures are likely bias towards coastal streams. Interior streams like Asotin Creek likely exceeded 7 day maximum temperatures of 18 °C prior to human development. Research also suggests interior populations of steelhead may have different tolerances to temperature and behaviors compared to coastal populations (Reeves et al. 2010). Also we have not seen a negative correlation with juvenile steelhead abundance, growth, or survival and stream temperature suggesting stream temperatures are not above critical thresholds (see section 9).



a)

b)

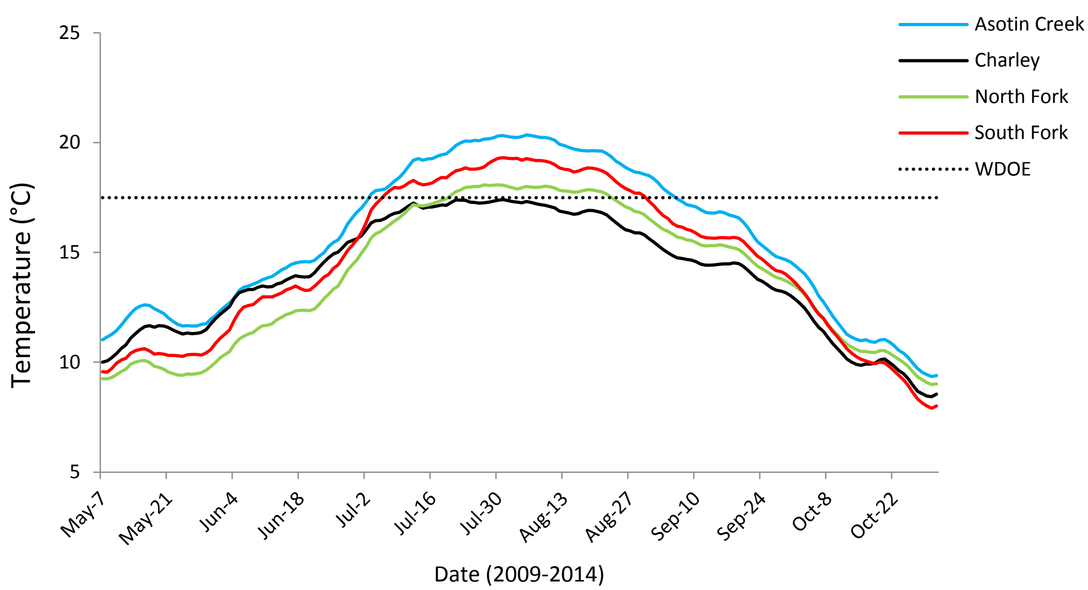


Figure 14. Average 7-day moving average of the maximum daily water temperature in Asotin Creek and the three IMW study creeks for the period a) 2000-2004 (measured by WDFW) and b) 2009-2014 (measured by ELR. Horizontal line is 17.5 °C the WDOE aquatic life temperature criteria in fresh water rearing and migration of salmonids.

4 ASOTIN IMW GOALS AND OBJECTIVES

4.1 Overarching Goals of the IMW

The overarching goals of the Asotin IMW are to test effectiveness of restoration at increasing the productivity and production of wild steelhead in Asotin Creek and to determine the mechanisms that lead to increased production through intensive monitoring of fish and habitat at multiple spatial and temporal scales. An increased understanding of the relationship between LWD restoration effectiveness and steelhead population response gained from this IMW will then be applied to restoration efforts in similar watershed settings.

A limiting factors analysis indicated that riparian function was the most significant limiting factor in the IMW study area. The limiting factors analysis also indicated that there are lower LWD and pool densities than were likely present during pre-European times. Due to these limiting factors, the proposed restoration treatments are to implement riparian and LWD treatments. The goals of these treatments are to:

- Promote the recovery of the riparian corridor through fencing, riparian planting, and invasive weed control.
- Increase pool habitat, habitat complexity, sediment sorting, production of dynamic bars and increased lateral exchange with the riparian corridor through the addition of LWD.
- Increase the productivity of juvenile steelhead in the treatment sections of the IMW study streams by some combination of increased abundance, growth, and survival.

4.2 Restoration Goals and Objectives

The restoration goals can be split into long-term and short-term objectives. In the long-term, we hope to restore riparian function by promoting the development and maintenance of healthy riparian zone that more resembles historic conditions. Much of the riparian habitat is in moderate to good condition and most riparian areas in the IMW study area are now managed by either direct fencing or management that excludes cattle. Asotin County Conservation District is implementing native species revegetation along Charley Creek as part of a SRFB project. We will not be assessing riparian recovery directly as part of the IMW due to the length of time it will take for the riparian to fully recover.

In the short-term, the goals of the LWD treatments are to learn how LWD additions change the hydrologic and geomorphic conditions in the study creeks. Ultimately, we want to cause a positive population response in wild steelhead as a result of the LWD additions and understand what the mechanisms are that lead to the response. A secondary goal is to develop an inexpensive, low impact, and widely applicable LWD restoration method that can be used in many small to medium sized tributaries to increase habitat complexity. We also want this restoration method to be more dynamic than traditional restoration approaches, insofar as we will allow the LWD to be more mobile and allow the river to rearrange the LWD, in order to build more dynamic and natural debris piles and create more diverse hydrologic conditions and geomorphic features.

The objectives of the LWD restoration are to change the average frequency and abundance of habitat and fish parameters in treatment sections compared to control sections (see section 5 - Experimental Design) pre (2008-2012) versus post-restoration (2013-2019). The specific objectives are to:

1. Increase LWD frequency in treatment sections by 100% or more to levels ≥ mean reference conditions,
2. Increase channel width variability by 25% or more,
3. Increase frequency of geomorphic units, pools, and residual pool depths by 50% as a measure of habitat diversity instream habitat diversity,
4. Increase number of bars by 50% (number of bars) and area of bars by 100%, and
5. Increase juvenile steelhead abundance and productivity by 25%.

5 EXPERIMENTAL DESIGN

We evaluated the applicability of several common types of experimental designs for use in evaluating a watershed scale restoration experiment such as an IMW: before-after, nested hierarchical, and staircase designs. Traditional designs of large watershed experiments often use before-after (BA), or before-after, control-impact (BACI) comparisons. In a BA locations within a stream are sampled before and after a restoration action, and in a BACI design a site or stream that is going to be restored is compared to a similar site or stream that will not be restored (Downes et al. 2002). The BA and BACI designs are powerful but often suffer from lack of replication, influence of the starting condition, and inability to infer about the scale of the response to the restoration. The nested hierarchical design implements restoration at multiple spatial scales (e.g., sections, streams, and watersheds) and is appropriate when the spatial scale and timing of the responses are unclear Underwood (1994). The hierarchical design also is more suited to detect changes in the variance of control and treatment areas as opposed to just changes in means (Downes et al. 2002). In a staircase design treatments are staggered so that treatment replicates are established in different time periods (Walters et al. 1988, Loughin 2006, Loughin et al. 2007). Two key advantages to using a staircase design are that staggering of the treatments over time allows for the distinction between the random effects of year and year/treatment interactions, and implementing the full suite of treatments over an extended period can be a benefit logistically and economically because large areas do not have to be treated all within one year.

5.1 Power Analysis

Based on our review of experimental designs, we chose to implement a hybrid design that combines the benefits of the nested hierarchical design and the staircase design and refer to this design as a ***hierarchical-staircase design (HS)***. We chose this design because it is not clear at what scale the fish response will be to the proposed restoration. Although we suspect this scale will be relatively local (i.e., within the restoration section of stream), we wanted to guard against year effects influencing the outcome of the experiment. We also consulted with Dr. T. Loughin of the Department of Statistics and Agricultural Sciences at Simon Fraser University to conduct a detailed power analysis of a BACI design, and two alternatives of the hierarchical-staircase design to determine if these designs would be able to detect a 25% increase in juvenile steelhead abundance and a doubling in pool frequency with 80% probability. The power analysis involved using estimates of variance derived from historic WDFW juvenile abundance data, current IMW juvenile abundance and pool counts, simulating pseudo-watersheds including the spatial and temporal layout of the Asotin IMW study, specified effect sizes, and applying several sampling plans based on the IMW monitoring plan (Loughin 2010). This analysis was conducted assuming the IMW would run from 2008-2019 and the treatments would begin in 2011. The power analysis confirmed that both BACI and HS designs have a high probability of detecting an increase in juvenile abundance and pool frequency due to restoration under the average levels of variance observed from the historic data (Loughin 2010). However, under conditions where the variance is at the high end of what has been observed historically, a hierarchical-staircase design that implements restoration in one section of each of the study creeks (HS-3) is significantly more powerful than both a BACI design and a hierarchical-staircase design that only implements restoration in a single stream (HS-1; Figure 15Figure 15). The analysis also found that the confidence interval lengths of HS-3 were roughly 2/3 those of the other designs (BACI and HS-1). This means that even if all the designs have similar power the HS-3 design is still more likely to detect true changes compared to the other designs (Loughin 2010).

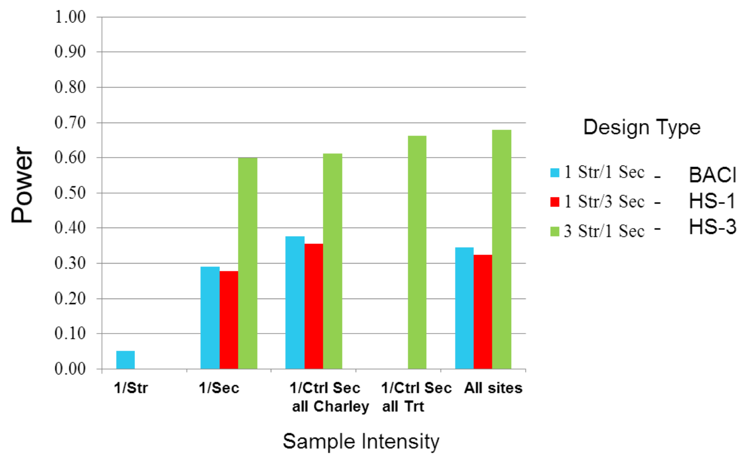


Figure 15. Estimated power to detect a 25% change in fish abundance (log) for different experimental designs and sampling plans under 'worst-case' (upper 95% CI) variability based on historic juvenile abundance data. Ctrl = Control, HS = Hierarchical-staircase design, Str = Stream, Sec = Section, Trt = treatment.

Power curves were generated by varying the treatment effect from a 5% increase to a 40% increase (Figure 16Figure 16). This was intended to allow more detailed comparison of the HS-1 and HS-3 designs, specifically addressing the concern that multiple treatments applied in different sections of the same stream may synergize to generate a larger treatment effect in each treated section than would be observed by treating only one section of a stream. By looking at the power curves for the two designs, we can see how much synergy (i.e., the addition of additional treatments increasing the effectiveness of existing treatments) would need to take place in order to make the HS-1 design over the HS-3 design. Based on pre-treatment sampling we did not expect much synergism between treatments (i.e., fish do not move much between sections and we do not expect a treatment section to significantly change habitat in a control section upstream or downstream; see section 9).

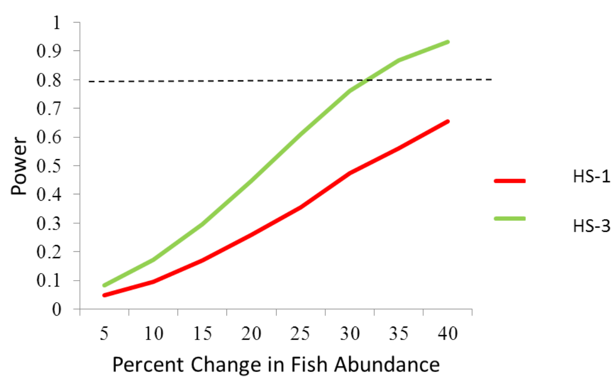


Figure 16. Power curves for varying for log-abundance under 'worst-case' variability for hierarchical-staircase design with one stream treated (HS-1) or three streams treated (HS-3).

Based on the above literature reviews and power analysis, we changed our original design which was to three sections in Charley Creek (i.e., treat one section per year until all three sections were treated; HS-1) to treating a single section in each study stream (i.e, HS-3; Figure 17). This is a more complicated design and is a departure from traditional BACI designs. We are making the explicit assumption that the control sections in each stream will not be compromised by treatments within the same stream; however, we should be able to test this assumption. The potential benefits of our approach are 1) treatments could be applied over multiple years reducing costs in any one year, 2) logistically more feasible to complete in a single instream work window, 2) each stream becomes a replicate experiment and we can assess the effectiveness of the treatment in three different sizes of stream with different flow regimes and “river styles”, 3) we can explicitly test for the interaction of year x treatment effects and assess how evaluations of restoration effectiveness can be biased by the year the restoration was implemented, 4) the design is flexible and we can add more treatments to this design by converting controls to treatments and increase the size of treatment (i.e., add another step to the staircase), and 5) if there is an overall positive effect (i.e., increase in production) within each treatment/stream combination it will increase our confidence that the additional of LWD is an effective restoration method (i.e., weight of evidence).

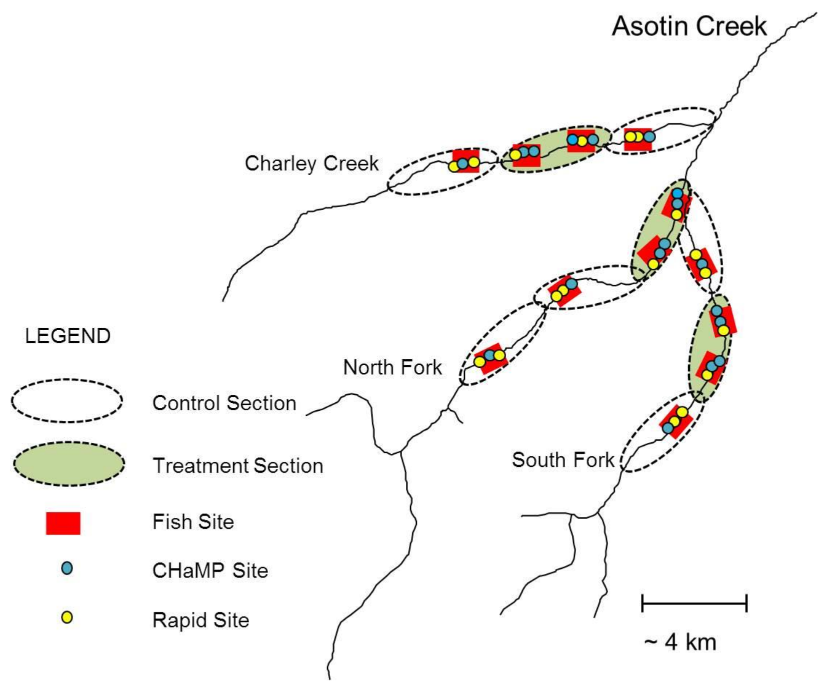


Figure 17. Hierarchical-staircase design for the Asotin Creek IMW. Each oval is a section 4 km long. Green sections are treatments (n = 3) where the restoration with LWD took place: South Fork in 2012, Charley in 2013, and North Fork in 2014. All other sections are controls (n = 6). Monitoring sites for fish (red boxes) and habitat (blue and yellow circles) are nested within each section. We sample twice as many fish sites and habitat sites in treatment sections as controls.

5.2 Experimental Units

In this report we define a ***watershed*** as Asotin Creek and all its tributaries. Specific IMW restoration and monitoring activities take place in study ***creeks*** (Charley, North Fork, and South Fork). At smaller scales, the lower 12 km of each stream is divided into three 4 km ***sections*** that we will refer to as ***treatment sections*** and ***control sections*** (Figure 17Figure 17). Each stream has two ***control sections*** where no restoration is implemented and one ***treatment section*** where the entire 4 km has been treated. The location of each treatment section was selected based on our habitat surveys and we chose the section in each stream that was the most degraded. The timing of restoration was chosen based on the expected length of the IMW (2008-2019) and a desire to have 4-5 years of pre-treatment data. We randomly selected the order of restoration treatments assigned to the creeks. The design called for 12 of 36 km of the study area to be treated (33.3%). Based on the preliminary results and responses of habitat and fish to the treatments we think it is advisable to treat another section (i.e., convert a control section to a treatment section) because the variability of smolt/spawner and production metrics are likely to be higher than the variance of metrics like pool frequency and fish abundance which were used to calculate power. Another full section of treatment would increase the overall treatment size to 16 km or 44.4% of the study area.

5.3 Design Hypotheses and Expected Responses

The following design hypotheses all directly or indirectly stem from the conceptual model of the current conditions we derived from reviewing past assessments and our ongoing habitat sampling (Figure 11). From this understanding of the current stream conditions we generated a vision of the restored condition that we then used to form specific, testable hypotheses, and a monitoring program to test those hypotheses.

We recognize two important plausible “responses” of the PALS additions: i) some structures will ‘fail’ (i.e., be swept downstream, or the channel will move around the structure, possibly leaving them outside the active channel), and/or ii) some structures will have limited immediate effect (i.e., create a limited number of all the possible responses). Rivers are dynamic and we fully expect both outcomes to occur at some structures. However, the density of structures and dynamic nature of the structures (i.e., temporary nature of the posts and non-secured LWD) are explicitly designed with these plausible outcomes in mind. Our monitoring program is also designed to learn how structures function and what characteristics of the channel and installation create positive responses.

5.3.1 Habitat Hypotheses and Responses

It is generally recognized that the addition of LWD into streams can increase pool habitat, sediment storage and sorting, and fish cover (Roni et al. 2015); however, the long-term effectiveness of LWD restoration approach has rarely been evaluated beyond determining a structures durability (Roper et al. 1998) but see Johnson et al. (2005) and Pierce et al. (2015). This IMW has the opportunity to track the function of LWD over several years and document how that function changes over time. Here we separate the habitat responses into what we expect to see at the structure scale in the short-term, how we expect different structures to work together in concert over the longer-term5.3.1.2, and finally how this will interact with the riparian zone and floodplain.

5.3.1.1 Short-term response at individual structures

The individual LWD structures are designed to produce an immediate hydraulic and geomorphic response by constricting the flow width and altering local hydraulics, sediment sorting, erosion, and deposition. The existing channel without LWD has limited hydraulic or geomorphic diversity (Figure 18). We expect hydraulic responses to occur immediately after construction and geomorphic changes to occur after the first high flow event. More detail on specific hypotheses for different structure types are described in Camp (2015), Wheaton et al. (2012) and Appendix II.

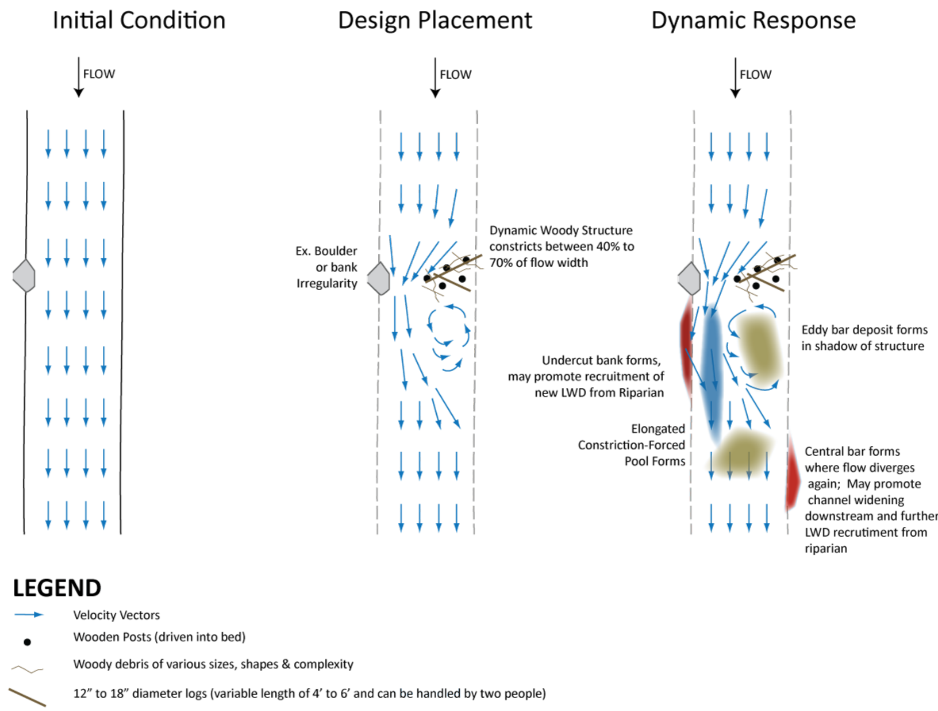


Figure 18. Schematic of the potential response to LWD placement or whole trees added to a relatively simple plane bed channel to constrict the flow. The majority of the LWD structures used in treatments are post-assisted log structures (PALS; see section 8 for more details).

5.3.1.2 Long-term and site scale response

Clearly, if our short-term design hypotheses turn out to be accurate, the continued evolution of these sites would lead to the eventual 'failure', shift, or evolution of the PALS. We expect the PALS to be ephemeral on the time frame of 5-10 years. Our most fundamental hypothesis at the site-scale over the long-term is that the overall concentration of PALS will be so high that when an individual PALS 'fail' or outlives its design life, the material (both wood and sediment stored in associated active bars) will re-deposit or accumulate at either the next intact downstream PALS or LWD jam, or some distance likely not more then 1-4 PALS or LWD jams downstream. Those building blocks at their new location are then likely to result in conditions similar to those hypothesized for the original PALS location. A PhD student is currently tracking LWD movement in both the Asotin IMW study area and the Tucannon River to address these questions.

Over the long-term, both sediment and woody debris change as they move downstream. Woody debris breaks down contributing to primary production, deteriorates and becomes smaller but is also an important energy source for the stream. By contrast, inorganic sediments tend to physically break-up and round as they move downstream over longer distances (e.g., downstream fining). On the scale of these treatments, we hypothesize that over our 5-10 year monitoring window:

- The LWD used in the initial placement of the PALS will break down, but natural LWD recruitment will roughly match the rate of breakdown (assuming bank erosion and LWD recruitment occur at individual PALS locations as hypothesized).
- There will be no appreciable 'loss' in sediment over these length scales due to downstream fining, but we do expect the residence time of gravels to increase, as indicated by a general increase in the number of active bar deposits, which regularly turn over and are replaced.

In addition, we expect that over the long-term the alteration in hydraulics at high flows is likely to have cumulative effects and:

- There will be an increase in exchange of sediment and woody debris between the riparian areas and the channel. Specifically, sediment that tends to only remain in the channel now will be deposited in riparian areas, sediment that is locked up in long-term valley fill alluvial deposits will be reactivated by lateral erosion and help supply material to in-channel bars. Also, woody debris will be recruited from the riparian areas during floods and some debris will be deposited in riparian areas.

5.3.1.3 Riparian Hypotheses and Expected Responses

We do not expect significant short-term riparian responses due to the length of time it will take for the riparian forest to respond to cattle exclusion, planting, and weed control. Specifically, we expect:

- No increase in LWD from riparian areas due to "natural" tree fall; however, if significant bank avulsions or lateral shifts in the channel occur due to PALS, this could cause significant input of mature alder trees to the stream.
- No change in summer water temperature as most sites are well shaded, and at sites with no shading, revegetation will not be fast enough to alter stream temperature during the IMW (however, we do expect a slight decrease in the rate of warming of stream temperatures in treatment sections due to increased hyporheic exchange caused by increased roughness and pooling of water above structures).
- No changes in fine sediments from hillslope and anthropogenic sources (e.g., roads) because these sediment sources do not appear to be a significant problem and most riparian habitat is intact enough to act as a buffer to these sources.

5.3.2 Fish Hypotheses and Expected Responses

We expect an increase in the productivity and production of wild juvenile steelhead in Asotin Creek in treatment sections compared to sections**.** We are focusing on measuring productivity and production of juveniles (pre-smolts) and smolts (presumed out-migrants) at the section, creek, and watershed scales because it is unlikely that we can accurately measure these parameters at smaller scales. However, we should be able to infer changes at the site scale from differences in the frequency of different geomorphic units in treatment and control areas. Measuring the juvenile and smolt productivity is an indirect measure of the survival of egg-fry, fry-juvenile, and juvenile to smolt life history stages which are the life stages stream restoration activities are attempting to benefit (Crawford and Rumsey 2011). Fish production is another way to measure the output of a population because unlike estimating abundance alone, production is the result of three key population parameters: abundance, growth, and survival which together measure population yield in biomass/unit area/time (Waters 1999, Almodóvar et al. 2006).

Steelhead are known to respond differently to LWD restoration and use different habitats than other salmonids (Roper et al. 1994). For example, steelhead are known to select riffle habitat in the summer and pool habitat in the winter when coexisting with coho in coastal streams (Hartman 1965, Bustard and Narver 1975, Bisson et al. 1982). By contrast, in early studies in Asotin Creek, steelhead abundance increased in the summer after the addition of LWD and creation of more pool habitat but winter abundance and smolt production were not measured (Viola et al. 1998). Coho are absent from Asotin Creek which may explain the differences in steelhead habitat use and response to restoration in Asotin Creek compared to coastal streams.

There are multiple pathways by which changes in habitat conditions can alter productivity or production (Figure 19Figure 19). Our habitat monitoring is directed at measuring many of these changes. For example, we visually assess changes in hydraulics at each structure and describe all geomorphic units upstream and downstream of each structure (Camp 2015). CHaMP habitat monitoring provides measures of substrate and LWD frequency by geomorphic unit and also generates a detailed topographic survey of each habitat site. These data can be used to both assess the effectiveness of the restoration treatment at creating more complex habitat but also in explaining fish responses. For example, if the restoration structures create eddy pools downstream and fast water off the end of the structures (due to constricted flow width), we will expect an increase in shear zones. These should lead to an increase in optimal feeding and refuge areas which should result in increased growth and/or survival of juveniles (Figure 19).

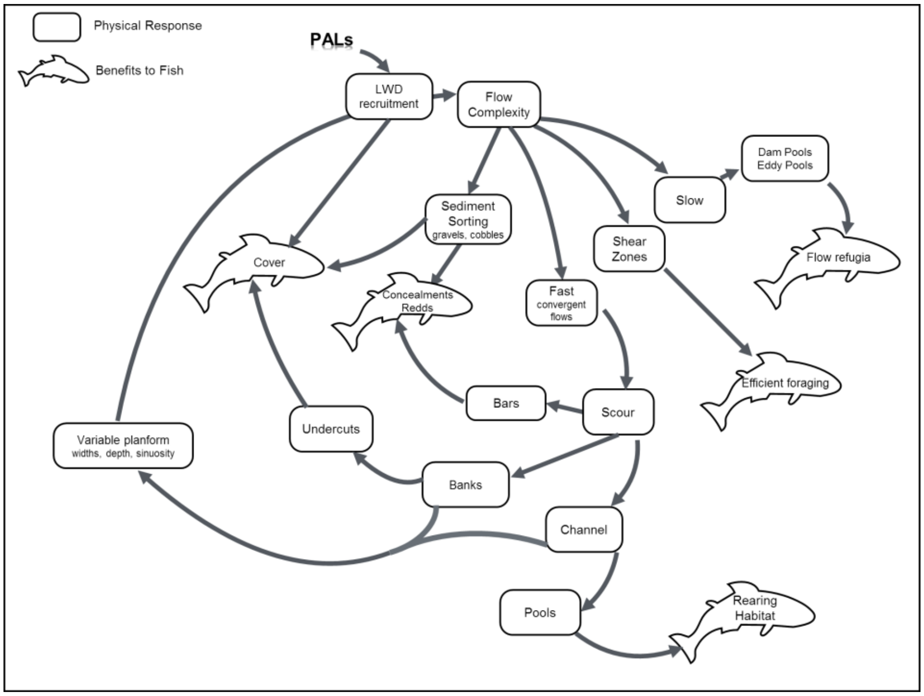


Figure 19. Conceptual framework of the influence of LWD (i.e., post assisted log structures – PALS) on stream process and habitat types thought to be critical determinants of individual and population fitness and ultimately production. Reversing the effects of decreased LWD by installing high densities of PALS can increase population fitness and production through multiple pathways and synergistic interactions.

5.3.2.1 Hypothesized site, section, and stream responses

The majority of our fish sampling occurs at 12 permanent fish sites (Figure 6). At these sites we estimate juvenile age, abundance, growth, and survival by season. Together, the abundance, growth, and survival of juvenile steelhead over a specific time period are a measure of production. However, due to the complex interaction between stream conditions, adult escapement, and density-dependence, it is difficult to determine which population parameters are most likely to change and in what direction. For example, juvenile abundance could decrease but if the mean growth of individuals and their survival increases as a result, the net production will increase. Therefore, we provide hypotheses that apply to the overall site production as measured by any combination of abundance, growth, and survival (Table 6).

Table 6. Hypothesized responses in juvenile and adult population parameters and the associated causal mechanisms and habitat changes from the installation of post-assisted log structures in the Asotin Creek IMW.

		Response				
Parameter	**Units**	**summer/ fall**	**winter/ spring**	**Mechanism**	**Habitat Change**	**Monitoring Method**
Age @ Migration	time	?	?	+ growth	+ shear zones	MR, PIT
Abundance (A)	fish/m^2	+	++	- predation, +survival	+ pools, cover	MR
Growth (G)	g/g/d	++	++	+ feeding efficiency	+ shear zones	MR
Survival (S)	%	+	++	- predation,+growth	+ pools, cover	MR, PIT
Movement	m	-	-	- searching micro-habitats	+habitat diversity	MR, PIT
Production (Pj)	g/100 m^2/season	+	++	+ A,G,S	+ carrying capacity	NREI modeling
Productivity (Ps)	recruits/spawner	+	++	+ Pj	+ carrying capacity	WT, MR, PIT, SS
Adults/Redds	count	N/A	++	+local hydraulics	+ bars, sediment sorting	WT, PIT, SS

Responses are trending positive (+), significantly positive (++), trending negative (-), significantly negative (--), unknown (?); Pj = juvenile production (pre-smolt), Ps = smolt productivity; Monitoring methods are MR = mark-recapture, PIT = PIT tag detections due to capture, mobile surveys, and traps, SS = spawning surveys , TR = adult weir and smolt traps (see section 6 for details or Bennett et al. 2012).

6 MONITORING DESIGNS AND METHODS

We have developed a monitoring infrastructure based on the experimental design, project goals and objectives, and hypotheses we have developed. Most of our sampling effort is directed to the lower 12 km of the study creeks as this is where we have applied the restoration treatments (Figure 6). The monitoring infrastructure has been developed from preexisting monitoring programs (e.g., WDFW Asotin Program, USGS gauges) and new installations, such as juvenile steelhead and habitat sampling sites, PIT tag arrays, temperature probes, and water levels gauges. This base infrastructure will allow us to relate responses of fish populations to hydrologic attributes (i.e., discharge and water temperature) and specific stream habitat attributes at the site/reach, stream, subbasin, and watershed scale. We briefly describe the monitoring methods below. See Bennett et al. (2012) for details.

6.1 Fish In Fish Out Monitoring

The WDFW has been conducting a detailed assessment of the steelhead population in Asotin Creek since 2004 (see below for more description of the WDFW project; Crawford et al. 2015). One of the primary goals of the WDFW assessment is to estimate the life stage survival rates of the steelhead population. To accomplish this goal WDFW operates a smolt trap and adult weir on the mainstem Asotin Creek. The smolt trap is operated for several months in the spring and fall to capture outmigrating steelhead smolts. An adult weir is operated from January to June to capture returning adults to Asotin Creek. Redd surveys are also conducted on approximately 20% of available spawning areas. We will use these data to 1) look at changes in watershed scale productivity in a before after design, 2) corroborate our estimates of smolt productivity from the study creeks, and 3) assess changes in spawning distribution pre and post-restoration.

Production out of basin, as defined by the smolt to adult return rate (SAR), will be calculated by the WDFW by using the adult weir, redd counts, and smolt trap. We will use this information to provide context to the IMW study and assess the relative influence of out-of-basin effects on production compared to the freshwater production we are measuring.

6.2 IMW Sample Sites

We established permanent fish and habitat monitoring sites in each of the control/treatment sections within the study streams in 2008 and 2009 (Figure 6 and 17). There are four fish sites in each creek, two in each treatment section and one in each control section for a total of 12 fish sites. Each fish site is 300-600 m long and was systematically located within a section so that they were centered either 1 km or 3 km upstream from the bottom of the section. This was done to ensure that there was independence between fish sites both within a treatment section and between treatment sections and control sections. The location of fish sites within the sections was selected randomly whereas each treatment section always has a fish site at the 1 and 3 km location. We periodically sample “upper” sites for fish which are sites 5-7 km upstream of the IMW study area. These sites are used to assess the boundary between anadromous and resident *O. mykiss*. Stream habitat is sampled at all fish sites.

6.2.1 Habitat Surveys

6.2.1.1 CHaMP Surveys

We began using the PIBO habitat protocol in 2008 (Heitke et al. 2008) but switched to the Columbia Basin Habitat Monitoring Protocol (CHaMP 2014) in 2011 (Appendix I). CHaMP collects data on instream, channel, and riparian characteristic and provides a topographic survey of the site. We monitor 18 CHaMP sites a year; four sites are allocated to each treatment section (12 sites) and one site is allocated to each control section (6 sites). This level of effort will result in approximately 30-40 restoration structures being “captured” by the topographic surveys in each treatment section. From these surveys, we are able to monitor changes to geomorphic units, channel form (depth, width, sinuosity, etc.) and differences in erosion and deposition pre and post-restoration (Camp 2015). LiDAR and aerial photography were collected in 2010 and will be collected again between 2015-2019 to determine changes to channel, floodplain, and riparian conditions.

6.2.1.2 Rapid Habitat Surveys

We implemented a rapid survey approach to increase our monitoring coverage to 100% of the LWD structures and the IMW study area periodically. To facilitate the rapid collection of restoration effectiveness data, we developed a mobile database application (app) deployable on iOS devices called the $_{HD}$LWD Effectiveness App. Using the app, we make annual visits to each structure after high flows to identify specific hydraulic and geomorphic responses relevant to the IMW restoration hypotheses (Camp, 2015; Camp and Wheaton, 2014; Wheaton et al., 2012). In addition, by recording the frequency, area, location, arrangement, and dominate substrate of each geomorphic unit around restoration structures, we can build spatially representative diagrams of the geomorphic units and quantify changes over time (i.e., pre vs post-restoration). In doing so, we are able to monitor geomorphic changes, such as an increase in pool density or water depth, around each structure (Figure 20).

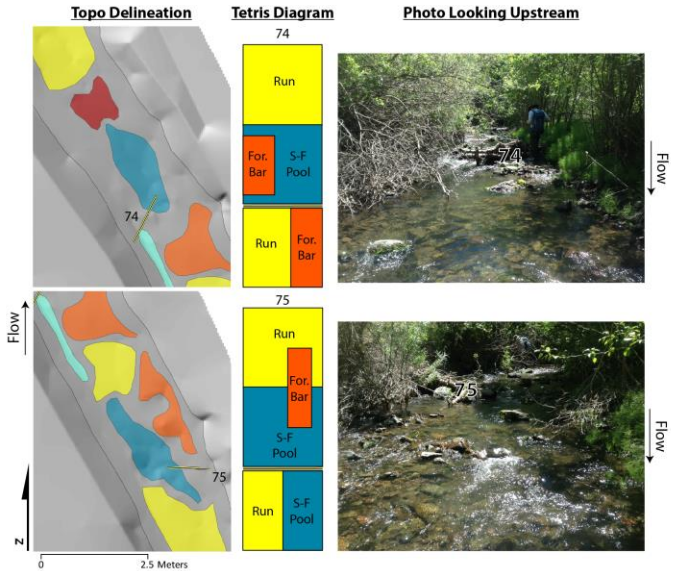


Figure 20. An example of geomorphic channel units delineated from topographic surveys (left) compared to the tetris diagrams which are created in the field (middle), and photographs of the site (right). The tetris diagrams are spatially representative assemblages of the geomorphic channel units surrounding a structure.

Flow and Temperature

Stream discharge and water temperature are two key variables we are recording throughout Asotin Creek. The size and frequency of discharge can have a large effect on all aspects of a salmonid's life history. Extreme low flow can limit adults from accessing spawning grounds, allow the buildup of fine sediments, and limit the amount of habitat available to juveniles. Temperature controls all physiological processes of fish and high temperatures can lead to increased stress, disease, and death in both adult and juvenile salmonids. Discharge and temperature can fluctuate over relatively small scales due to local conditions like anchor ice, bedrock formations, riparian conditions, substrate size and fine sediment, and the presence of groundwater springs. Therefore, we have developed a watershed wide discharge and temperature monitoring infrastructure incorporating existing monitoring stations and new sites (Figure 6).

6.2.2 Juvenile Steelhead Surveys

Our fish monitoring program is primarily focused on juvenile steelhead capture, PIT tagging, and recapturing or resighting of fish within the study creeks. We are focusing on this proportion of the population because it will provide the best measure of freshwater production that is most directly influenced by stream habitat conditions and restoration actions. These fish monitoring efforts will be enhanced by WDFW monitoring of outmigrating smolts and returning adults with the mainstem smolt trap and adult weir respectively (Crawford et al. 2015).

6.2.2.1 Juvenile Abundance, Growth, Movement, and Survival

To assess the direct effects of stream restoration we are capturing and PIT tagging juvenile steelhead within the treatment and control sections of the study creeks. Juvenile tagging in the study creeks will allow us to determine juvenile abundance, growth, movement, and survival pre and post restoration in treatment and control sections.

We started tagging juvenile steelhead in 2008 (a pilot year) where we captured and PIT tagged juveniles at three fish sites in each study creek. Starting in 2009, we increased sampling in Charley Creek from three to six sites assuming we would treat all of Charley Creek (HS-1 design). However, as of 2011 we decided to implement restoration in each stream (HS-3) and now capture and tag juvenile steelhead at four fish sites in each study creek (12 total sites) per year (Table 7). Each fish site is visited twice a year during a summer tagging session (late June to July) and a fall tagging session (late September to October). The two tagging sessions allow us to calculate the population parameters over shorter time periods (i.e., summer to fall and fall to the following summer).

To estimate juvenile abundance at each site we used 2-pass mark-recapture surveys which provide more precise and less biased estimates than traditional depletion estimates (Rosenberger and Dunham 2005). We do not use block nets for the mark-recapture surveys because of the relatively long site lengths we are using (i.e., 300-600 m) and tests that we conducted that indicate we are not violating the assumption of mark-recapture estimates that fish are not leaving the sample site during the capture session (Bennett et al. 2010).

We also conduct mobile PIT tag surveys in the winter (late December to January) and spring (March to April) to detect PIT tagged juvenile steelhead overwintering in the study area. The mobile PIT tag detections, along with the summer and fall capture sessions, are used to assess fish movement within sites and between sites and are used to estimate seasonal survival rates using a Barker model (Conner et al. 2014).

Table 7. Fish sample site matrix with completed and proposed sample schedule through to the end of the IMW project. Grey shading represents the length of time each section will be in a "post-restoration" state. All "X's" without shading represent control samples.

Stream	Section	Fish Site	Year											
			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Charley	1	CC-F1		X	X	X								
		CC-F2	X	X	X	X	X	X	X	X	X	X	X	X
	2	CC-F3	X	X	X		X	X	X	X	X	X	X	X
		CC-F4		X	X			X	X	X	X	X	X	X
	3	CC-F5	X	X	X	X	X	X	X	X	X	X	X	X
		CC-F6		X	X	X	X							
North Fork	1	NF-F1	X	X	X	X	X	X	X	X	X	X	X	X
		NF-F2					X	X	X	X	X	X	X	X
	2	NF-F3												
		NF-F4	X	X	X	X	X	X	X	X	X	X	X	X
	3	NF-F5												
		NF-F6	X	X	X	X	X	X	X	X	X	X	X	X
South Fork	1	SF-F1												
		SF-F2	X	X	X	X	X	X	X	X	X	X	X	X
	2	SF-F3	X	X	X	X	X	X	X	X	X	X	X	X
		SF-F4					X	X	X	X	X	X	X	X
	3	SF-F5	X	X	X	X	X	X	X	X	X	X	X	X
		SF-F6												
Total Sites/Year			**9**	**12**	**12**	**10**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**

* Sites 5-7 km upstream of the IMW study area (i.e., first 12 km of each study stream) are surveyed periodically to assess the boundary between anadromous and resident O. mykiss.

6.2.3 Productivity and Production

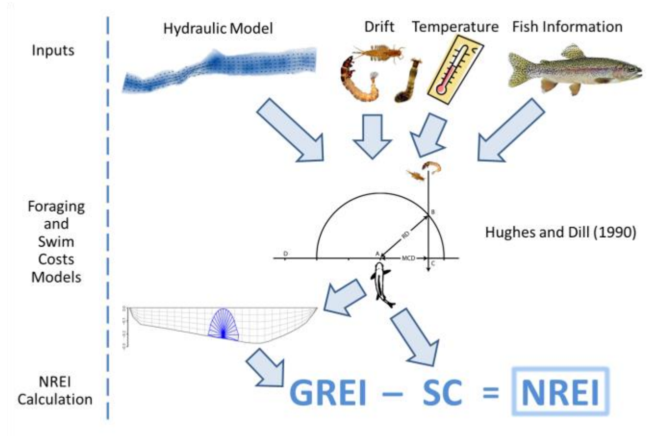
We will measure juvenile and smolt productivity of each study stream using either estimates of PIT tagged adults or redd counts from each stream and estimates of juvenile abundance and smolt out-migration from PIT tag and detections at arrays. A calculation of the number of smolts produced per adult (or redd) is a measure of freshwater productivity which we assume will be positively affected by the proposed restoration treatments. The calculation of smolts/adult spawner requires estimates of array efficiencies, adults entering study streams (including sex ratios), age estimates of juveniles, estimates of the number of smolts leaving each tributary, and estimates of the abundance of fish in each section (to estimate unmarked proportion of the population). Trials of this approach were correlated to WDFW fish in fish out estimates of smolt estimates suggesting this method could be effective at determining productivity at the stream and section scale.

We will estimate biomass production as a way to interpret the above measures of productivity. The production of ecological systems has been measured as a way to compare the conversion of nutrients and solar energy through biological processes into different forms of biomass per unit area per time. To better understand changes in overall steelhead productivity we will also measure steelhead freshwater biomass production in terms of biomass/unit area/time period/spawning adult or redd. This allows for an objective way of measuring ecosystem output, and in systems that are being actively resorted, measuring biomass production can help assess the effectiveness of the restoration activities (Horton et al. 2009, Wipfli and Baxter 2010).

6.3 Synthesis of Fish and Habitat Data

We have been developing different methods for synthesizing the information from habitat and fish monitoring to assess the response of fish to restoration treatments and to better understand the system as a whole. One method we are using is the net rate of energy intake model (NREI; Hayes et al. 2007). We have expanded the application of the NREI model from single habitat unit applications to entire stream reaches to predict carrying capacity for juvenile steelhead in our treatment versus control sections. The model uses data from CHaMP surveys (topographic data, hydraulic model), drift samples (collected annually at all fish sites), water temperature, and fish abundance information as inputs into the Hughes and Dill (1990) foraging and swim cost models (Figure 21). The foraging model estimates the area a fish might use to feed (i.e., capture area) and uses the capture area to estimate GREI (gross rate of energy intake). A swim costs model (SC) predicts the energetic costs of swimming in the current and the NREI is calculated by subtracting swimming costs from GREI. The carrying capacity of a site is calculated with an iterative process whereby the highest NREI value in the raster is assigned a fish. A territory rule is then used to exclude another fish from occupying a location within the territory. The next highest NREI value outside the first fish's territory is identified and assigned as a fish location. This process is repeated until all the suitable locations in a site are occupied by fish. The carrying capacity is calculated as the total of all fish capable of being supported. See Wall (2014) for more details on the NREI modeling process we used.

a)



b)

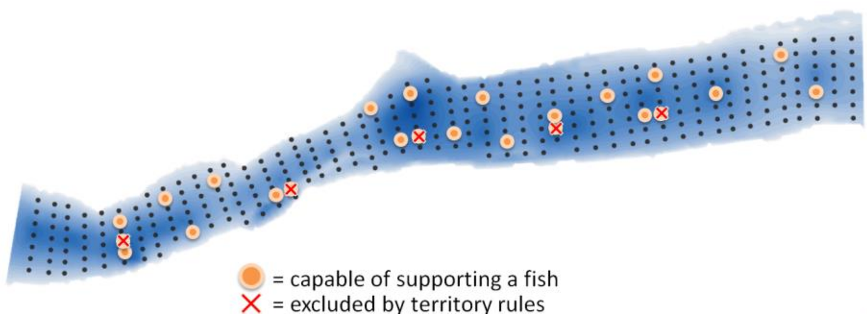


Figure 21. a) Net rate of energy intake (NREI) modeling process used to synthesize fish and habitat data and b) converting NREI raster values into carrying capacity based on territory rules for juvenile steelhead (Wall 2014). Site carrying capacity equals the summation of all sites capable of supporting a fish.

7 DATA MANAGEMENT AND QUALITY CONTROL/ASSURANCE

A vast amount of fish and habitat data is being produced from this IMW project. To manage these data we are working closely with ISEMP to utilize and assist in the development of data management tools to store, analyze, and distribute the data (Appendix III). Where possible we are using data loggers and custom applications to collect the data in the field and upload the data to custom built databases. Data loggers are the aid in quality control and assurance by forcing users to fill in all required fields, providing drop down lists of acceptable values, and decreasing errors when transferring data to databases. Appendix III explains the data collection tools, transfer process to data storage, and where appropriate, path of the data to larger regional databases. Our PIT tag array data is all loaded to PTAGIS daily (automatically) via data loggers and phone modems. Mark-recapture tagging is loaded at the end of each capture session (once in the summer and once in the fall). Data with a spatial component is being loaded into a GIS to allow analysis of spatial arrangement of attributes and estimate movement patterns and habitat use (e.g., mobile fish surveys and fluvial audits). All CHaMP data is loaded to champmonitoring.org where it is put through rigorous quality assurance and control procedures both in the field and upon submission to champmonitoring.org. See online documentation of data management procedures for CHaMP data. All of our data is publically available upon request.

8 RESTORATION ACTIONS

8.1 Restoration Philosophy

Our restoration philosophy is that restoration actions should be implemented in a way which maximizes learning, and that the treatments are intended to kick-start natural fluvial processes that will eventually restore high quality salmon and steelhead habitat and be self-sustaining through time. When it comes to the role of LWD in streams, it is clear that both size and density matter. However, the vast majority of past restoration efforts that have used LWD focused on size and placed a relatively small number of pieces of LWD in a relatively small number of locations (Roni et al. 2008). While we recognize that size of LWD does matter, we hypothesize that the density of in-channel LWD is more important in terms of promoting habitat complexity and conditions for fish over the scale of the entire stream. Another way of conceptualizing the role of LWD, is as roughness elements. The current conditions in the IMW study creeks are very much like the gutter of a bowling alley - there is very little variation in width, depth and there are virtually no roughness elements to change the speed or course of the bowling ball (i.e., floods carrying water, sediment and LWD). Virtually anywhere on these creeks where there is some variation in width, depth and large-scale roughness (i.e., LWD and boulders), we observe temporary storage of sediment in bars, persistent pools and more complex habitat. This suggests that the bowling balls (i.e., floods) are carrying useful material with them for constructing and maintaining such habitats. There simply are not enough places where the flow varies enough to promote higher residence time of the material (sediment and LWD) and exchange with the riparian corridor. We postulate that a high density of LWD and/or debris catching structures, will help 'initiate natural fluvial processes' which through time can maintain themselves and recruit more LWD from adjacent riparian and hillslope areas. Although it is possible to place structures in a way to induce specific hydraulic and geomorphic responses, we only use these techniques to initiate the desired responses. It is not critical that a specific structure works precisely as anticipated, nor whether or not it persists over the long term. The broader design philosophy and restoration strategy is to have a large enough number of these structures that the large scale roughness of the stream is fundamentally altered over long term timescales.

Stream complexity is the product of dynamic processes, which means that the precise details of the arrangement of a reach are very difficult to predict (Fausch et al. 2002). However, harnessing this inherent variability can be a very effective restoration strategy (Wissmar and Bisson 2003). Our philosophy not only accepts the inherent uncertainty of natural stream systems but also embraces it (Sear et al. 2008, Wheaton et al. 2008). We embrace uncertainty by focusing less on individual highly engineered structures and more on a complex of many structures over a large area (several km) where wood movement is not seen as a failure. We liken this approach to the phrase coined by Zeedyk and Clothier (2009) " Let the Water Do the Work". See Wheaton et al. (2012) for further discussion of our restoration philosophy.

8.2 Restoration Method – Riparian Protection

Virtually all of the riparian areas within the IMW study area are now protected from further disturbance by either cattle exclusion or fencing. Most of riparian areas are recovering and providing shade and other benefits to the stream (i.e., allocthonous inputs). We estimate approximately 70% of the existing riparian and valley habitat within the three study creeks is partially or fully functioning. Therefore, passive restoration (i.e., prevent further disturbance) will be applied as a restoration treatment to these areas. In the remaining 30%, Asotin County Conservation District, WDFW and USFS are working to control invasive species and where necessary plant riparian and upland vegetation. We will not be directly assessing riparian restoration as part of the IMW but will be able to assess changes in riparian conditions with the riparian data collected at CHaMP surveys and we another LiDAR survey.

8.3 Restoration Method - $_{HD}$LWD

In previous reports we referred to the individual structures as Dynamic Woody Structures (Wheaton et al. 2012). We have updated the name of the structures and the overall approach based on a revision of the restoration plan. We have named the overall approach as ***high-density large woody debris*** (**$_{HD}$LWD**) and changed the name of the Dynamic Woody Structures to ***Post Assisted Log Structures*** (PALS). The general goal of the $_{HD}$LWD restoration is to increase the LWD density over a large area (several km) to broadly mimic the densities of LWD that would be found in reference conditions. Numerous small LWD structures (secured and unsecured) are built primarily by hand to mimic trees that would have naturally fallen into the stream from riparian areas and nearby upslope areas. We use three main structure types in the $_{HD}$LWD approach: post-assisted log structures, key pieces, and seeding.

PALS are built using wooden fence posts and small pieces of LWD. Key pieces are large trees that can be added using heavy machinery where access to the stream permits. Key pieces are intended to act as buffers to large floods and potentially help create large debris jams by collecting added LWD and naturally occurring LWD during high flows. Where key pieces cannot be added due to limited access for heavy equipment, we build debris jams to simulate key pieces. Seeding is simply adding pieces of LWD by hand to provide more wood to the stream that can be trapped on PALS or key pieces creating more complexity. All of these types of LWD are intended to last in the system for 5-10 years depending on stream gradient, width, and magnitude of flood events. Depending on the condition of the existing riparian habitat, natural LWD inputs may be restored by a single treatment of $_{HD}$LWD if recruitment of LWD and interaction between the channel and floodplain is sufficiently increased.

There are three major PALS types and two LWD types used in $_{HD}$LWD:

- Post-assisted log structures (PALS)
    - Bank attached
    - Mid channel
    - Debris jams
- Seeding (including cover and spanners)
- Key pieces

All LWD added to the stream has a specific function, design, and construction, and are strategically placed to mimic the form and function of natural accumulations of LWD. Each structure is designed with defined objectives for triggering and/or maintaining geomorphic and hydraulic processes leading to channel and floodplain rehabilitation (Table 8). See Appendix IV for photos of each type of structure. A design manual is being developed for the $_{HD}$LWD method that will be publically available by the end of 2015.

Table 8. Intended function, design considerations, and construction approach of five large woody debris structures types used in the $_{HD}$LWD approach to increase wood frequency in wadeable streams.

Structure Type	Function	Design	Construction
Bank attached PALS	Constricting flow, creating a scour pool, eddy pool, or dam pool, building eddy bars, upstream or downstream bars, and/or recruiting riparian vegetation, sediment	Partial channel spanning structure (70-90%) oriented 120° downstream. Enhance natural flow constrictions at meanders and in-channel structural elements	Straight post-line with pieces of LWD secured. Large pieces tight to stream bed to increase flow constriction. Several layers high to constrict flows at different stage heights.
Mid channel PALS	Split flow in wide shallow areas to increase depth variability and hydraulic diversity. Create two scour pools on either side of structure, mid channel bar downstream of structure.	Intended to simulate a tree with a root wad. Large face upstream to split flow with long tapered truck parallel to the flow. Block 40-80% of the flow in mid channel.	Use large log perpendicular to flow at upstream end. Build head of structure 2-4 layers high. Extend downstream parallel to flow with several long logs
Debris jam PALS	Flow impounding structure that can also be intended to force channel avulsion into disconnected side channel or floodplain area. Water storage, channel aggradation, flow dispersion, and groundwater exchange	Channel spanning PALS (90-100%) built adjacent to and extending laterally onto floodplains, benches, and terraces. Crest elevation greater than bankfull	Straight post-line. Built across the entire channel and possibly up onto the floodplain
Key pieces	Act as less mobile LWD by being longer and larger diameter than pieces of LWD used for PALS. Increase LWD diversity and potentially act as starting points for large natural log jams	Install where access permits and damage to existing riparian is minimal.	Install with heavy machinery or draft horses
Seeding	Provide additional LWD for building more complex structures after high flow events or to provide fish cover	Add opportunistically and as LWD source permits	Can be left on existing bars or on the floodplain depending on objectives

8.3.1 Design of Post-assisted Log Structures

Post-assisted log structures (PALS) are not a new idea. PALS are similar to artificial boulders and log complexes and post vanes that have been used in several restoration projects to induce meanders (Zeedyk and Clothier 2009), reduce channel incision by trapping sediment and promoting inset floodplain development (Pollock et al. 2011), create overwintering habitat for salmonids (Cederholm et al. 1997), scour pools (Koski 1992) and create LWD jams (Slaney and Zaldokas 1997).The basic design of bank-attached PALS uses non-treated, wooden fence posts (10 cm diameter and 1.8 – 2.0 m long) to be driven into the stream bed approximately 30 cm apart to effectively narrow the width of the stream and act as woody debris catchers (Figure 22Figure 22). The posts are driven in at least 60-90 cm when possible with a hydraulic post driver and aligned at 90-120 degrees to the stream flow. The depth ensures that the posts will last long enough to withstand low-flow hydraulic forces, and promote the likelihood of debris being caught up on the structures. The posts installed in a staggered pattern to create a rougher surface more likely to act as trap for complicated pieces of wood, as opposed to a straight wall that could simply deflect floating debris around the structure. LWD is partially secured in place by "pinning" some pieces in place with posts. Branches are added to the structures to force water around the structure (i.e., decrease permeability). Bank attached and mid channel PALS are usually built to constrict 70-90% of the active channel and debris jams are built to constrict 90-100% of the channel. Once driven into the substrate the posts are cut to a height 10-20% above the mean annual flood height as determined by evidence of flood activity and other bank full indicators. See Table 7 for basic design principles for the other PALS types and non-PALS we use and Appendix II for design hypotheses we are testing for each PALS type.

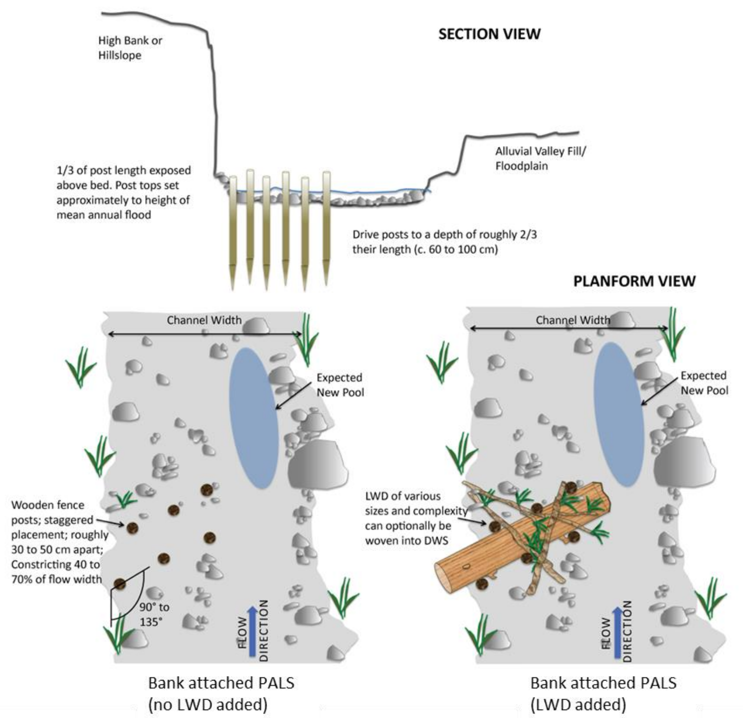


Figure 22. General design schematic for installation of bank attached (river left) post-assisted log structures (PALS).

8.3.2 Construction of Post-Assisted Log Structures

This installation method is designed to be possible with mostly hand tools and labor (Figure 23). The only equipment required for installation is a hydraulic post driver, a chainsaw to trim the posts, manual log hauler and/or an ATV to transport posts and equipment when the sites were not near a road. The post driver can be manipulated by two people and has a 25 m hose connected to a gas engine power unit. The driver weighs approximately 30 kg and the power pack weighs approximately 75 kg. The power unit has large rubber wheels to improve transport over rough terrain. The armor layer of the stream bottom is typically removed by hand where the post is going to be driven if the substrate is cobble or boulder. Each post typically takes only a minute or two to drive to the desired depth. If the post hits an obstruction before it is driven at least 0.6 m, then the post is removed driven in another location. Between 10-20 PALS were constructed/ day using a crew of 4-6 people.

Figure 23. Example of the a) average size of LWD, b) hydraulic post driver that is used to install posts, c) installation of a post with the driver, d) transport of LWD with ATV, e) transport of LWD with log hauler, and f) completed bank attached post-assisted log structure (PALS).

8.4 Restoration Extent

We built 197 structures in the South Fork, 208 in the Charley Creek, and 135 in North Fork treatment sections from 2012-2014 (Figure 24). We estimated that a minimum of 200 pieces of LWD/km would need to be added to each treatment section to increase the existing density of LWD to equal the mean reference conditions (Bennett and Bouwes 2009). However, we used smaller pieces of LWD to build structures (2-5 m long and 0.1. – 0.4 m diameter) than would naturally occur so we decided to add more pieces per treatment. The total number of pieces of LWD added to each treatment section was 585 pieces in the South Fork, 497 pieces in Charley Creek, and 568 pieces in North Fork (Figure 24). These wood counts do not include small braches (< 0.1 m diameter) which were used to increase the hydraulic effectiveness of the structures by making them less permeable. We estimate that a total of 3000-4000 branches were added to the treatment sections.

The majority of structures built were bank attached PALS in all streams. On average the structures were approximately 20 m apart. Photos examples of bank attached, mid-channel, debris jams, and key pieces are presented in Appendix IV. Our hierarchical-staircase design calls for a minimum of 12 km to be restored within the IMW study area, 4 km in each stream. We may choose to increase the extent of the treatments to increase the chance of detecting a population level response. We will review this each year to determine if a larger section needs to be treated, in line with our adaptive management strategy.

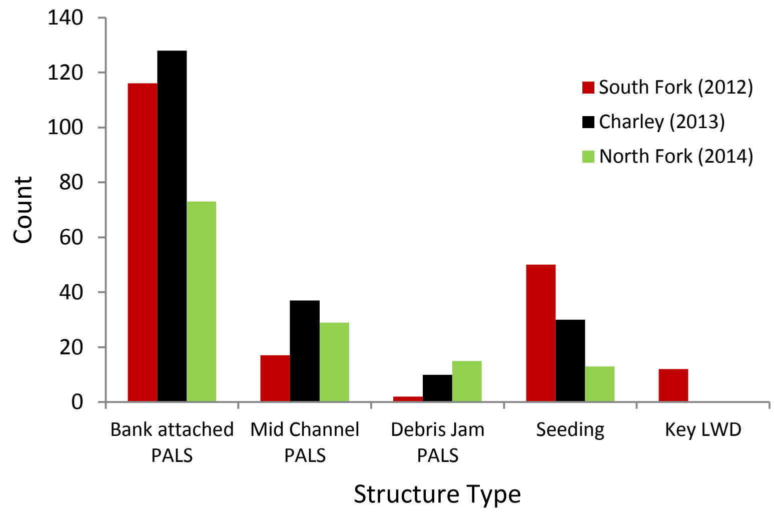


Figure 24. Count of each large woody debris structure type built in treatment sections in South Fork in 2012, Charley Creek in 2013, and North Fork in 2014. No wooden posts were used to secure seeding and Key LWD. All other PALS (post assisted log structures) were not built using non-treated wooden fence posts driven into the stream bottom.

9 WHAT WE HAVE ACCOMPLISHED AND LEARNED

9.1 WDFW Fish IN Fish OUT

WDFW tags a large number of juvenile steelhead each year as well as all returning wild adults that are captured at the adult weir (Table 9Table 9). An average adult steelhead escapement in Asotin Creek above the confluence with George Creek between 2005 and 2014 is 657 (Crawford et al. 2015). There are two juvenile out migration periods: one in the spring which starts in February or March and peaks in May and one in the fall that begins in September and peaks in October or November. The spring juvenile outmigration is on average more than three times larger than the fall migration except for 2007 when the fall migration was larger than the spring migration. The average steelhead smolt outmigration is estimated at 30,803 in the spring and 7,845 in the fall. There is no apparent trend in either the adult escapement or smolt production.

Table 9. Summary of the number of juvenile steelhead (> 70 mm) PIT tagged in Asotin Creek from 2005 to 2014 at the smolt trap on the Asotin mainstem by WDFW and in the IMW study creeks by Eco Logical Research Inc.

Stream	2005	2006	2007	2008	2009	2010	2011	2012	2013*	2014*	Total
Asotin	2,462	1,552	1,895	1,862	946	2,605	4,002	4,680	3,944	4,880	28,828
Charley	-	-	-	424	1297	1955	1283	1136	1246	1180	8,521
North Fork	-	-	-	372	470	1397	906	931	1796	1545	7,417
South Fork	-	-	-	549	737	1862	1275	1495	1939	1846	7,857
IMW subtotal	-	-	-	1,345	2,504	5,214	3,464	3,562	4,981	4,571	23,795
Total	**2,462**	**1,552**	**1,895**	**3,207**	**3,450**	**7,819**	**7,466**	**8,242**	**8,925**	**9,451**	**52,623**

** includes 620 and 362 juveniles PIT tagged on mainstem and captured with hook and line in 2013 and 2014*

The majority of smolts outmigrating in both the spring and fall are age 1 and 2 but age one fall migrants make up a much larger proportion of the out-migrants (Figure 25 and 26). No age 0 out-migrants are caught during the spring but age 0 steelhead are a significant portion of the fall out-migrants (Crawford et al. 2015).

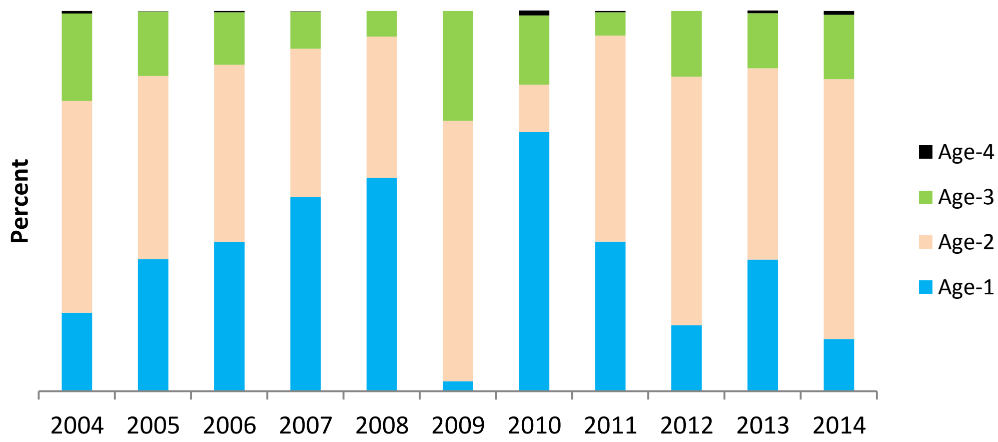


Figure 25. Age structure of emigrants sampled during spring out-migrations, 2004-2014. Reproduced from Crawford et al. (2015).

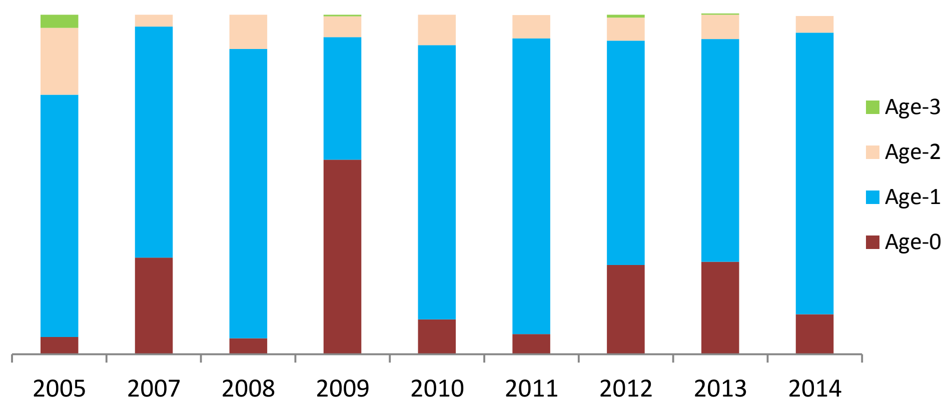


Figure 26. Age structure of emigrants sampled during fall out-migrations from Asotin Creek, 2005, 2007-2014. Reproduced from Crawford et al. (2015).

Despite the large number of age 1 smolts that are captured at the smolt trap, very few adults that spent 1 year rearing in Asotin Creek return to spawn (Figure 27). The majority of returning adults spend two years rearing in Asotin Creek and 1-2 years maturing in the ocean. Females spend on average 2 years in the ocean compared to males that spend on average 1 year in the ocean. Repeat spawning is rare for either sex (~2%).

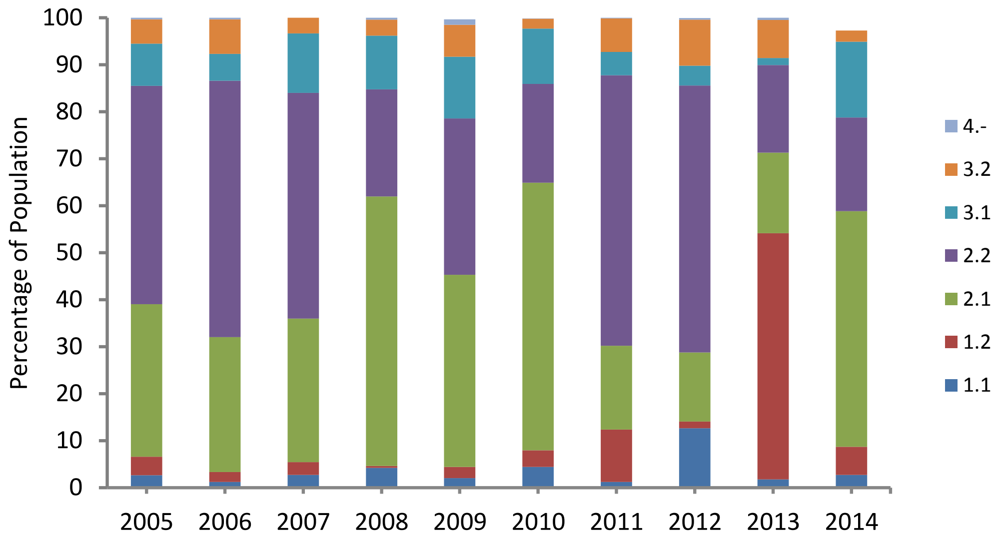


Figure 27. Comparison of total ages of natural origin adult steelhead captured at Asotin Creek weir, 2005-2014. Age '2:1' = 2 years freshwater rearing and 1 year ocean rearing. Reproduced from Crawford et al. 2015. *Note: Repeat spawners have been omitted.

9.2 IMW Juvenile Tagging Program

Since 2008 we have tagged 23,795 juvenile steelhead > 70 mm in the three study creeks of the IMW (Table 9Table 9). We capture relatively few bull trout and Chinook and have only tagged 25 bull trout and 131 Chinook since the start of IMW. The age structure of the juvenile steelhead population during summer sampling is heavily skewed towards age 1 fish and very few of the fish we capture > age 3 (age 1 = 64%, age 2 = 28%, and age > 3 = 7%). This suggests that the majority of the fish we are capturing are steelhead and not resident rainbow trout, as we would expect a higher proportion of older age fish if the resident component was dominant. All of the following data summaries are for juvenile steelhead (> 70 mm) unless otherwise stated.

9.2.1 Abundance

The density of juvenile steelhead is very similar across all three study creeks and generally tracks across years (Figure 28Figure 28). South Fork tends to have the highest densities of juvenile steelhead and the North Fork tends to have the lowest. The average density of juvenile steelhead in the treatment sections appears to be increasing from 2013 onwards compared to the density in control sections. A preliminary assessment of this trend was analyzed using an intervention analysis where we calculated the average density of juvenile steelhead in all treatments sections and all control section combined pre and post restoration (Figure 29; Carpenter et al. 1989). We then subtracted the average density of juvenile steelhead in treatment sections from the density in control sections and compared these differences pre and post restoration (Figure 29). The average difference between the density of juvenile steelhead in treatment compared to control sections increased from 1.78/ 100 m^2 to 6.24/ 100 m^2 from pre to post restoration indicating the density of steelhead increased in the treatment section compared to the control section after restoration. This trend was significant when compared using a t-test with $\alpha = 0.1$ (P =

0.052). See Bennett et al. 2012 and Appendix V for analyses showing how abundance varies by different factors (Stream, Site, Year, Season, Treatment type) and boxplots of data showing variability between sites.

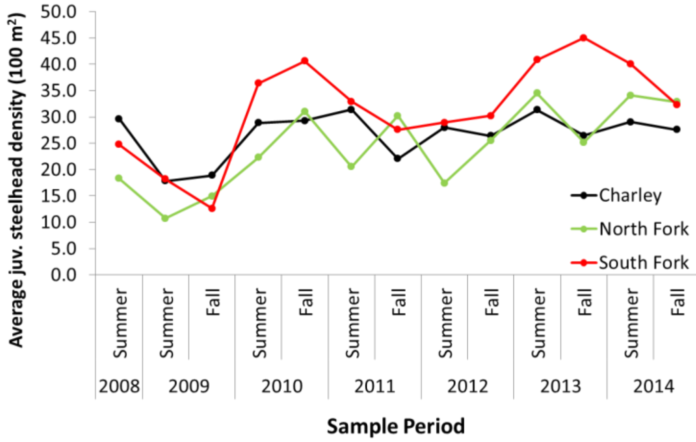


Figure 28. Average density of juvenile steelhead > 70 mm by study creek, season, and year: 2008-2014.

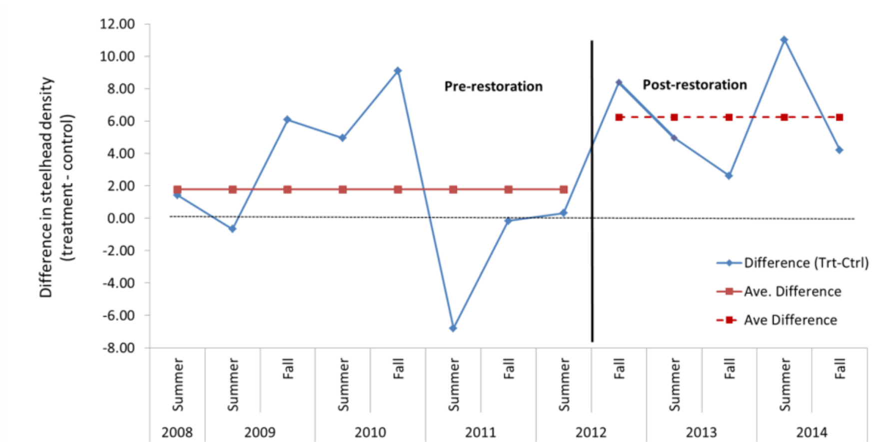


Figure 29. Difference of juvenile steelhead density between all treatment sections combined and all controls combined (blue line). Red lines represent the average of differences in density (treatment minus control) pre and post restoration. Differences between pre and post restoration are significant (α = 0.10, P =0.052).

9.2.2 Growth

Growth rates were gererally correlated across study streams and were lower in Charley Creek compared to the North Fork and South Fork (Figure 30Figure 30). Three distinct periods of very low average growth were observed (summer to fall 2009, 2010, and 2014). Low growth happened during periods with high abundance but not consistently which suggests other factors (e.g., food, flow, and temperature) are likely infuencing growth. We conducted the same an intervention analysis for growth, comparing the average growth in the all treatment sections combined to the average growth in all other control sections combined (Figure 31Figure 31). The average growth in the treatment sections appeared to decrease slightly after the restroation was implemented compared to growth in the control sections. See Bennett et al. 2012 and Appendix V for analyses showing how growth varies by different factors (Stream, Site, Growth Period) and boxplots of data showing variability between growth periods.

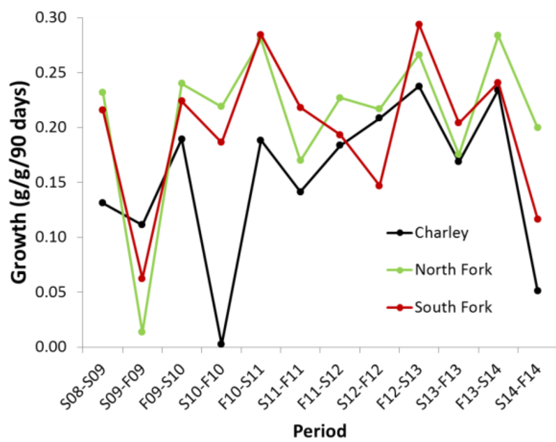


Figure 30. Average juvenile steelhead growth rate (g/g/90 days by study creek and growth period. Growth periods are summer (S) to fall (F) and fall to the following summer from 2008-2014.

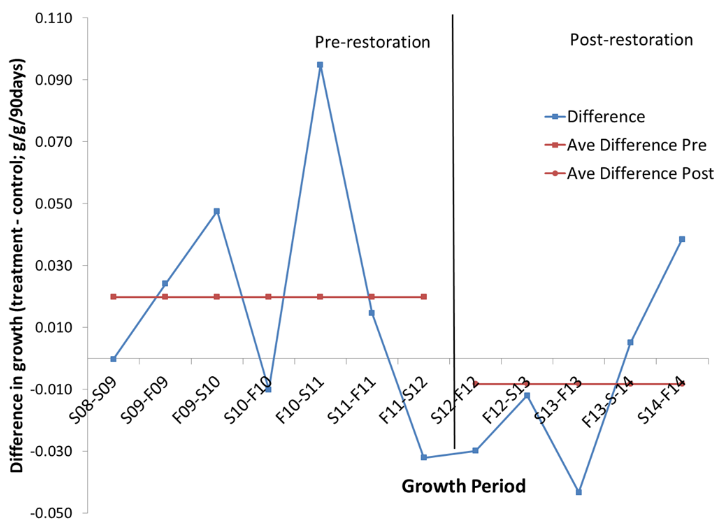


Figure 31. Difference of juvenile steelhead growth rate (g/g/90 days) between all treatment sections combined and all control sections combined (blue line). Red lines represent the average of differences in growth (treatment minus control) pre and post restoration. Difference between pre and post treatment is not significant (α = 0.10, P =0.12).

9.2.3 Fish Movement

A preliminary assessment of juvenile and adult steelhead movement was presented in previous reports (Bennett et al. 2012). It appears that there is limited movement of juvenile steelhead between fish sites within a stream (i.e., most fish captured at site X are recaptured at site X). There is also little juvenile movement between streams (i.e., fish tagged in stream Y are recaptured in stream Y). We have documented a significant proportion of juvenile steelhead that migrate from the study creeks and spend up to one year in the mainstem Asotin Creek before they smolt and leave the watershed. Approximately 45% of the adult steelhead migrating past the WDFW adult weir on the mainstem of Asotin Creek above George Creek enter one of the IMW study creeks (Bennett et al. 2012, Crawford et al. 2015). Future work will focus on quantifying smolt production/spawner in each tributary.

9.2.4 Fish Survival

We have been developing a method to improve survival estimates using a Barker model instead of the commonly used Cormack-Jolly Seber (CJS) method. We have recently published a paper demonstrating that the Barker method can provide more precise and less bias estimates of true survival (i.e., survival accounting for emigration) compared to the apparent survival estimates of the CJS method (Conner et al. 2014). We will be calculating new survival estimates in 2015 to reflect this improved method.

9.3 Habitat Monitoring

9.3.1 Wood and Pools

The number of pieces of wood (≥ 0.1 m diameter and ≥ 1.0 m long) has remained relatively low in the study creeks throughout the monitoring period. The average number of pieces of LWD in the treatment sections was consistently lower than the LWD in all the other control sections combined throughout the study until 2012 after the restoration in South Fork (Figure 32). We estimate that there is almost three times more LWD in the treatment sections compared to the control section as of the completion of the North Fork restoration in 2014. The addition of LWD appears to have caused an upward trend in the average number of pools in the treatment sections as predicted (Figure 33).

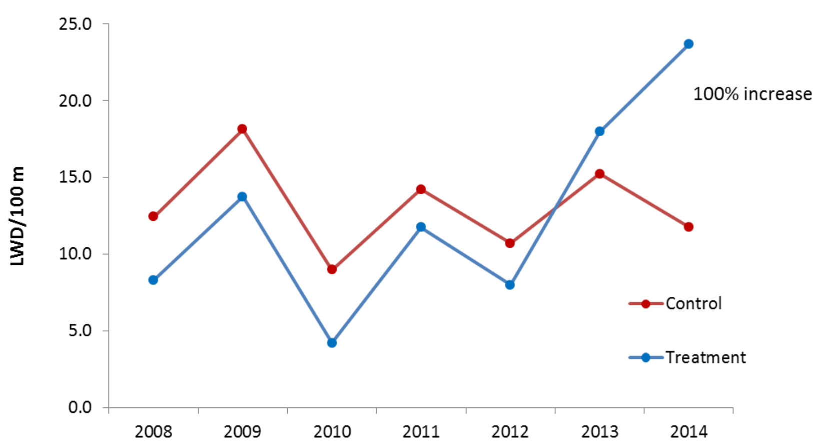


Figure 32. Average frequency of large woody debris (LDW) per 100 m in treatment and control sites: 2008-2014. Dashed line represents approximate LWD frequency post restoration in 2014 (data not completely summarized).

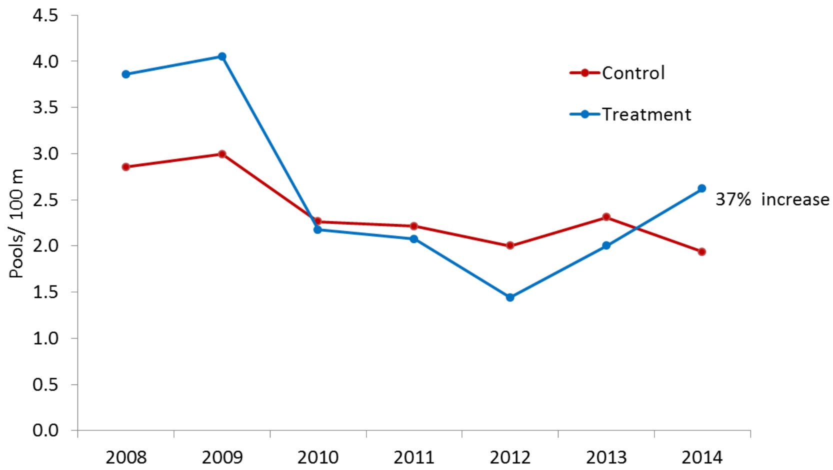


Figure 33. Average frequency of pools per 100 m in treatment and control sites across all study creeks: 2008-2014.

9.3.2 Habitat Complexity

Since restoration on Charley Creek and the South Fork, structures have imposed several changes to typically uniform flow patterns in the channel. As of 2014, the majority of structures have created upstream and downstream eddys, and convergent jets off the end of the structures (Figure 34). While these hydraulic responses may have implications for juvenile steelhead habitat, they also lead to specific and predictable geomorphic responses, in the forms of erosion and deposition, during high flows. We identified the results of these geomorphic responses as distinct channel units.

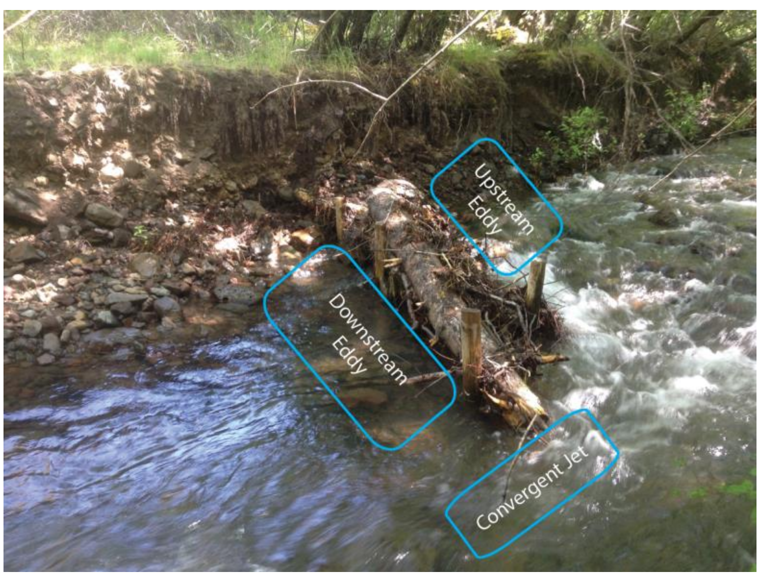


Figure 34. An example of hydraulic responses that significantly increased at restoration structures on the South Fork of Asotin Creek and Charley Creek since restoration (note flow direction is from right to left).

At all of the combined treatment sections, the proportional area of all tier two units significantly changed after restoration. Pool and bar area increased by 3.6% and 3.1% and planar feature area decreased by 8.0% ($p < 0.0001$ for all changes). However, control sites did not remain the same after restoration implementation either. At control sites, pool area increased by 3.1% and bar area increased by 1.5% ($p < 0.0001$ for both changes). Planar features at control sites did not significantly change. In contrast, the number of bars, pools, and planar feature units per 100 m all significantly increased at treatment sites, but did not change at control sites (Figure 35). At treatment sites, the number of pools and bars per 100 m increased by 2.0 ($p = 0.006$) and 2.8 ($p = 0.006$). Planar features per 100 m also significantly increased by 2.0 ($p = 0.01$) at treatment sites. More specifically at treatment sites, the most common increases were in structurally forced pools and forced bars, while runs were the most common unit to decrease (Figure 36).

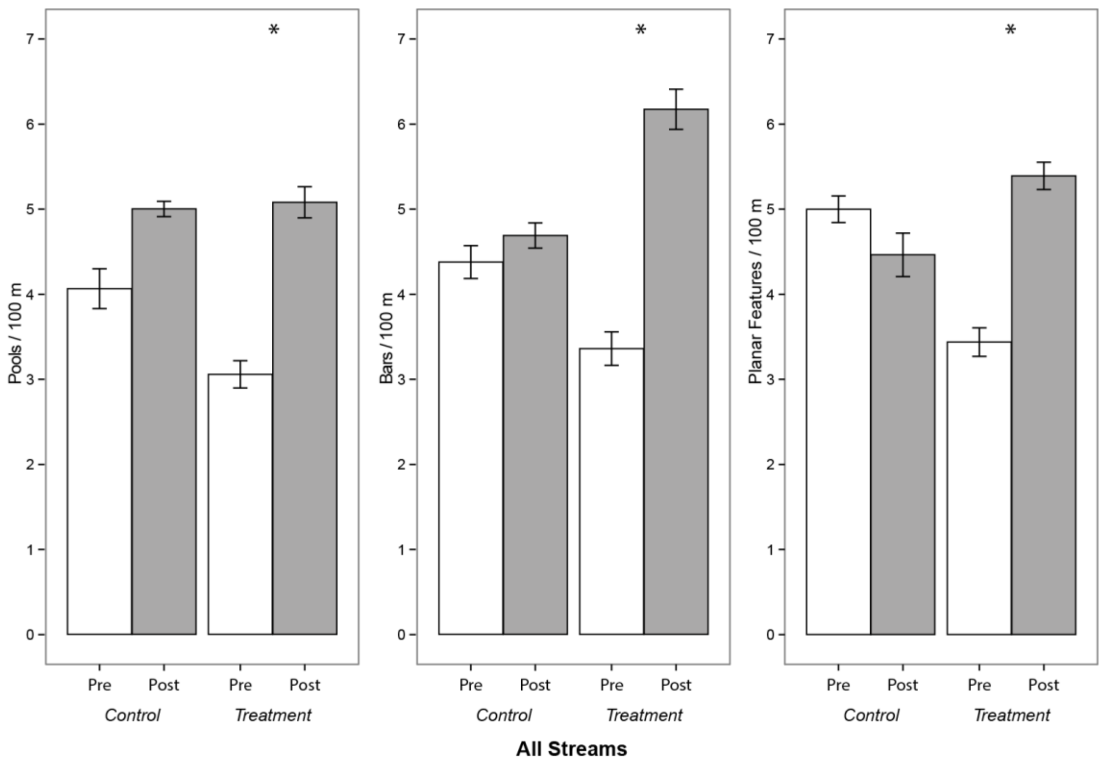


Figure 35. Comparison of the number of pools, bars, and planar features per 100 meters at treatment and control sections, pre and post restoration. This comparison includes data from Charley Creek and the South Fork of Asotin Creek. Asterisks (*) above a bar pair represent and significant difference between pre and post restoration.

Figure 36. Example of the increased number of pools and bars after restoration within a CHaMP site on the South Fork of Asotin Creek. The left image shows the topography and delineated units pre restoration, and the right image shows the changes post restoration.

9.3.3 Geomorphic Change Detection

We have used the topographic surveys to create digital elevation models (DEM) to assess changes (erosion or deposition) where we have placed structures. The best example of change is at three trial structures we built in North Fork in 2011. These structures were subject to a large flood in the spring of 2012 and performed as hypothesized. We subtracted the DEM from 2011 from the 2012 DEM and it revealed the amount of erosion and deposition along a 150 m site (Figure 37a). Virtually all change in the topography occurred around the structures with erosion taking place downstream of the structure below the constriction point and bars forming upstream and downstream of the structures. These changes have continued to increase base on visual estimates and bars have grown substantially (Figure 37b).

a)

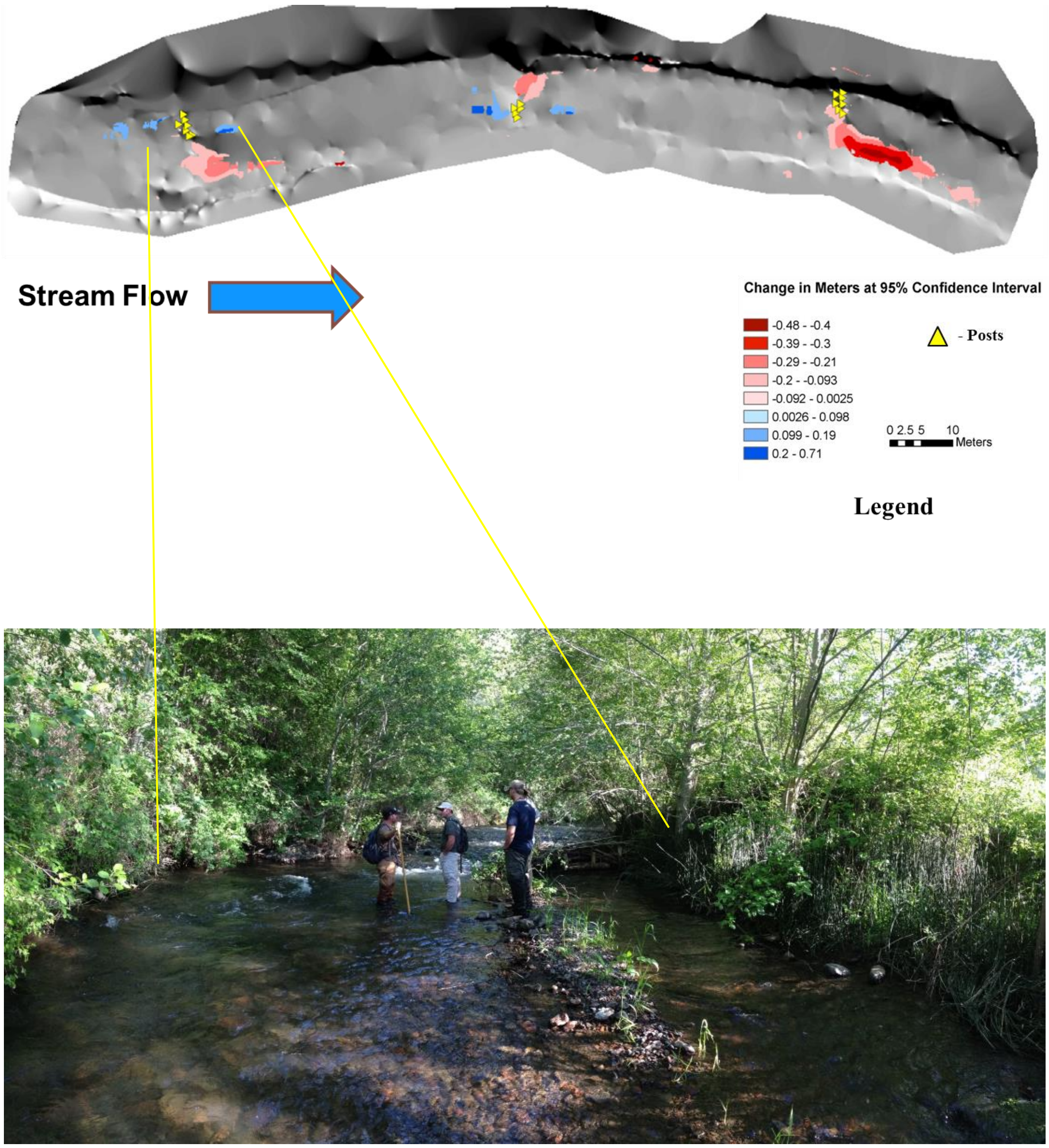


Figure 37. Example of a) geomorphic change detection for North Fork Asotin Creek trial structures 1-3. Image is the digital elevation model of difference (DoD) resulting from the differences in elevation values between years (2011-2012). Only changes (erosion = red, deposition = blue) within 95% confidence interval limits are shown. b) picture of trial # 3 in 2013 showing large bar developing downstream of the structure and scour pool.

9.4 Synthesis of Fish and Habitat Responses to Restoration

To date we have helped to improve the process for generating the necessary data streams from CHaMP data to more rapidly calculate net rate of energy intake (NREI) at multiple reaches (champmonitoring.org). We have also assessed if the predictions of fish density and carrying capacity predicted from NREI are correlated to fish densities we observed both in Asotin Creek IMW and Bridge Creek IMW in the John Day Watershed. Our findings suggest that there is a relatively strong and significant correlation between observed juvenile steelhead density and predicted fish density (i.e., carrying capacity) from NREI in both IMWs ($r^2 > 0.61$, $p < 0.001$; Figure 38a). When we assumed spatially uniform drift densities and small fish territories, carrying capacity predictions were related to the number of foraging locations simulated, suggesting the model is highly sensitive to territory size assumptions (Wall 2014).

We compared foraging before restoration and again following restoration implementation to assess the effect of restoration on fish habitat and carrying capacity (Figure 38b). We used raster differencing to compare the `NREI before' to the `NREI after' restoration. The mean NREI before (2012) was -0.05 J/s (standard deviation = 0.12), while the mean NREI after (2013) was 0.015 J/s (standard deviation = 0.12). These calculations were only done on a 50 m segment of the restoration segment in South Fork. These results suggest the mean net energy intake increased and that more areas shifted from having an acceptable energy balance than to an unacceptable energy balance following restoration.

a) b)

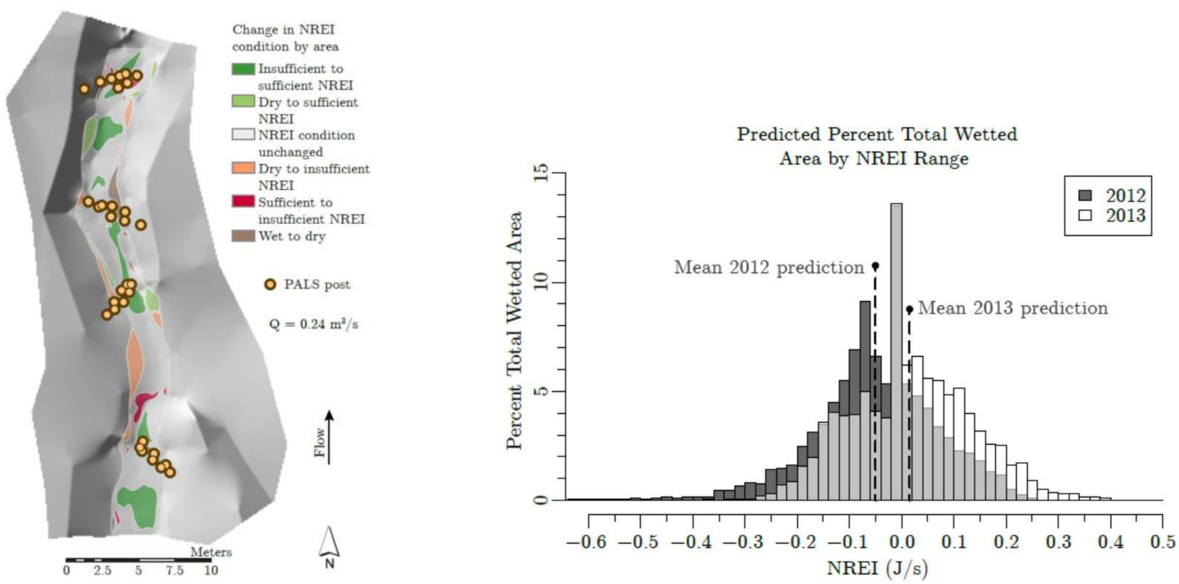


Figure 38. An example from a 50 m segment of South Fork treatment section showing a) changes in net rate of energy intake (NREI) condition from 2012 to 2013 after restoration with post assisted log structures (PALS), and b) the distribution of NREI values in the segment in 2012 (dark gray) and 2013 (white). Light gray bars indicate overlap between two years. Mean NREI value increased from -0.05 J/s (SD = 0.12) in 2012 to 0.015 J/s (SD = 0.12) in 2013.

10 CONCLUSION

We have designed and implemented an experiment to test the effectiveness of a common restoration method in southeast Washington. We have completed five years of pre-treatment (2008-2012) and two years of post-treatment (2013-2014) monitoring of fish and habitat attributes at multiple scales (stream, section ,site, habitat unit) across the Asotin Creek watershed. We completed 12 km of restoration in the Asotin Creek watershed from 2012-2014 using a method we are calling high-density large woody debris ($_{HD}$LWD). The $_{HD}$LWD approach uses mostly hand built LWD structures to simulate natural wood loading in streams and is relatively low cost to implement. This method can be used in places where there is recovering riparian habitat with because it causes minimal damage. The majority of the structures we built were post assisted log structures (PALS) which are constructed using a post driver to pound wooden fence posts into the substrate to secure pieces of LWD in place. These structures appear to be achieving many of their hypothesized effects including creating scour pools, building bars, and backing up water onto floodplain surfaces (Camp 2015). The Asotin IMW monitoring is also finding evidence that these structures are increasing the abundance of juvenile steelhead (Bennett and Camp 2015). The $_{HD}$LWD approach appears to be an effective and low cost approach to reducing the large-scale deficit of woody debris that streams in the Pacific Northwest are experiencing (Al-Chokhachy et al. 2010). Determining how effective the restoration is at increasing steelhead productivity will be the focus of the next five years of monitoring.

10.1 Best case - worst case

Our approach is different than other IMWs in that we have three replicates of a stream experiment and control and treatment sections are within each stream (i.e., no out of basin controls). This is potentially a more powerful and ultimately informative design if all the assumptions that went into our power analysis are true (e.g., estimates variance, independence of sites, no synergism of treatments). Each treatment stream is unique ranging from two high gradient streams - a small spring feed stream (Charley) and a flashy medium sized stream (South Fork); to a large lower gradient, less confined stream (North Fork). Applying the restoration to all three of these streams increases the potential to learn how effective the treatment is across a broader ranges of conditions which will help when it comes to extrapolating the results. If we see a positive habitat and fish response in all three streams this will also increase our confidence that the methods is robust and that the response was not “stream specific”.

However, there is a risk in this approach. Our pre-treatment data indicate that most juvenile and adult steelhead use a single stream and juveniles move very little within streams. If there is considerable fish movement between streams or within streams this could confound our experiment. Having a large number of PIT tagged fish (> 25,000 juveniles) and a robust set of arrays will help us assess movement throughout the study.

10.2 Evil Variance

Variance between years, streams, sections, and sites is moderate to high as was expected (Appendix V). Some of this variance is due to changes in our design, missing sites, and poor sampling conditions. North Fork is especially hard to sample for fish because it is a larger stream and our capture efficiency is lower than in Charley and South Fork. Topographic surveys are more challenging in Charley Creek because it is small and riparian vegetation creates a tunnel over the stream. These are common problems of all sampling programs and cannot be eliminated. However, the model we will use to assess much of our data is based on the HS design and it has the ability to tease apart some of these sources of variance including year to year variability and the effect of when the restoration was implemented. Another approach to dealing with variance is to look for several lines of evidence of a response rather than just one. That is why we are assessing numerous fish and habitat metrics. If multiple responses are trending in the same direction, and we can explain them with an understanding of the underlying mechanisms of change, we will be more confident that the response was positive.

10.3 Factors out of our control

We lost some continuity in our data collection due to a landowner denying access to sites along Charley Creek which will complicate our analysis due to missing data in the pre-treatment phase. However, we have one site in each section in each stream that has been continually sampled for fish and habitat since 2008 (except for missing one year at site 3 on Charley Creek). The amount of funding for monitoring has varied considerably each year which has made it difficult to schedule sampling and conduct other directed studies that would help better understand casual mechanism. Continued low stream flow since restoration was implemented are limiting the amount of potential geomorphic change that can be produced. It would be beneficial if we had a flow of the magnitude of the spring 2012 or greater to help fully assess the PALS and see if benefits to fish increase with larger stream flows. The removal of a partial juvenile migration barrier at Headgate dam (~ 10km downstream of IMW study area) could change the movement patterns of juveniles in Asotin Creek. We are currently working with WDFW to monitor juvenile movement above and below the dam. Finally, loss of PIT tag arrays would limit our ability to fully assess the effectiveness of restoration because we are going to use PIT tag detections and estimates of array efficiencies to estimate smolt production from the study creeks.

10.4 Transferability

Determining the effectiveness of adding LWD to streams with simplified habitat could be transferable to other wadeable streams with low to moderate gradient (0.5-3+) assuming other watershed scale factors are well understood (i.e., there are no fluvial or riparian processes that compromised such that instream work is not justified). Order 5 streams and less are generally considered wadeable and majority of the streams that steelhead occupy are order 5 and less (Figure 39). The restoration actions are probably applicable across a broad range of climatic and land cover conditions. Essentially if there is evidence that LWD played an important role in the stream historically but current riparian conditions are not providing an adequate source of LWD, this method may be applicable. We are in the process of completing a detailed geomorphic assessment of Asotin Creek using the River Styles framework (Brierley and Fryirs 2005) – our group plans to expand this assessment to the entire Columbia River Basin which would facilitate our ability to determine the applicability of this restoration action to other watersheds. This is an aspect of IMW projects that has not been well developed to date.

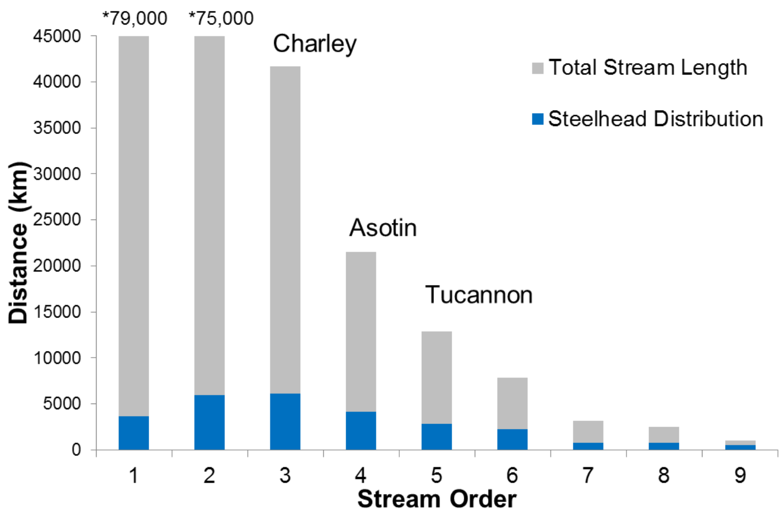


Figure 39. Length of each stream order occupied by steelhead (blue bars) compared to the total length of each stream order in the Columbia Basin (gray bars). Not order 1 and 2 streams exceed the y-axis (values listed on each bar).

10.5 Knowledge Transfer

It is still early in the IMW to provide managers with information about the effectiveness of the restoration at increasing productivity or how better to design restoration actions using LWD to increase the effectiveness of the treatments. We have however, learned a lot about the basic life history characteristics of juvenile steelhead in Asotin Creek related to abundance, growth, movement, and survival. We have also made progress in developing various mobile applications, fish and habitat survey protocols, and analysis methods that are key to helping fulfill the IMW's goals and since 2008 we have published manuscripts and theses on these topics and presented preliminary results throughout the PNW by speaking and presenting posters at numerous symposia and professional meetings (Appendix VI). We caution the Monitoring Panel though to have patience during the post-restoration phase of the IMW, as there is a significant amount of analyses required and time needed to fully assess the restoration and fish response due to the age structure of steelhead populations.

10.6 Improvements and Recommendations

- Secure consistent and reliable monitoring funding; it should not be a mystery what funds will be available each year
- Organize biannual meetings of IMWs to share results and coordinate approaches and analytical methods
- Patience … it took 150 years to screw things up; it is going to take a while to figure out how to fix it and due to the extent of disturbance, recovery may be slow – but the best way to speed recovery is to learn what works and what doesn't.

APPENDIX I. SUMMARY OF THE CHANGES TO THE ASOTIN CREEK INTENSIVELY MONITORED WATERSHED PLAN FROM ITS INCEPTION IN 2008 TO THE END OF FOUR YEARS OF PRETREATMENT MONITORING IN 2011.

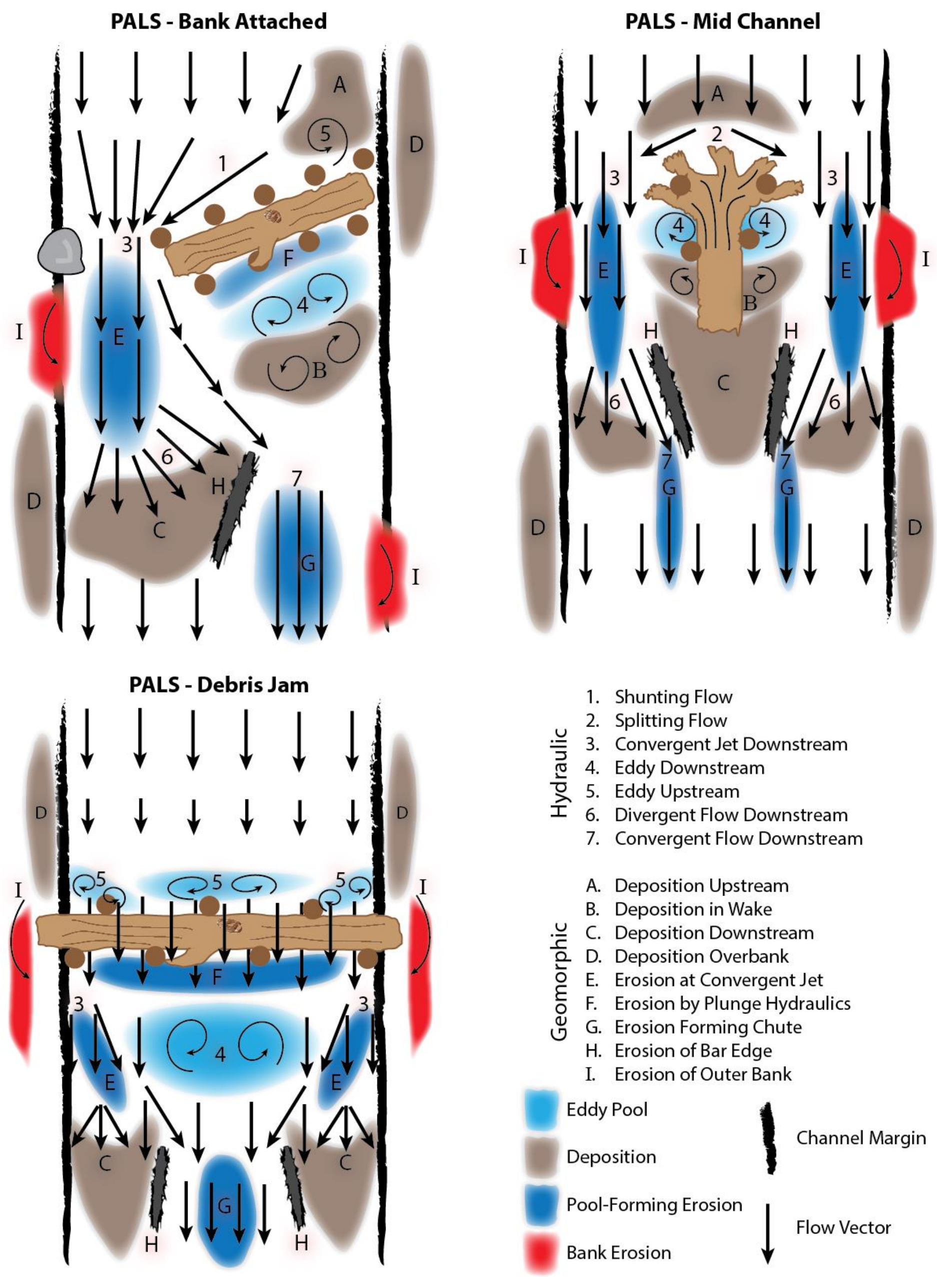
This appendix summarizes all the significant changes to the Asotin Creek Intensively Monitored Watershed Plan since the original plan was developed in 2008 (Bennett and Bouwes 2009). Many of the changes that have been made are due to new information or analyses that have become available over the course of four years of pretreatment monitoring. However, because we are implementing the restoration design over several years and across multiple spatial and temporal scales in a hierarchical-staircase design, there is built in flexibility in the year to year implementation of the IMW (experimental, restoration, and monitoring designs). For example, a fundamental requirement of the restoration action is that a fish response can be detected at the population level. If, after restoring 4 km of one creek, we have not been able to detect any population level responses, it will be possible to treat another 4 km in the same creek the next year (i.e., increase the treatment effect per creek), or complete the proposed treatment of all three creeks (i.e., 4 km per creek) and then treat a second 4 km section in a particular creek. This approach is part of our adaptive management strategy. The following sections describe the timing, extent, and rationale for the changes we have made to the Asotin IMW project.

Table A1. Summary of the significant changes to the Asotin Creek Intensively Monitored Watershed project plan: 2008-2012.

Project Element	Description of change	Rationale for change	Timing of change
Experimental Design	Timing of restoration actions changed from 2011, 2014, and 2017 to 2012-2014	Funding was not available to initiate the restoration in 2011 and the treatments needed to be consecutive to provide a greater period of post treatment evaluation	Summer 2010
	Arrangement of restoration actions changed from 3 treatment sections in Charley Creek to 1 treatment section in Charley Creek, North Fork, and South Fork	Statistical power analysis of the initial experimental design indicated that under worst case scenario conditions (i.e., higher levels of variance) that the 1 treatment per stream design has significantly greater power to detect a change	Sept 2010
Monitoring Design	Changed stream habitat monitoring protocol from PacFish/InFish (PIBO) to the Columbia Habitat Monitoring Protocol (CHaMP)	We helped develop a new habitat protocol that was more focused on measuring attributes important to fish and that provides a greater level of habitat mapping. However, crosswalks are available between the two approaches.	August 2010
	Changed the allocation of fish monitoring sites from an emphasis on Charley Creek to an even split of sites between all three study streams (i.e., four fish sites per study stream)	Due to changes in the experimental design, we reallocated two fish sites from Charley Creek (CC-F4 and CC-F6) to the North Fork (NF-F2) and the South Fork (SF-F4). We did this so that each treatment section would have two fish sites and each control section would have one fish site.	February 2012

	Changed the allocation of habitat monitoring sites from permanent and rotating sites with an emphasis on Charley Creek to all permanent sites with either CHaMP monitoring or Rapid habitat surveys	To better survey the treatment sections and in particular the post assisted log structures (PALS), we changed the arrangement of one permanent and two rotating habitat sites per fish site to all permanent sites (i.e., sampled ever year). In treatment sections we will survey four habitat sites using CHaMP and two habitat sites using a Rapid habitat protocol each year (2 CHaMP and 1 Rapid per fish site x 2 fish sites). In the control sections we will survey one habitat site using CHaMP and 2 sites using the Rapid protocol.	February 2012
Restoration Design	Location of restoration treatments changed (see section 4 Experimental Design)	Increases statistical power of experiment and provides us an opportunity to assess the restoration action on a range of stream types (i.e., small, spring fed, single channel stream to larger less confined stream)	
	Restoration treatment changed from a focus on engineered log structures and whole trees to “post debris catchers” with hand placed LWD	There is a significant amount of riparian vegetation along all the study streams that we want to preserve; therefore, heavy machinery is not an option for creating LWD structures in most locations. Instead we will use posts driven into the stream bottom and 2-4 m long pieces of LWD to create hand built structures which can be built without significant disruption of the existing riparian vegetation and that simulate large trees.	Spring 2011
	Design of post-assisted log structures	After assessing the effectiveness of our trial structures for two years and the first IMW treatment for one year (South Fork Asotin Creek: 2012-2013) we realized that larger and more aggressive structures were better at creating hydraulic and geomorphic change. We therefore, increased the constriction width of PALS in the next two treatments from ~ 70% to ~ 80-90%.	
Landowner Access	One of the two private landowners in Charley Creek (B. Koch) decided to not allow WDFW and IMW staff to access their property which contained 2 fish sampling sites (CC-F3 & CC-F4)	The landowner wanted compensation for access that we could not provide. Also, WDFW began negotiating with landowner to purchase property and the landowner did not want people working on the property while the negotiations were ongoing. ***This property has since been purchased by WDFW.	Spring 2011

APPENDIX II. DESIGN AND EXPECTED RESPONSES OF THE THREE POST-ASSISTED LOG STRUCTURE TYPES: RED INDICATES BANK EROSION, BLUE INDICATES SCOUR, BROWN INDICATES DEPOSITION, AND ARROWS INDICATE FLOW DIRECTION AND VELOCITY.



APPENDIX III. DATA MANAGEMENT FRAMEWORK FOR THE ASOTIN CREEK IMW.

Data Group	Data Source	Data Collection	Data Transfer	Data Storage	Description
Fish	Capture Surveys	Data Logger with custom ISEMP PIT tag application	Direct Transfer from Logger App >>> Fish Capture Database	ISEMP AsotinRovingFish Access database	All 2-3 pass mark-recapture tagging data collected during summer and fall tagging sessions at permanent fish survey sites
	Array Detections	Biomark MUX and Campbell Scientific Data Loggers	via phone connection or manual upload >>> PTAGIS	PTAGIS and AsotinRovingFish Access database	All arrays are connected to Biomark MUX readers and Campbell Scientific data loggers and PIT tagged fish crossing the antennas are detected, data stored, and uploaded automatically
	Mobile Surveys	Data Logger with custom ISEMP PIT tag application and GPS	Transfer from Logger App >>> Excel >>> Fish Capture Database	ISEMP AsotinRovingFish Access database	all fish detected during mobile PIT tag surveys are recorded on data logger along with date/time, GPS location, and habitat unit
	WDFW	Smolt trap, adult weir, redd counts	WDFW databases and/or PTAGIS >>> IMW database	ISEMP AsotinRovingFish Access database	all captures and recaptures at WDFW sites are stored in IMW database to aid in querying movement and PIT tag detection data
	ISMEP Adults	Arrays and adult weir	via phone connection or manual upload >>> PTAGIS	PTAGIS and AsotinRovingFish Access database	ISEMP/WDFW are PIT tagging 9-10% adult steelhead and Chinook at Lower Granite dam; we are recording the number of these fish that move into the Asotin and are detected by the arrays or at the adult weir
Habitat	PIBO	standard field datasheets	Hand entered into custom IMW database	AstotinPIBO database	from 2008-2009 we used the PIBO habitat protocol to collect habitat data - we are integrating these data with the current habitat monitoring protocol (CHaMP)
	CHaMP	custom ISEMP data logger	custom upload process to champmonitoring.org	champmonitoring.org and excel spreadsheet of metric data	ISEMP collects all data collected using CHaMP and runs QAQC on the data and then posts raw data, summarized data, and site metrics. Data is also run through the River Bathymetry Toolkit to produce metrics from the topographic data
	Riparian	aerial photography, LIDAR, PIBO riparian protocol	all aerial photography and LiDAR are transferred into GIS; riparian site data was collected on data sheets and hand entered into excel spreadsheets	transferred to GIS or stored in excel	imagery is processed using GIS; site riparian data (canopy cover), species presence, etc. are summarized and stored in excel

Data Group	Data Source	Data Collection	Data Transfer	Data Storage	Description
Water	Water Quality	site collection of basic water quality measures at each fish site	Direct Transfer from Logger App >>> Fish Capture Database	ISEMP AsotinRovingFish Access database	collect conductivity, pH, temperature, alkalinity, nitrogen, phosphate, turbidity annually at fish sites
	Temperature	temperature loggers recording water temperature every hour at 22 sites	download 1-2 times a year to HOBO software and export to excel	custom ISMEP database	water temperature at each fish site, array location, and selected sites throughout the Asotin watershed has been collected since 2008;
	Discharge	continual water level or discharge estimates at USGS, DOE, and IMW established sites	download 1-2 times a year from internet (USGS and DOE) or manually download from IMW sites and export to excel	custom ISMEP database	use existing and IMW installed discharge monitoring sites to collect hourly discharge record of each study stream and the mainstem Asotin Creek; instantaneous discharge is also collected at each CHaMP habitat site
Watershed/ Landscape	LiDAR, aerial photography	collected every 3-5 years using contractors (i.e., Watershed Sciences or with our own UAV)	transferred from contractors or image collection devices (i.e., aerial cameras)	processed and stored in GIS geodatabase	watershed scale imagery and topographic data collected using fixed wing or unmanned aerial vehicles (UAV) every 3-5 years to detect changes in channel and floodplain condition (including riparian extent and cover).
	Watershed Attributes	soils, geology, topography, aerial imagery, climate, precipitation, basin statistics, etc.	information collect from a variety of sources online including federal, state, and university sources	processed and stored in GIS geodatabase	data collected on Columbia River Basin scale to aid in putting Asotin Creek watershed into context within CRB in a multiscalar framework (i.e., River Styles)

APPENDIX IV. EXAMPLES OF THE TYPES OF LWD STRUCTURES BUILT IN SOUTH FORK ASOTIN CREEK (2012), CHARLEY CREEK (2013), AND NORTH FORK ASOTIN CREEK (2014).


Mid-channel structures in Charley Creek.


Debris jam Charley Creek


Deflector structure Charley Creek


Deflector structure Charley Creek


Mid-channel structure North Fork Asotin Creek

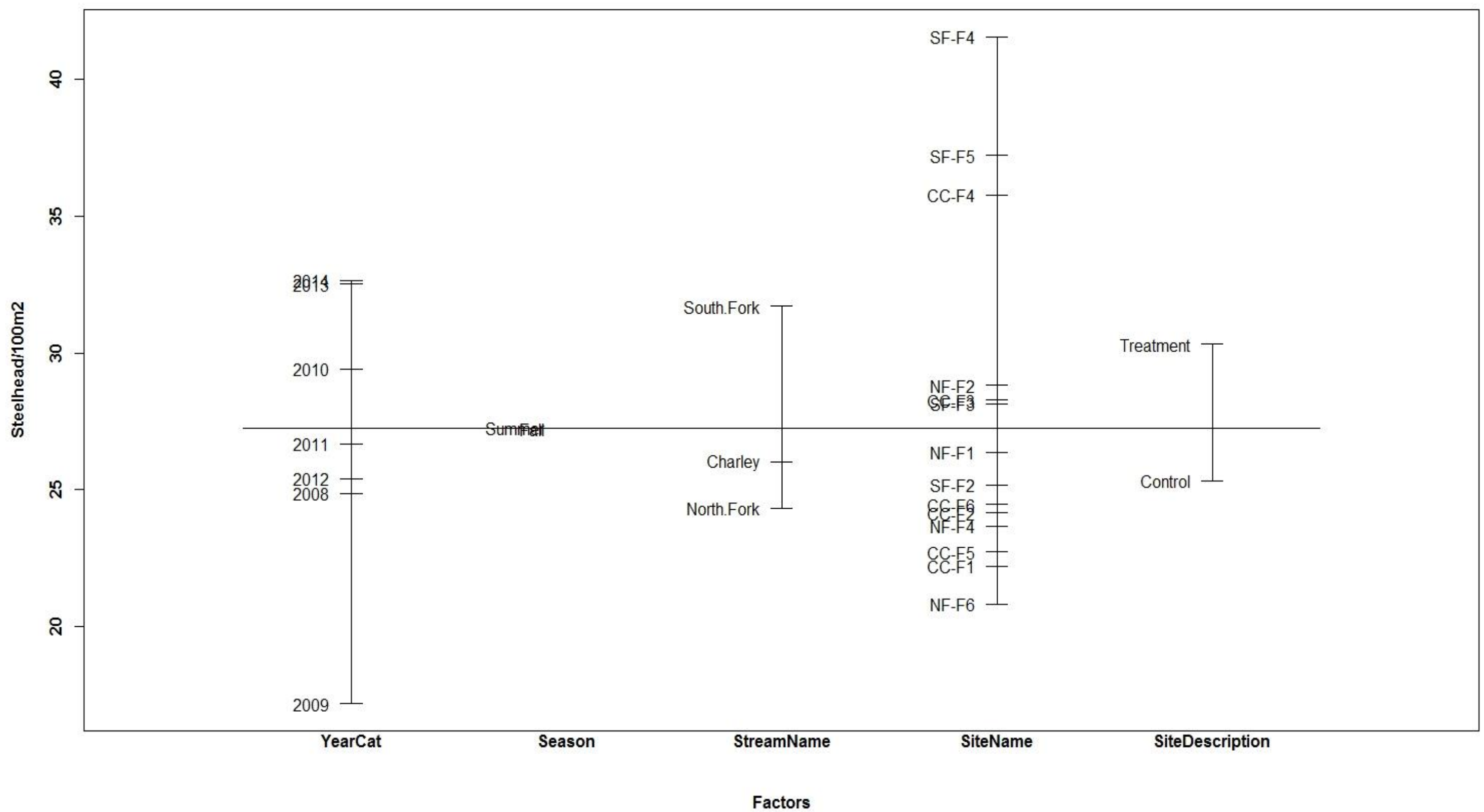

Seeding North Fork Asotin Creek


Debris jam North Fork Asotin Creek

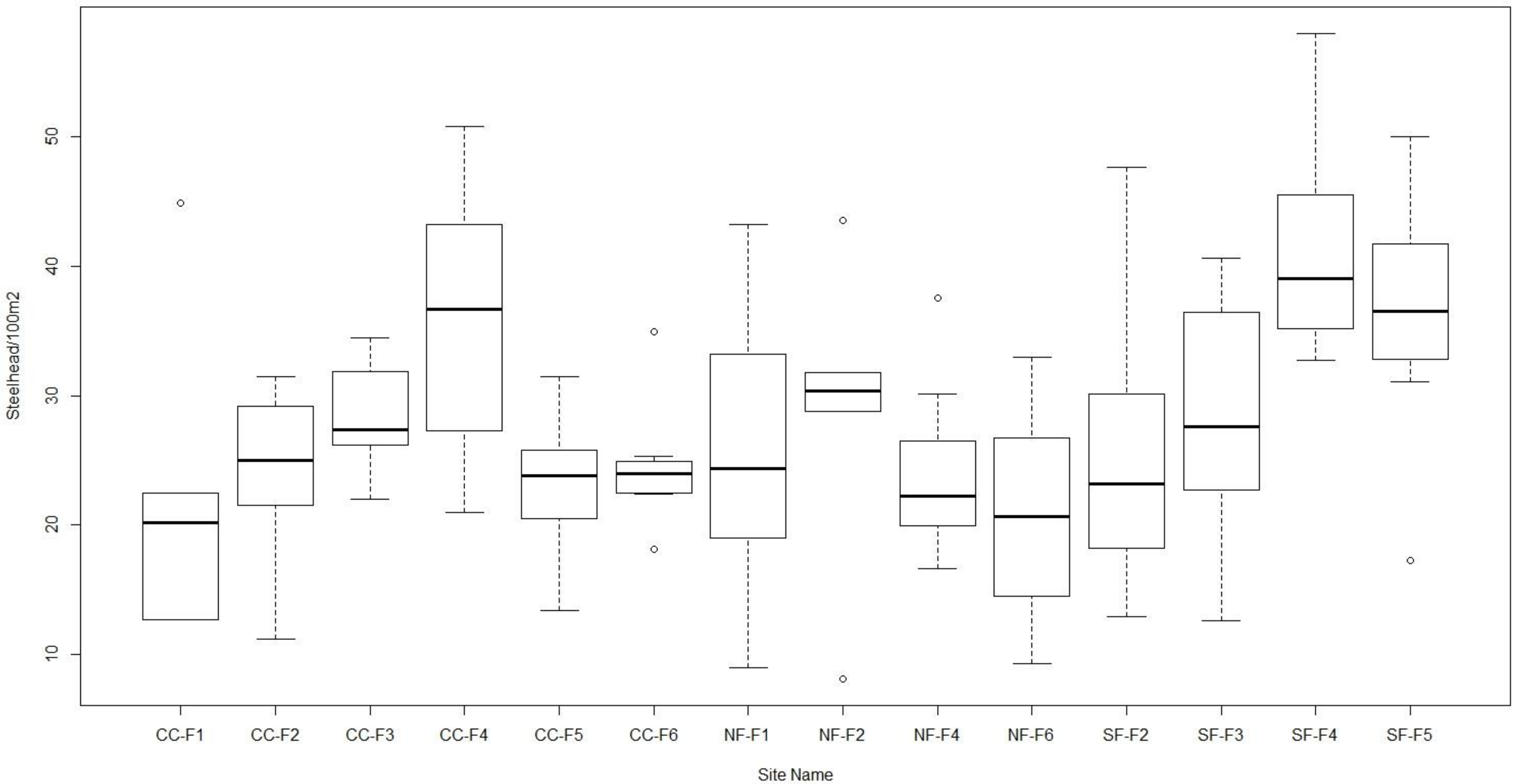

Deflector North Fork Asotin Creek

 Mid-channel structure South Fork Asotin Creek	 Key piece South Fork Asotin Creek
 Debris jam South Fork Asotin Creek	 Deflector South Fork Asotin Creek

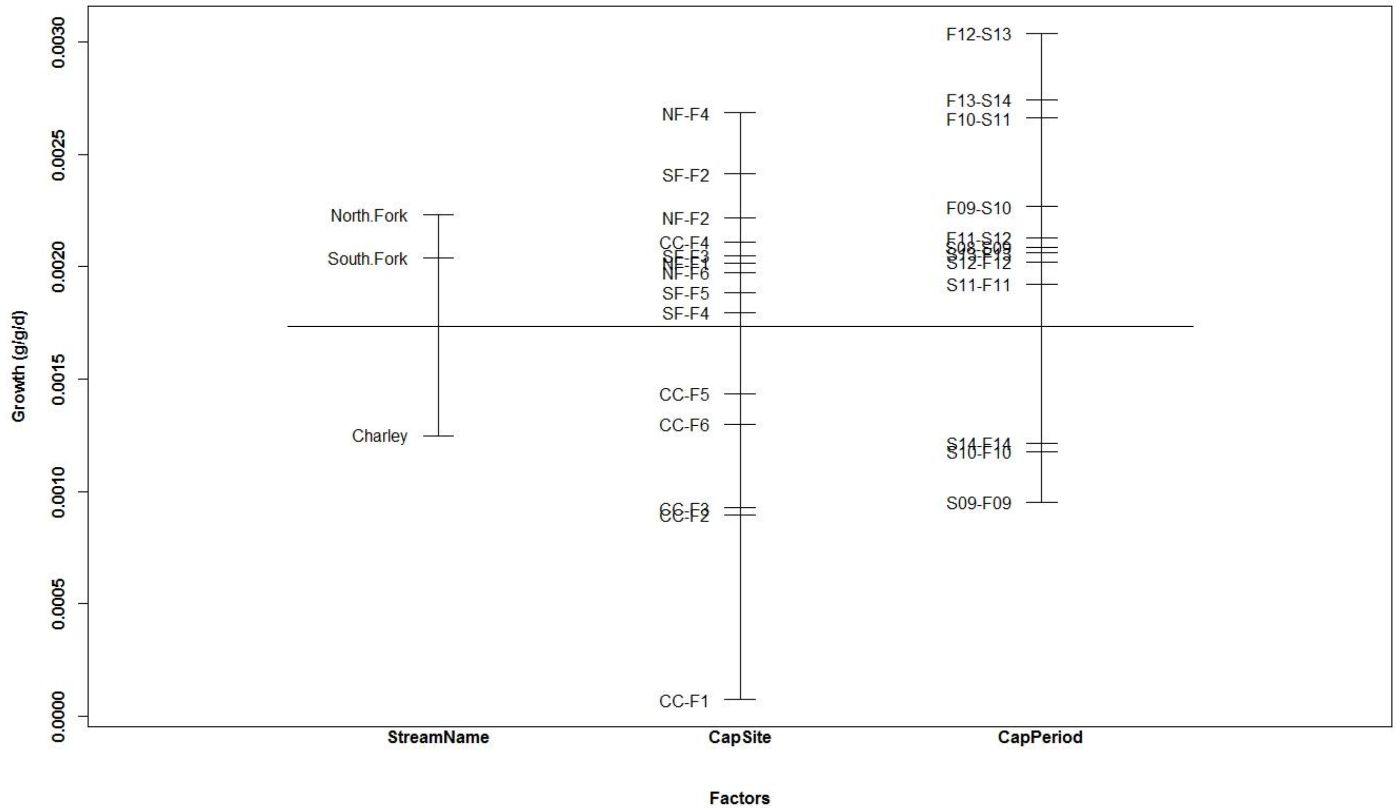
APPENDIX V. EXAMPLES OF VARIABILITY OF ABUNDNACE AND GROWTH



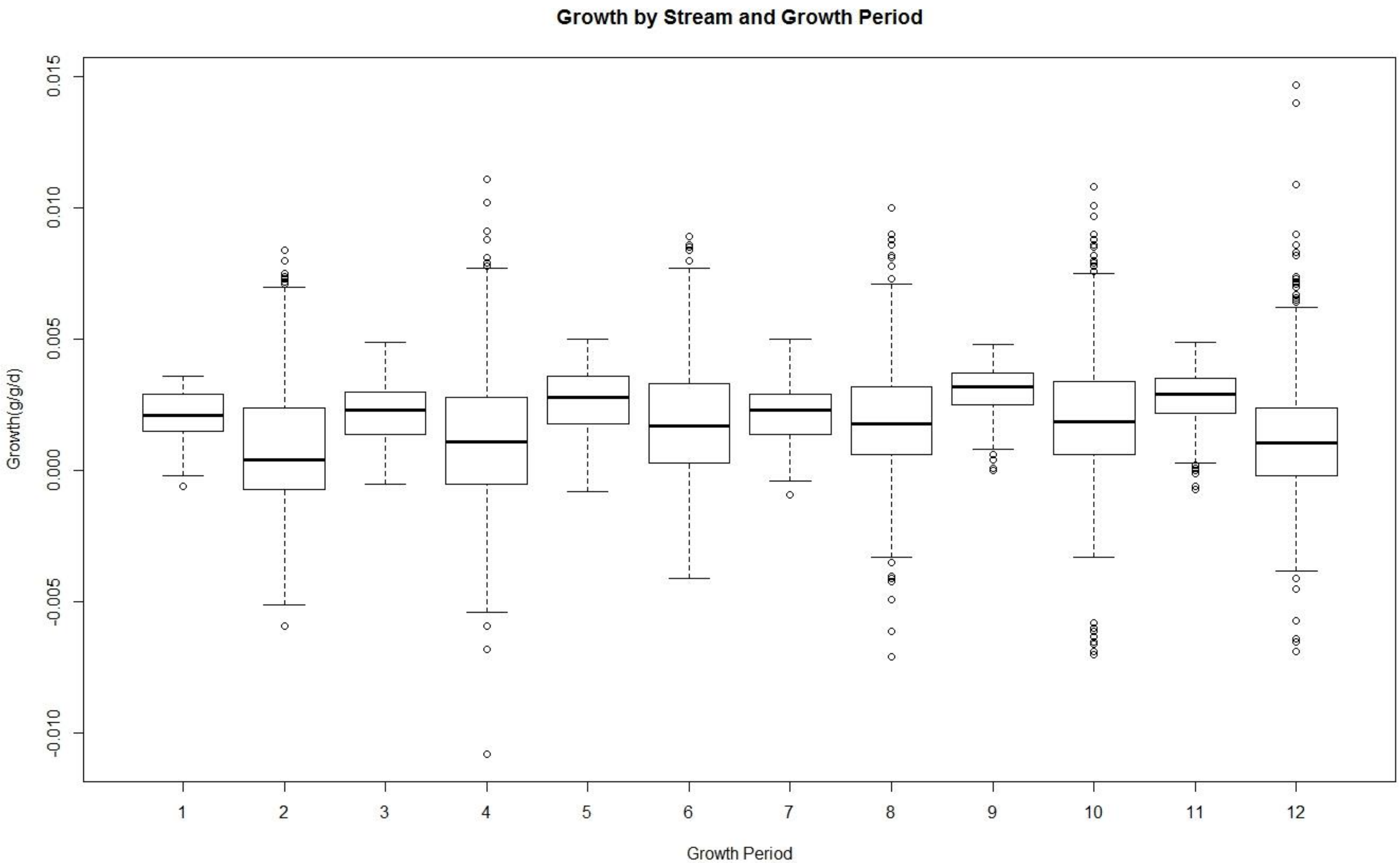
A) Main effects of five significant factors (Year, Season, Stream, Site, SiteDescription) on the mean density of juvenile steelhead $\geq$ 70 mm based on two pass mark-recapture estimates in IMW study streams. YearCat = Year, SiteDescription = whether the site is a treatment or control site. Horizontal line represents the mean across each factor and position on vertical lines indicates mean measure within a factor (e.g., "2009" on YearCat represents the mean length of all juvenile steelhead $\geq$ 70 mm from all seasons, streams, and sites combined for 2009). All factors were significantly different at $p < 0.05$ except season.



b) Distribution of steelhead density (≥ 70 mm) by mark-recapture fish site for all years and seasons combined. Box ends represent the 25th and 75th percentiles, the line in the box is the median, the whiskers are 1.5 x the interquartile range (IQR), and the open circles are outliers. CC = Charley, NF = North Fork, SF = South Fork, site numbers represent location with 1 being near the mouth and 6 being near upstream end of study each study creek.



c) Main effects of three factors (Stream, Site, Cap Period) on the growth rate of juvenile steelhead ≥ 70 mm. CapSite = Fish Site, Cap Period = Growth Period (summer to fall, fall to summer). Horizontal line represents the mean across each factor and position on vertical lines indicates mean measure within a factor (e.g., "North Fork" on StreamName represents the growth rate for all steelhead in North Fork across all periods. All factors were significantly different at $p < 0.05$.



d) Distribution of growth rates (≥ 70 mm) by growth periods for all sites combined. Box ends represent the 25th and 75th percentiles, the line in the box is the median, the whiskers are 1.5 x the interquartile range (IQR), and the open circles are outliers. Growth period 1 = summer 2008-summer 2009; 2 = summer09-fall09; 3=fall09-summer10; 4 = summer10-fall10; 5 = fall10-summer11; 6 = summer11-fall11; 7 = fall11-summer12; 8 = summer12-fall12; 9 = fall12-summer13; 10 = summer13-fall13; 11 = fall13-summer14; 12 = summer14-fall14.

APPENDIX VI. OUTREACH AND KNOWLEDGE TRANSFER

a) The following is a list of publications related to methods or results we are developing that directly relate to the implementation and assessment of the Asotin Creek IMW.

Bangen S , Wheaton JM, Baiely P, Brierley G., Bouwes N, and O'Brien G. Derivation of Fluvial Geomorphic Units from Topography. For submission to Earth Surface Dynamics.

Bennett, S., and coauthors. 2015. Progress and challenges of testing the effectiveness of stream restoration in the Pacific Northwest using Intensively Monitored Watersheds. Fisheries In review.

Bouwes, N., S. N. Bennett, and J. M. Wheaton. 2015. Adapting adaptive management for testing the effectiveness of stream restoration: an Intensively Monitored Watershed example Fisheries In review.

Camp, R. J., Bennett, S. N., Bouwes, N., Roper, B., Wheaton, J. M. 2015. Short term effectiveness of cheap and cheerful restoration using high density large woody debris. Geomorphology *In Prep*.

Camp, R. J., Bennett, S. N., Bouwes, N., O'Brien, G., Wheaton, J.M. 2015. The role of geomorphic condition in steelhead restoration. Northwest Science *In Prep*.

Camp, R. J., Bennett, S. N., Bouwes, N., Hough-Snee, N., McHugh, P., Wheaton, J.M. 2015. Using PIT tags to assess winter habitat preference of juvenile steelhead. Transactions of American Fisheries Society *In Prep.*

Camp, R. J. 2015. Short-term effectiveness of high density large woody debris, a cheap and cheerful restoration action, in Asotin Creek (Thesis). Utah State University, Logan, UT.

Conner, M. M., S. N. Bennett, W. C. Saunders, and N. Bouwes. 2014. Comparison of Tributary Survival Estimates of Steelhead using Cormack–Jolly–Seber and Barker Models: Implications for Sampling Efforts and Designs. Transactions of the American Fisheries Society 144(1):34-47.

Hough-Snee N*, Laub B, Merritt DM, Long L, Nackley LL, Roper BB, and Wheaton JM. Multi-scale environmental filters and niche partitioning govern the distributions of riparian vegetation guilds. Submitted to Ecosphere. Preprint available at: DOI: 10.7287/peerj.preprints.653v1. *In Review*♦.

Hough-Snee, N., Kasprak, A., Rossi, R., Bouwes, N. and Wheaton, J., Hydrogeomorphic and biotic drivers of instream wood differ across sub-basins of the Columbia River Basin, USA. Submitted to River Research and Applications. *In Review.*

Kasprak AK*, Hough-Snee N*, Beechie T, Bouwes N, Brierley G, Camp R*, Fryirs K, Imaki H, Jensen M*, O'Brien G, Rosgen D, and Wheaton JM. Choosing the Right Tool for the Job: Comparing Stream Channel Classification Frameworks. For Submission to PLOSOne. Preprint available at: DOI: 10.7287/peerj.preprints.885v1. *In Revision.*

Majerova M, Neilson BT, Schmadel NM, Wheaton JM, and Snow C. Impacts of beaver dams on hydrologic and temperature regimes. Hydrology and Earth Systems Science Discussions, 12: 839-878. DOI: 10.5194/hessd-12-839-2015. *In Review*♦

Schaffrath K, Belmont P and Wheaton JM. Landscape-scale geomorphic change detection: Quantifying spatially-variable uncertainty and circumventing legacy data issues. For submission to Geomorphology. *In Review.*
Vericat D, Wheaton JM and Brasington JA. Re-defining the morphological approach with repeat high resolution topography. Invited submission for edited volume for Gravel Bed Rivers 8. *In Review*.

Wall, C. E., N. Bouwes, J. M. Wheaton, W. C. Saunders, S. N. Bennett. 2015. Net Rate of Energy Intake Predicts Reach-Level Steelhead (Oncorhynchus mykiss) Densities in Diverse Basins from a Large Monitoring Program. Canadian Journal of Fisheries and Aquatic Sciences. Submitted.

Wall, E., Bouwes, N. Bennett, S. and others. Restoration design evaluation and monitoring with a foraging model suggests post-assisted log structures are energetically beneficial for juvenile steelhead trout (Oncorhynchus mykiss). Transactions of American Fisheries Society. *In Prep.*

Wall, C. E. 2014. Use of a net rate of energy intake model to examine differences in juvenile steelhead (Oncorhynchus mykiss) densities and the energetic implications of restoration. MSc Thesis, Utah State University, Logan, Utah.

Wheaton, J. M., S. N. Bennett, R. J. Camp, and N. Bouwes. 2015. Restoration of wadeable streams with High-density Large Woody Debris: a cheap and cheerful approach to reducing the legacy deficit of wood in streams. Restoration Ecology *In prep*.

Wheaton JM, Fryirs K, Brierley G, Bangen S, Bouwes N, and O'Brien G. Geomorphic Mapping and Taxonomy of Fluvial Landforms. Submitted to Geomorphology. *In Review♦.*

b) The following is an abbreviated list of the meetings and symposia we have attended and presented Asotin IMW related methods and findings.

Poster and presentation: AFS Annual meeting 2011, Seattle – Asotin IMW pretreatment findings.

Poster: Sullivan, M., Detmar, T., Bennett, S., Bouwes, N. and R. Camp. 2011. Developing the Asotin Creek Intensively Monitored Watershed Project: Answering the Question "Does stream restoration increase freshwater production of steelhead?" Presented at American Fisheries Society, Western Division, Seattle, WA.

Presentation: AFS Western meeting 2013, Boise –Asotin IMW and NREI modeling

Joint Aquatic Sciences Meeting 2014, Portland – presentation on restoration approach and effectiveness

Presentation: Wall E, Bouwes N, Bennett S, Hill A, Camp R. Assessing the predictive ability of a process-based net rate of energy intake model for drift-feeding salmonids. American Fisheries Society Western Division Annual Meeting. Boise, ID.

Poster: Wall E, Bouwes N, Bennett S, Wheaton JM, Camp R. Giving fish more energy without giving them more food: Can streambed topography influence a fish's net rate of energy intake? American Fisheries Society Annual Meeting. Seattle, WA.

Presentation: Wall E, Bouwes N. Can we give fish more energy without giving them more food? Utah State University Water Initiative Spring Runoff Conference. Logan, UT.

Webinar: Wheaton JM. 2013. Geomorphic Change Detection: Harnessing Repeat Topographic Surveys. CUAHSI Cybersminar Series on Multidisciplinary Approaches to Investigating River Processes.

Presentation: Wheaton JM. 2013. Beaver: Restoration liaison between riparian and upland systems. Restoring the West Conference, Logan, Utah. .

Webinar: Wheaton JM. 2013. Cheap and Cheerful Stream & Riparian Restoration- With Beaver? Webinar to National Riparian Service Team.

Presentation: Wheaton JM. 2013. Cheap and Cheerful Stream Restoration & Monitoring - The Example of Partnering With Beaver In Riparian Restoration, Presentation to Utah Riparian Team: Salt Lake City, UT.

Wheaton, JM, Bennett, S., Bouwes, N. and Camp, R., 2012. Cheap and Cheerful Stream Restoration ? An Example of System Wide Woody Addition Treatment, Fall Meeting AGU. EOS Transactions, San Francisco, CA.

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