ASOTIN CREEK
INTENSIVELY MONITORED WATERSHED:

RESTORATION PLAN FOR CHARLEY CREEK, NORTH FORK ASOTIN, & SOUTH FORK ASOTIN CREEKS

APRIL 25, 2012

Prepared For:

Snake River Salmon Recovery Board

Dayton, Washington

Prepared By:

Joe Wheaton[1], Stephen Bennett[2], Nick Bouwes[2], and Reid Camp[2]

[1] Watershed Sciences Department,

Utah State University, Logan, Utah

[2]Eco Logical Research Inc.,

Providence, Utah

EXECUTIVE SUMMARY

- Asotin Creek in southeast Washington was chosen as a site to develop an Intensively Monitored Watershed Project (IMW). The purpose of the IMW program 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 will be treated (i.e., restoration applied) with the remaining sections acting as controls. Treatments will be staggered over three years with one section treated each year starting in 2012. A total of 12 km will be treated.
- 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 a lack of pool habitat and cover for fish, particularly a relatively low abundance, density and mean size of large woody debris (LWD) compared to reference conditions and assumed historic recruitment levels. Therefore, LWD restoration treatments have been proposed for the Asotin IMW.
- 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 simple, unobtrusive, method of installing Dynamic Woody Structures (DWS), which are constructed of wood posts, driven into the streambed, and augmented with LWD cut to lengths that can be moved by hand.
- Dynamic Woody Structures are 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 an easy and cost-effective method to transfer to other streams.
- Dynamic Woody 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 DWS 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 DWS 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 DWS 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 15 trial structures installed in the summer of 2011 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 produced many of the intended hydraulic and geomorphic responses.

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 provide local assistance. Funding for the primary research components of the IMW are from the NOAA Pacific Coastal Salmon Recovery Fund (PCSRF). Funding for the restoration activities comes from PCSRF through the State of Washington's Salmon Recovery Funding Board (SRFB), BPA, Conservation Commission, USFS, and WDFW. We are particularly grateful for support we receive from Ethan Crawford of WDFW in the form of field staff from the Clarkston office to assist in all aspects of the IMW project, and Bonneville Power Administration (BPA) which supports WDFW’s efforts to collect fish in-fish out data in Asotin Creek. 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.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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
DWS	- 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 (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. 2004). 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 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). For practical purposes, it is assumed a population level response will need to be large (i.e., ≥ 20%) to be detected by most monitoring efforts (Hinrichsen 2010). The main goals of the IMW initiative 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) and a summary of the most recent fish and habitat data collected within the watershed can be found in Bennett et al. (2012 *In preparation*) and Crawford et al. (2011).

An experimental study design has been developed and refined for the Asotin IMW that includes treatment and control sections within the Asotin Creek tributaries of Charley Creek, North Fork Asotin Creek, and South Fork Asotin Creek (hereafter referred to as "study creeks"; Figure 1). Bennett and Bouwes (2009) show that the study creeks generally exhibit homogenized and degraded habitats, with exceptionally low availability of pool habitat for summer and overwintering refugia, which is thought to be limiting salmonid production (Solazzi et al. 2000). Bennett and Bouwes (2009) hypothesized that the notable lack of large woody debris (LWD) in the channel and low LWD recruitment is limiting the creation, shaping and maintenance of pool habitat. **Riparian enhancement and large woody debris additions are the proposed restoration treatments in the Asotin IMW**. The riparian enhancement treatments include a mix of short and longer term measures ranging from fencing, selective thinning, some plantings and encouragement of a more diverse riparian corridor (in terms of age and species structure) that is sustained by fluvial processes and more regular interaction and exchange with the channel (Opperman and Merenlender 2004). Among the long-term benefits of such a riparian treatment are the reestablishment of sustainable levels of wood recruitment (of all sizes) to the channel. By contrast, the LWD additions focus on intensive additions of high densities of LWD and dynamic woody structures (DWS) designed to work in concert with one other to initiate and promote more dynamic creation, shaping and maintenance of active bar and pool habitat by fluvial processes.

As compared to nearby reference streams, these processes are largely arrested and constrained in Charley Creek and South Fork Creek, and are not reaching their full potential in North Fork Creek. The restoration treatments will be applied to treatment sections of the study creeks in a hierarchical-staircase design, whereby one 4 km long section in one of the study creeks will be treated every year for three years until a minimum of 12 km total is treated. The first restoration treatment is planned for 2102. Summer run, wild steelhead (*Oncorhynchus mykiss*) are the target species for the Asotin Creek IMW.

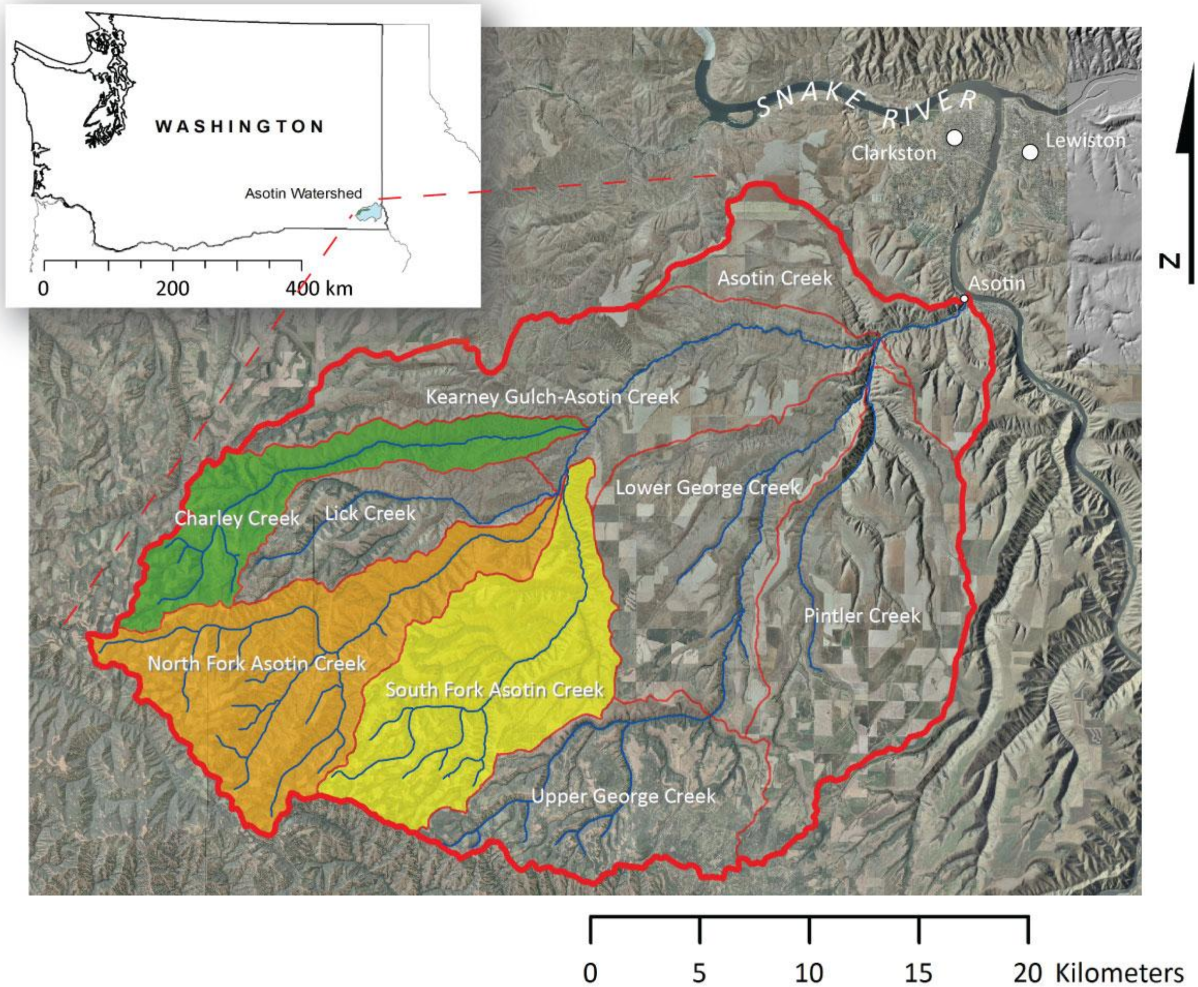

Figure 1. Location of Asotin Creek within Washington and the Asotin Creek Intensively Monitored Watershed study creek watersheds (i.e., three colored watersheds) within the Asotin Creek.

1.2 Purpose of the Restoration Plan

This document's primary purpose is to articulate the details of the restoration plan, highlighting the design rationale, clearly posing our design hypotheses, explaining the monitoring to test those hypotheses, and emphasizing the opportunities for adaptive management feedbacks in the restoration and IMW process. As the restoration will be implemented within the framework of an IMW, we focus some of this plan on opportunities for learning and to what extent the treatment and monitoring methods may be transferable to other watersheds. The primary LWD treatment we are proposing is novel and potentially transformative example of a low-cost, unobtrusive restoration treatment. We expect the LWD treatment can be applied with hand labor over large lengths of stream, producing a geomorphic response that enables the creeks to sustain dynamic, heterogeneous habitats through fluvial processes in an otherwise stable and degraded state. The restoration technique uses wood posts driven into the stream bottom to act as flow deflectors, debris catchers, and/or to act as temporary anchors for large woody debris (LWD) placed in the stream (Slaney et al. 1997, Zeedyk and Clothier 2009). Specific decisions on large wood placement will be made in the field at the time of construction using the outlined design criteria.

To provide context, the report summarizes the watershed setting of Asotin Creek with an emphasis on the study creeks. A review of the methods and results of past assessment work is presented, which underscores how we arrived at the restoration plan for the Asotin Creek IMW. We use the conclusions of the assessment work to form the basis for the proposed restoration design.

1.3 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). 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 diagramed our vision of the adaptive management process for the Asotin IMW (Figure 2).

Figure 2 not only provides a basis for understanding the restoration design, but also the organization of this report (see the § section references throughout the figure). Starting with the problem definition, §1 of this report lays out the basic problem the restoration seeks to address and how we have arrived at assessing whether that problem is real or perceived (particularly §1.4 - 1.5). From that, we *establish ecosystem goals and objectives* (§1.6). Section 2 (§2) lays out our conceptual models of how hydrologic, geomorphic, and riparian systems in Asotin Creek function, and we describe in §3 how we undertook targeted research to better understand these systems (e.g., IMW baseline monitoring and fluvial audits). The results of this and a trial project installed in the summer of 2011 to test the feasibility of the LWD treatment are reported in §4 and we can see how this feeds back to 'redefine' our conceptual models in Figure 2. Section 5 (§5) is a synthesis of these findings and conceptual understanding, which we later formalize as testable design hypotheses, which we report in §6.5. Section 6 (§6) lays out the details of the proposed large scale implementation to begin in 2012, and §6.7 describes the specifics of how we intend to implement the treatments on the ground. The design hypotheses then dictate the monitoring (§ 7) necessary to test those hypotheses and undertake the critical adaptive management learning loop through assessment and evaluation of this data. As the treatments are staggered in space and time according to a hierarchical-staircase experimental design (§1.7.2), this learning loop will be revisited at least nine times over the next decade with continued opportunities before later implementations to adapt the assessment of the problem, the restoration goals, the conceptual models and restoration actions.

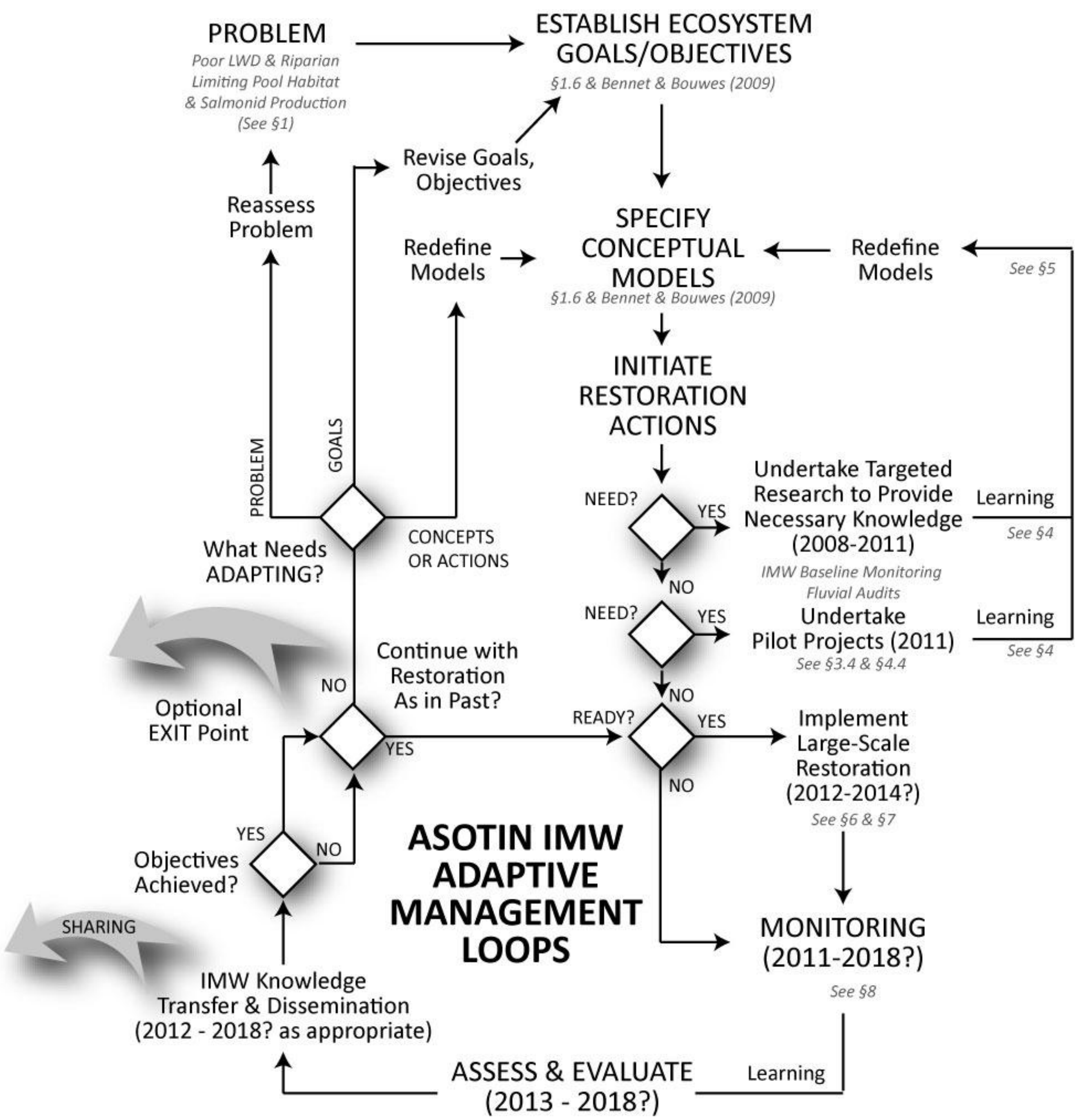

Figure 2. Asotin IMW adaptive management schematic through the design, pre-treatment, treatment, and post-treatment phase. Figure adapted from Kondolf (2000).

1.4 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 Creeks, 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).

1.5 Current Limiting Factors

Prior to the initiation of the IMW study in Asotin Creek, Ecosystem Diagnosis and Treatment (EDT) analysis was used to reassess limiting factors for steelhead in Asotin Creek (SRSRB 2006). Common limiting factors that were identified in the Asotin Creek watershed included elevated sedimentation, substrate embeddedness, water temperature, decreased riparian function, decreased floodplain connectivity, decreased habitat diversity, low LWD, and low pool frequency and quality. Many of the limiting factors identified in Asotin Creek are directly or indirectly related to degraded riparian function. Riparian ecosystems link terrestrial and aquatic ecosystems through the flow of energy, nutrients, and water and their importance is far greater than the relative area they occupy on the landscape (Gregory et al. 1991). Riparian habitats interact with streams to provide many important functions including shading, organic inputs, bank stabilization, and filtration of sediments (Naiman et al. 2005).

Two recent approaches to understanding baseline riparian conditions are historical reconstructions (McAllister 2008) and vegetation modeling (LANDFIRE 2010). The historical reconstruction and modeling approaches both have similar findings and suggest that the riparian habitat along Asotin Creek and its tributaries was likely more forested than it is at present. In this Restoration Plan, we are making an explicit assumption based on these larger scale assessments of riparian condition and our surveys in the watershed that historical riparian forests along these study creeks had larger trees dominated by cottonwood, ponderosa pine, and Douglas-fir. Further, the removal of these large trees over the last several decades, and the subsequent replacement of these trees by alder dominated forests, has resulted in reduced riparian function and channel complexity.

While numerous factors have been implicated in limiting steelhead populations in the Asotin Watershed, LWD has the potential to ameliorate many of these. The role of LWD in riparian areas and its influence on stream systems is well documented. Large woody debris has the potential to alter both the structure and function of stream ecosystems (Harmon et al. 1986). The effects of LWD on stream ecosystems are far-reaching as it can alter sediment storage and routing (Montgomery et al. 2003), stream channel morphology and dynamics (Keller and Swanson 1979, Montgomery et al. 1995, Montgomery 2003), invertebrate habitat and abundance (Wallace et al. 1995) and fish habitat (Dolloff 1986, Fausch and Northcote 1992). These effects can occur across multiple spatial scales. At the channel and reach scale the influence of LWD typically increases with decreasing stream width and LWD accumulates at a faster rate in smaller streams due to lower turnover rate via fluvial transport (Beechie et al. 2000). In streams where riparian vegetation has been removed, creation and maintenance of pool habitat as new LWD enters the stream is more rapid in smaller steeper streams and pools are more frequent where there are large volumes of LWD (Montgomery et al. 1995, Beechie and Sibley 1997). At the landscape scale LWD can create a forced "step-pool" morphology in small steep streams (1.5-4% gradient), and removal of LWD can cause the channel to revert to a cascade or bedrock channel depending on the stream type (Montgomery et al. 2003). Large woody debris from riparian zones can enter the stream at infrequent intervals as a result of riparian tree mortality or undercutting of trees on the bank (Bilby and Bisson 1998). Large natural disturbance events like fire, flooding, or windthrow can add large amounts of LWD to stream channels in a short period of time (Bilby and Bisson 1998).

Restorations that involve some type of LWD addition to streams are commonplace in the Pacific Northwest and a primary goal of the Asotin IMW is to understand how effective LWD restoration is at increasing fish production. A global review of LWD additions found that most studies detected a positive local response of fish to LWD additions; however, few studies found statistically significant results over larger spatial scales due to poor study designs and the authors stress the need to focus future studies on multiple scales including watershed scale assessments of changes in smolt production after wood additions (Roni et al. 2008). In a few studies where inputs of LWD were replicated and control sites were used, salmonid population responses have been demonstrated. The size of the treatments were relatively large, for example winter habitat in the form of pools and LWD cover was increased by 150-1300% (Cederholm et al. 1997, Solazzi et al. 2000, Roni and Quinn 2001). These studies found that LWD additions affected salmonids differently based on species and season. In general, juvenile steelhead abundance did not respond to LWD in the summer or fall; however, winter abundance and smolt outmigration often increased, in some cases as much as 735%. In local unpublished studies in the Asotin watershed WDFW have found similar results with assessment of instream habitat alterations using LWD (Mendel 1984, Hallock and Mendel 1985, Viola et al. 1989). It is important to note that age 0+ steelhead either did not increase in abundance or only increased in abundance 1 year post treatment, whereas juvenile (1+) steelhead continued to show increases in abundance 5 years post treatment (Viola et al. 1989).

1.6 Asotin IMW Goals and Objectives

The goals of the Asotin IMW are to test effectiveness of restoration at increasing the productivity 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. **The goal of the restoration treatments is to increase the productivity of wild steelhead in Asotin Creek.**

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 specific objectives of these treatments are to:

- Promote the recovery of the riparian corridor through riparian thinning, grazing exclosure fencing, and riparian planting, to encourage improvement in fish habitat, increased LWD recruitment and facilitation of fluvial processes with more regular lateral exchanges between the channel and riparian area.
- Increase pool habitat, habitat complexity, sediment sorting, the production of dynamic bars and increased lateral exchange through fluvial processes with the riparian corridor through the addition of LWD and dynamic woody structures (described in §3.4 and §6.3).
- Riparian fencing and planting are expected to take a decade or more to have a significant effect; therefore, the addition of LWD is the main treatment to which the adaptive management program will respond.

The goals of this Restoration Plan are to provide rationale and design concepts for the restoration implementation phase of the Asotin Creek IMW. This Restoration Plan also describes the general philosophy that was applied to the design concepts and provides specific design hypotheses that will be tested during the ongoing monitoring phase of the Asotin IMW. The specific objectives of the Restoration Plan are described in detail in the Design Hypotheses section of the Restoration Design.

1.7 Experimental and Monitoring Design Setting

1.7.1 Need for Experimental Approach to Restoration

The majority of restoration projects have had no effectiveness monitoring (Roni et al. 2008) and even fewer projects have been implemented in an experimental framework (Roni et al. 2010). As such, restoration managers and funding agencies can seldom answer basic questions such as i) how much habitat needs to be restored to significantly increase fish abundance, ii) how much habitat needs to be restored to achieve recovery of threatened and endangered populations, and iii) how many fish were created by restoration (Roni et al. 2010).

One approach to evaluating restoration actions in an experimental framework is the Intensively Monitored Watershed Program (Roni et al. 2002, Bilby et al. 2005, PNAMP 2005). Coordination at the regional scale has been initiated to develop a network of IMWs to assess a variety of restoration actions in the Columbia Basin. The goal of the IMW program is to improve our understanding of the relationship between fish and their habitat (Bilby et al. 2004; PNAMP 2005). Financial and logistical constraints make the IMW approach impractical for all restoration actions. Therefore, the IMW approach must be implemented in the framework of experimental management where the goals are to benefit the resource while maximizing learning so that the results can be extrapolated to other situations (Walters 1986). In order for IMW projects to meet these goals, the restoration action must be large enough to cause a population response that is detectable with common monitoring methods and the experimental design must be robust enough to cope with the high levels of natural spatial and temporal variability in fish populations and habitats. Here we seek to define the IMW Experimental Design for the Asotin Watershed that will achieve these requirements.

1.7.2 Asotin IMW Experimental Design and Rationale

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 (e.g., control; 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.

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 an ***hierarchical-staircase design***. 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 needed 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). The power analysis confirmed that all the 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. However, under conditions where the variance is at the high end of what has been observed historically, an hierarchical-staircase design that implements restoration in multiple streams is significantly more powerful than both a BACI design and a hierarchical-staircase design that only implements restoration in a single stream. This restoration plan is presented within the context of the hierarchical-staircase design with restoration actions implemented in multiple streams.

To see a more thorough review of the experimental design process and power analysis results refer to Bennett et al. (2012 in preparation) and Loughin (2010). Based on the above reviews and analysis, we are proposing to implement the experimental design in three tributaries to Asotin Creek: Charley Creek, North Fork Creek, and South Fork Creek. Figure 3 shows the experimental and monitoring layout for the IMW.

In this report we define a ***watershed*** as the IMW project area which includes Asotin Creek and all its tributaries. Specific IMW restoration and monitoring activities take place in ***tributaries*** to Asotin Creek (namely, Charley, North Fork, and South Fork Creeks). 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 ***contro***l ***sections*** (Table 1). Each stream will have two ***control sections*** where no restoration is implemented and one ***treatment section*** where the entire 4 km will be treated as part of the restoration effort. The location and timing of restoration ***treatment section*** was selected without replacement so that each section of creek (lower, mid, or upper section) was included in the design to specifically test if the response to restoration will vary depending on the distance upstream. Four years of pre-treatment monitoring has taken place since 2008 and the first ***treatment section*** will be implemented in the middle ***section*** of the South Fork in 2012. The upper section of Charley Creek will be treated in 2013 and the lower section of North Fork will be treated in 2014. Monitoring will continue until 2018. If the preliminary results of fish response to the restoration are very weak or undetectable, we will consider treating more sections within one stream. ***Control sections*** will be maintained in each study creek throughout the IMW project.

Fish and habitat responses to the restoration will be monitored at different scales (both extent and resolution) to build confidence in the inferences we draw from our samples. The monitoring that has already been undertaken is described in §3 and §4, whereas the proposed monitoring to track the restoration is described in §7. Here we introduce the terminology as it relates to the experimental design. For fish monitoring, it is practically impossible to census the entire population and as such our monitoring will rely on sampling. At the scale of the three study creeks, fish are monitored with both mobile antenna PIT tag surveys and PIT tag arrays installed at the mouth of each creek. Across the six ***control sections*** and three ***treatment sections***, it is impractical to intensively sample fish over the entire 36 km within the three study creeks. As such, 300-600 meter long, permanent fish sampling sites (referred to as ***fish sites***) were established. 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*** 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 section*** and ***control sections***. The location of ***fish sites*** within the ***control sections*** was selected randomly whereas each ***treatment section*** always has a fish site centered at 1 and 3 km; although the location of these fish sites are somewhat arbitrary, the extended length of the sites means that they take into account a substantial amount of geomorphic variability along the channels, allowing us to capture fish responses which may partially be a function of physical channel characteristics.

We will blend three types of monitoring to capture stream habitat responses, which combine the best tradeoffs in spatial extent, spatial resolution, temporal resolution and cost effectiveness. We will rely on relatively expensive, but spatially extensive and reasonably high-resolution remotely sensed imagery (e.g., UAV flights) and airborne LiDaR to provide watershed level context as well as changes in riparian structure over the longer-term (e.g., 5 year time scale). The remotely sensed data is of inadequate resolution to resolve in-channel changes to physical habitat and the responses to the restoration treatment for these small study creeks. As such, high-resolution repeat topographic and habitat surveys will be completed over short distances. These stream habitat surveys will be sampled at three discrete ***habitat sites*** within every ***fish site*** (Figure 4). One of the three ***habitat sites*** is sampled every year using the Columbia Habitat Monitoring Protocol (CHaMP) and the other two ***habitat sites*** are sampled every year using a rapid survey (see section 7.2 for more details). We will be able to robustly detect change at ***habitat sites*** within the ***treatment sections***, attribute that change mechanistically to specific geomorphic processes, and infer whether the changes are a result of restoration or other drivers. However, to ensure that we are not missing something within the treatment units, we will conduct rapid-assessment geomorphic response surveys along the entire stretch of ***treatment sections***. These rapid assessment surveys will not be able to resolve the same detail of the CHaMP ***habitat site*** surveys, but they should give a complete census of the geomorphic response in the ***treatment sections*** and their accuracy can be verified with the overlap at the ***habitat sites***.

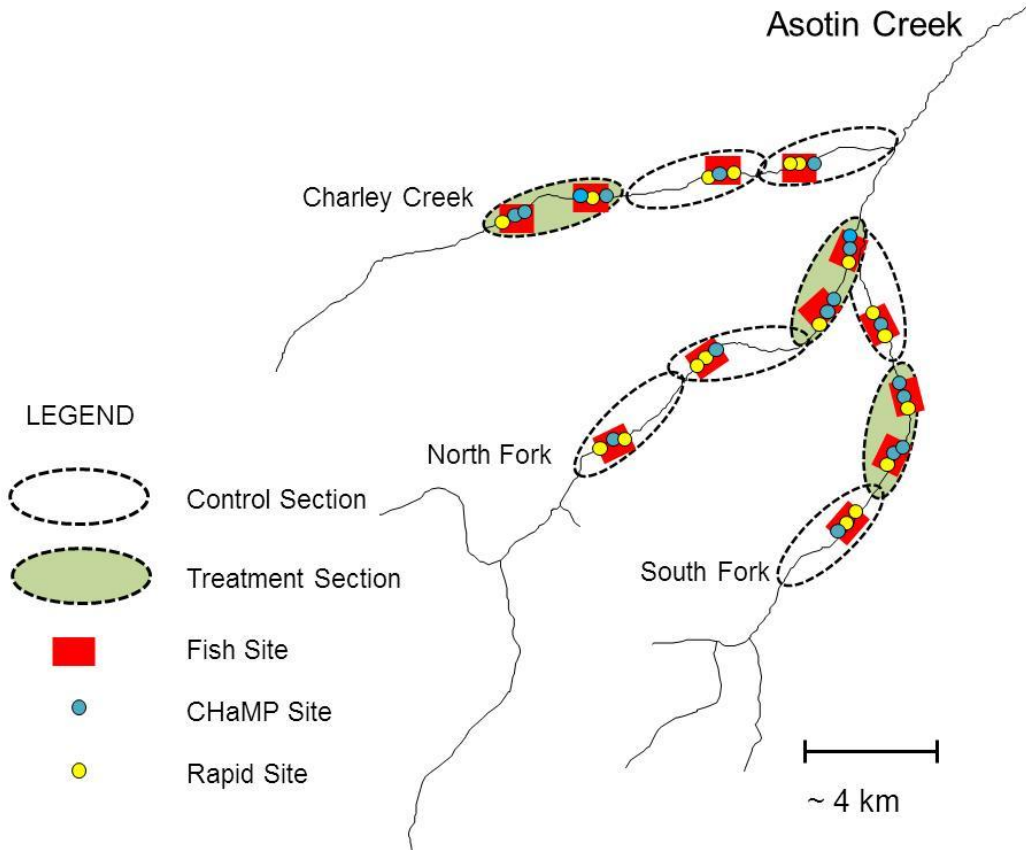

Figure 3. Experimental and monitoring design layout. The green sections are restoration treatments: South Fork restoration will be implemented in 2012, Charley Creek in 2013, and North Fork in 2014. All sections not colored will be controls throughout the project. Fish sites and habitat survey sites are nested within each section.

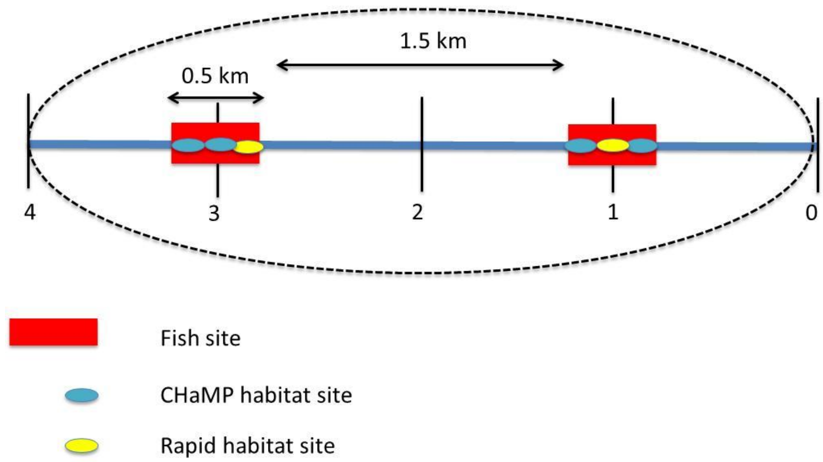

Figure 4. A detail of the location of annual fish and habitat monitoring sites within a treatment/control section of the Asotin IMW experimental and monitoring design. Fish sites were located systematically at either the 1 km or 3 km form the downstream end of a section to keep a minimum of 1.5 km between any two sites.

2 WATERSHED SETTING

2.1 Study Area

Below we briefly describe the Asotin Creek study area but for more detail please refer to ACCD (1995) and ACCD (2004). 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 1). 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. The study creeks occupy the western half of the watershed and drain the headwaters of the Asotin Watershed. Charley Creek is a left bank tributary to the mainstem Asotin Creek and its confluence is approximately 2 km downstream of the split between the South Fork Asotin Creek and North Fork Asotin Creek confluence.

2.2 Geology and Soils

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.

Table 1. The hierarchy of sample design terms going from the most basic (element) to the most general (Target Population). Adapted from Thompson et al. (1998).

Increasing Unit Size →

Experimental Design Term	**Elements**	**Sample Unit**	**Treatment Unit**	**Sample Population** *(Sample Size)*	**Sample Frame**	**Target Population** *(Scope of Inference)*
Fish Sampling	Individual Fish	Fish Survey Site (300-550 m)	4 km Treatment or Control section (3 sections per creek)	Number of Sites Surveyed (12 fish sites)	All 600 m sample site in lower 12 km of study creeks (72 possible sites)	All juvenile steelhead in lower 12 km of study creeks
Habitat Sampling (e.g., CHaMP)	Habitat Unit (pool, piece of LWD)	Habitat Survey Site (200 m)	4 km Treatment or Control section (3 sections per creek)	Number of Sites Surveyed (36 habitat sites)	All 200 m site in lower 12 km of study creeks (225 possible sites)	All habitat units in the lower 12 km of study creeks
Habitat Census	Habitat Unit (pool, piece of LWD)	Treatment section (4 km each; total of 12 km)	4 km Treatment section (3 sections per creek)	Rapid Assessment - All Treatment and Control Units (12 total; 36 km)	All Treatment Units (12 total; 36 km)	All habitat units in the lower 12 km of study creeks
Monitoring Methods	PIT Tags/ Habitat unit enumeration	Mark-Recapture/ CHaMP surveys	PIT tag arrays/ LiDaR, aerial photography and rapid surveys	PIT tag arrays, Smolt and Adult traps/ LiDaR, aerial photography and rapid surveys	Combination of all methods	Combination of all methods

Figure 5 shows a generalized geology of the Asotin Watershed, with the Mv (Middle Miocene Andesites) making up the entirety of the Charley Creek and North Fork Asotin Creek watersheds, and most of the South Fork Asotin Creek watershed. The area has been mapped at a finer 1:100,000 scale by Schuster (1993), who shows that the Mv andesite shown is a part of the CRBG and is comprised of several basalt/andesite flows ranging in age from 14.5 to 15.6 million years ago that make up three members of the Wanapum Basalt Formation. Two flows from the oldest member, the Eckler Mountain Member (Mv_{wem}), sliced across what is now the headwaters in a southeasterly direction. This was later overlaid by a much more expansive flow that comprises the Roza Member (Mv_{wr}) and covers the majority of the basin, and was later overlain in what is now the lower part of the basin by flows of the Priest Rapids Member (Mv_{wpr}). Most of these flows averaged 30-50 meters in thickness. What is mapped in Figure 5 as Qce (Pleistocene loesses) is underlain by the same flows, and represents the uplifted high plateaus that were mantled by much more recent fine grain loess deposits sourced from Bonneville and Missoula Flood overbank deposits, which have supported the cultivation of cereal grains and other crops in the headwaters of portions of the South Fork Asotin watershed and much of George Creek Watershed.

The geology of the Asotin Watershed summarized above is critical in constraining the character of streams that can exist in this basin and the range of habitats for salmonids they might support. Although the basaltic lithology is relatively porous rock, which is typically permeable and supports good aquifers, rates of runoff can be high. In Charley Creek for example, this aquifer supports numerous springs, which help maintain baseflows. The weathering of these rocks produces sediment that not only makes up the stream bed, but also is the parent material for soil development. The development and distribution of soils is obviously a critical ingredient in supporting growth of forests in both the riparian and on the steep hillslopes of the canyons the study creeks occupy. There are over 50 different kinds of soil in the watershed with a wide range in texture, depth, natural drainage, and other characteristics (Gentry 1991). Figure 6 shows a subset of these most common along the study creeks and on the hillslopes connected to the study creeks.

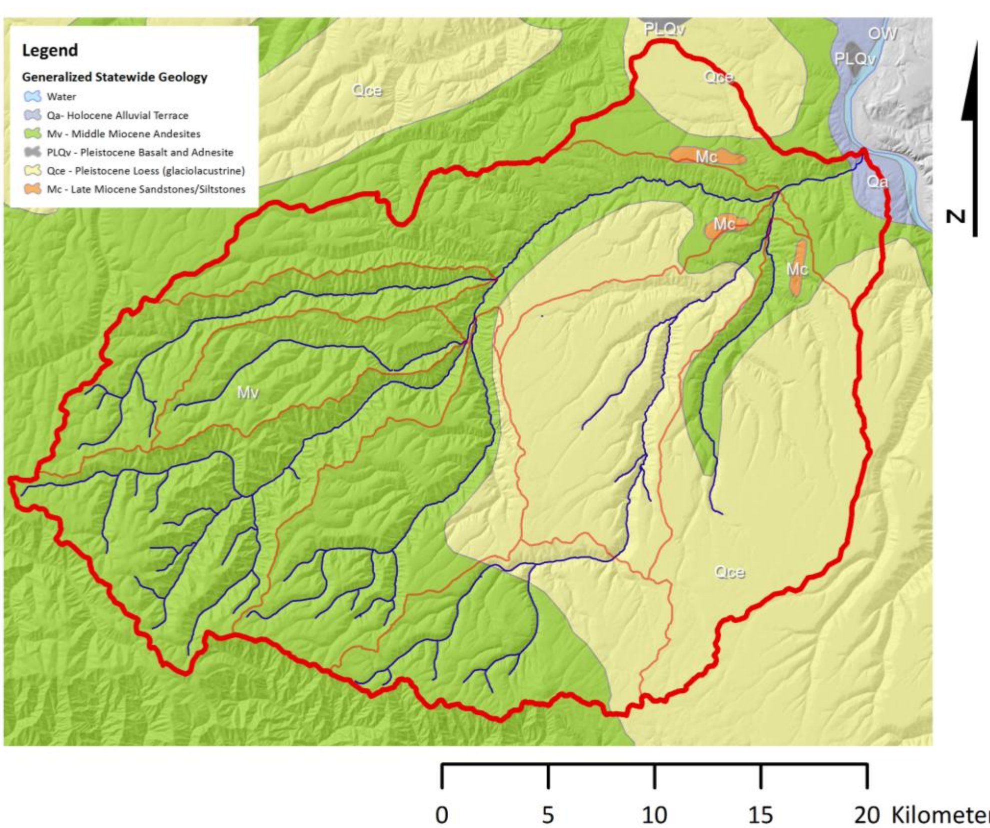

Figure 5. Asotin Creek Watershed bedrock and surficial geology; data obtained from WA State Geologic Map.

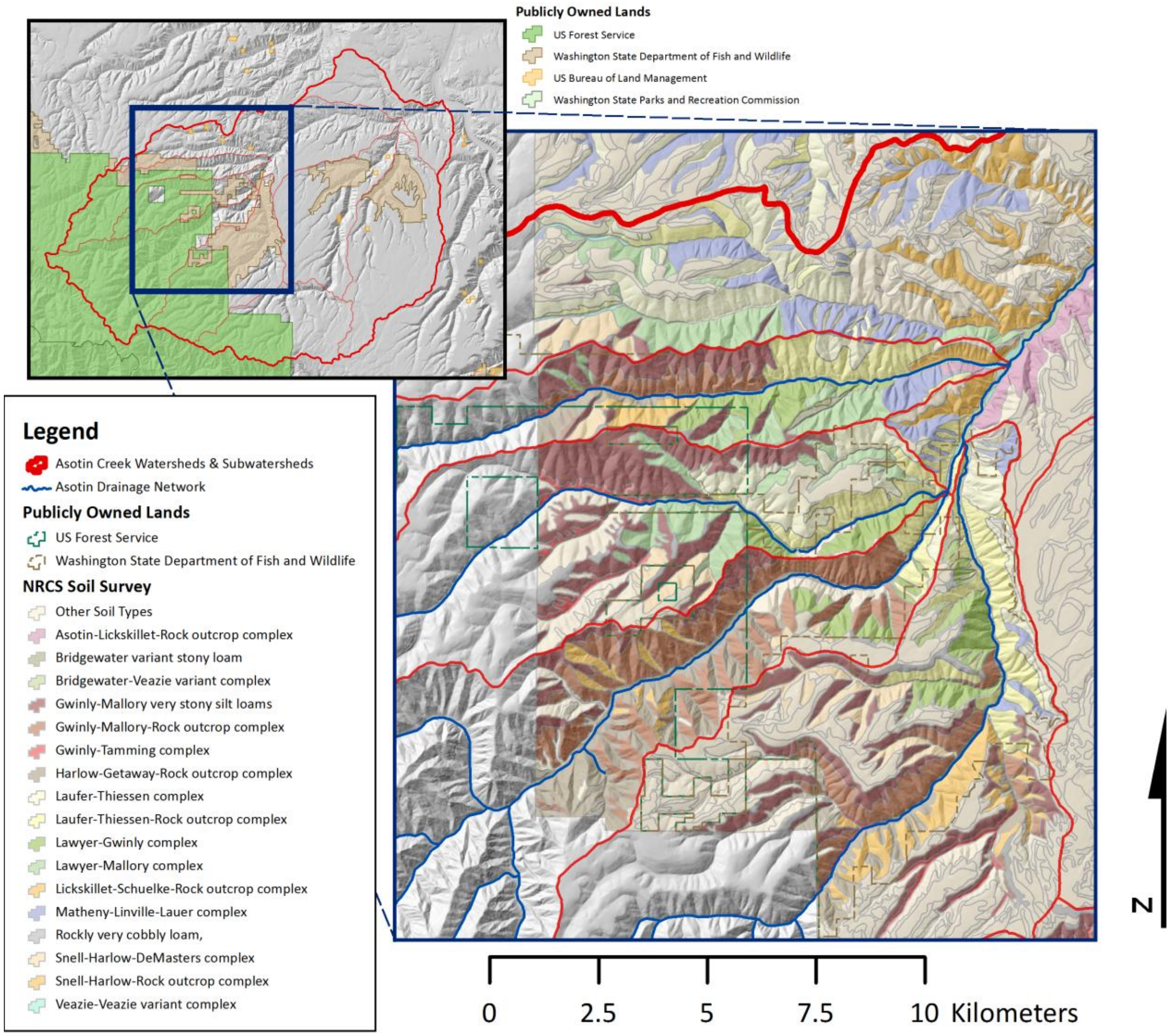

Figure 6. USDA NRCS Soil Survey soil types in study watersheds from Gentry (1991) and SSURGO. The distribution of soil types is strongly topographically and aspect controlled. The upper portion of the watershed (where soil classification stops) has no digital spatial or tabular data from SSURGO, and corresponds roughly with the US Forest Service boundary (see watershed location map in upper left).

Most low elevation hillside soils do not support tree growth and are dominated by a mixture of native and cultivated rangeland grasses and forbs. The slopes that connect the upland plateaus and canyon/valley bottoms are steep (30-90 %) with numerous rock outcrops and cliffs. Upslope soils are typically shallow, coarse (very gravelly, cobbly, or stoney), and well drained, with north facing slopes having deeper soils and generally supporting more dense forests. Most upland soils mantling the plateaus are silt and clay loams formed from loess, colluvium, and slope alluvium erosion. All upslope soils are very susceptible to erosion (SCS 1984). Excessive erosion from upland farming is presumed to have been reduced in recent years due to the implementation of the Model Watershed Plan and associated restoration activities (ACCD 1995).

Aside from those fine grained soils formed from loess, the soils in the watershed are generally formed in colluvium (i.e., from sediment on hillslopes) derived from basalt parent material (Gentry 1991). As Figure 6 shows, the distribution of soil types is strongly aspect controlled. South-facing slopes in all three study creeks are dominated by Gwinly-Mallory rock outcrop complexes comprising the staircase of cliffs leading up to the plateaus above, and Gwinly-Mallory very stony silt loams, making up the colluvial talus slopes below. The Gwinly and Mallory series soils both consist of well drained soils on canyon walls and shoulder slopes, with Gwinly being shallow and Mallory soils being moderately deep. By contrast, many of the north facing slopes are dominated by the Snell-Harlow DeMasters Complex and the north facing canyon walls by the Snell-Harlow rock outcrop complex. Table 2 summarizes some of the key characteristics of these soils, settings in which they are found and the principal tree species they support.

Table 2. Dominant soil types along the Asotin IMW study creeks and adjacent hillslopes.

Site Unit Name	Slope (%)	Description	Type/Location	Top Layer - depth (cm) and drainage	Water Erosion Hazard	Principal Tree Species
Asotin-Lickskillet-Rock outcrop complex	40-90	moderately deep, and well drained	north facing canyon walls	50-100	very severe	?
Bridgewater-Veazie variant complex	0-3	deep, well drained,	floodplains	20 ; mod permeability	slight	Black Cottonwood, Ponderosa Pine
Bridgewater variant stony loam	0-8	very deep, moderately well drained	floodplains	76 , rapid permeability	slight	Douglas fir, Grand fir
Gwinly-Mallory very stony silt loams	30-70	shallow and well drained	south facing canyon walls	25-50, slow permeability	very severe	?
Gwinly-Mallory-Rock outcrop complex	40-90	shallow and well drained	south facing canyon walls	25-50; well drained	very severe	?
Gwinly-Tamming complex	30-70	shallow and well drained	south facing canyon walls	25-50; well drained	very severe	Ponderosa
Harlow-Getaway-Rock outcrop complex	60-90	permeability is slow	north facing mountain slopes and canyon walls	25-50; well drained	very severe	Douglas fir, Ponderosa pine
Laufer-Thiessen complex	30-70	shallow and well drained	south facing canyon walls	25-50	very severe	?
Laufer-Thiessen-Rock outcrop complex	40-90	shallow and well drained	south facing canyon walls	25-50; well drained	very severe	?
Lawyer-Gwinly complex	40-90	deep and well drained	north facing mountain slopes and canyon walls	100-152; slow permeability	very severe	?
Lawyer-Mallory complex	30-90	moderately to very deep and well drained	norht facing canyon walls	100-152; slow permeability	very severe	
Lickskillet-Schuelke-Rock outcrop complex	40-90	shallow and well drained	south facing canyon walls	25-50; well drained	very severe	?
Matheny-Linville-Lauer complex	40-90	moderately deep, and well drained	north facing mountain slopes and canyon walls	100-152	very severe	?
Rockly very cobbly loam,	3-30	very shallow well drained	ridgetops	100-152	moderate	?
Snell-Harlow-DeMasters complex	60-90	moderately deep, and low to moderately well drained	norht facing canyon walls	50-102	very severe	?
Snell-Harlow-Rock outcrop complex	40-90	moderately deep, and well drained	north facing mountain slopes and canyon walls	100-152	very severe	?
Veazie-Veazie variant complex	0-3	deep, well drained, cutbanks subject to slumping	floodplains/ alluvial fans	20-40; mod permeability	slight	Black cottonwood

Valley bottom soils are often formed in alluvium and occur on the floodplains bordering streams. There are only three soil types that are present along the study creeks. In contrast to the soils that make up the hillslopes and canyon walls, the water erosion hazard of these soils is slight. Over 95% of the soils making up the riparian corridors of the South and North Forks are of the Bridgewater group, as are 70% of those in Charley Creek. The remaining soils in the riparian corridors are primarily of the Veazie-Veazie variant complex. All of these soils are capable of supporting various mixes of coniferous and hardwood riparian and upslope forests. The headwaters of these creeks are predominantly ponderosa pine and Douglas fir forests. Although the hillslopes throughout the lower portions of the study creeks are largely devoid of tall trees, the valley bottoms appear to have supported a healthy forest corridor extending down and out of the headwaters based on historical analyses reviewed in Bennett and Bouwes (2009). The historic large trees in riparian areas would have been capable of supplying ample quantities of large woody debris to the channel.

From an instream habitat perspective, the additional significance of the soils is that these have dictated both land-use and the fine fraction of sediment supply to the channel. Other than the loess mantled plateaus, which were used for arable agriculture and really only make up the headwaters of part of the South Fork Asotin Creek, the poor soils in this area and steep canyons have meant that the land was poorly suited for arable agriculture and the primary land uses have been cattle grazing and logging in the headwaters. Despite the harsh, rugged setting defined by the basaltic geology and semi-arid climate, the riparian corridor along these streams would have been well shaded, full of a diversity of age and species of tree species and well suited for salmonids.

2.3 Hydrology

The hydrology of the Asotin Creek watershed is strongly controlled by the semi-arid climate and geology described above. 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).

On average, Asotin Creek has a typical snow melt dominated flow pattern with the peak runoff usually happening in late May (Figure 7). Streamflow is monitored by the United States Geological Service (USGS), Washington Department of Ecology (DOE), and SRSRB. Historical monitoring of streamflows was limited with the earliest record starting in 1928 (Headgate dam which is no longer active) and the longest record of continuous data being 31 years. The SRSRB also maintains water level loggers on Charley and South Fork Creeks since fall 2009 and the mainstem Asotin and North Fork Creeks since summer of 2011 (Figure 8). The water level loggers measure water height every 2 hours and these measurements are combined with periodic field measurements (usually 2-3 times a month) to develop stage discharge relationships for each logger site (Figure 9).

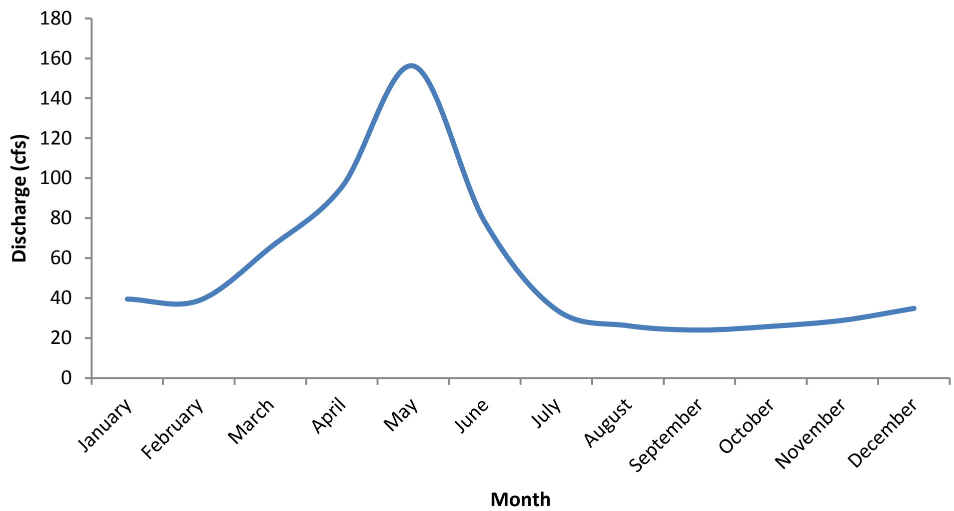

Figure 7. Average monthly discharge over the last 10 years (2001-2010) as measured at the USGS gauge #13334450 at the confluence of North Fork and South Fork Asotin Creeks.

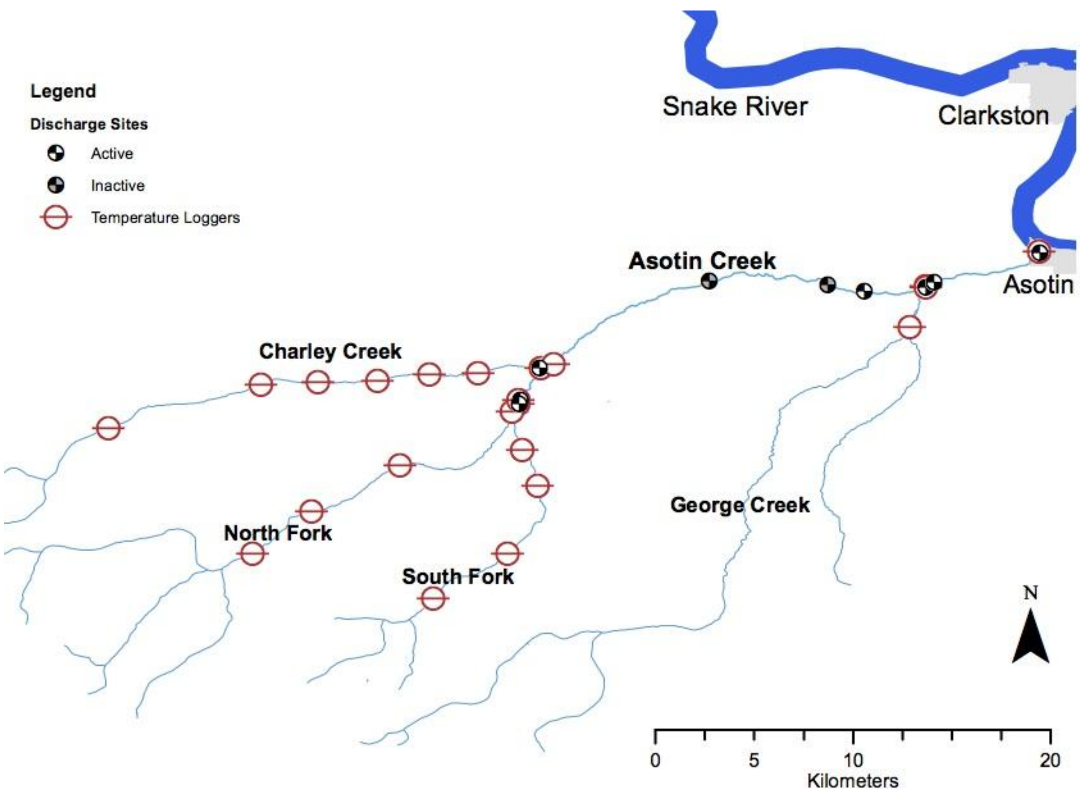

Figure 8. Location of stream gaging stations (active and inactive) and temperature loggers within the Asotin Watershed.

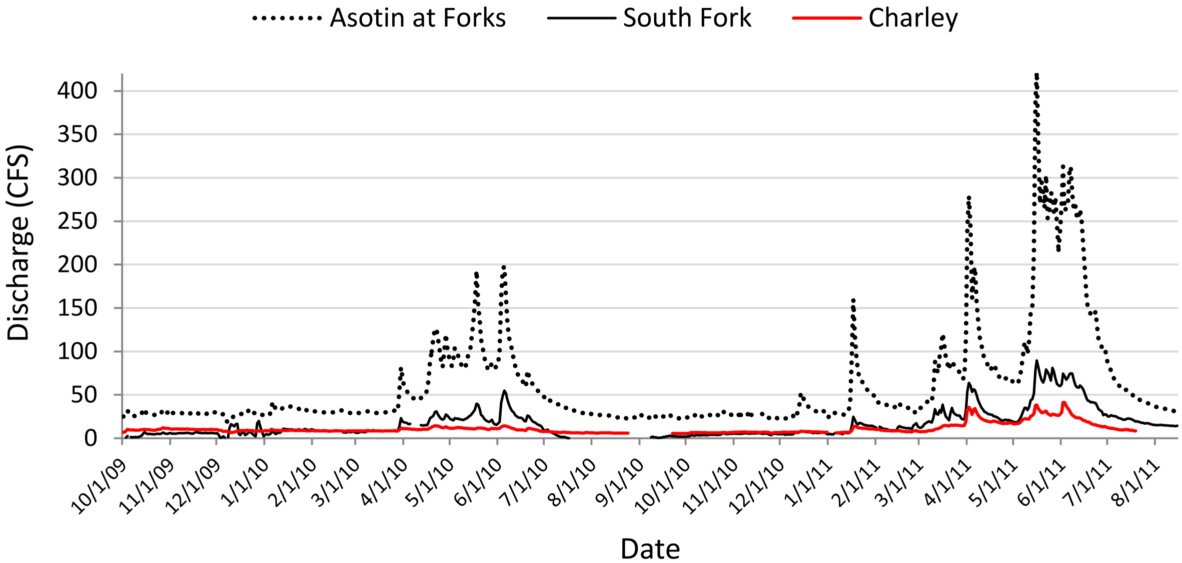

Figure 9. Average daily discharge of Charley Creek and South Fork as measured with recently installed water level gages compared to the discharge of Asotin Creek at the Forks USGS gauge #13334450.

The mean annual discharge of Asotin Creek is approximately 78 cfs (as interpreted from several mainstem gauge data sets). The North Fork's mean annual discharge is approximately 40 cfs (calculated by subtracting estimated South Fork discharge from the USGS gauge at the Forks), South Fork is 15 cfs, and Charley is 10 cfs (based on only 2 years of continuous discharge monitoring). The North Fork and South Fork discharges track each other closely based on a relatively predictable pattern of snow melt in the spring whereas the discharge from Charley Creek is dominated by spring-fed flows that give it a more consistent base flow (Figure 9). 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 9).

As long-term records only exist for the USGS gages downstream on the mainstem of Asotin Creek, it is difficult to produce reliable estimates of flood flow frequency for the study creeks. In the absence of a flow record of adequate duration, tools like the USGS Stream Stats application can be used to crudely estimate the magnitude of various return interval flows based on regional regressions scaled based on drainage area and watershed characteristics (Table 3). The absolute predictions from the Stream Stats analyses should be treated with caution, but the relative differences between the subwatersheds are helpful for highlighting the relative differences between potential peak flows.

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
Basin Area- square km	5,835	16,490	10,383	84,083
Mean Basin Elevation in m	1,216	1,305	1,234	1,021
Min Basin Elevation in m	521	561	564	228
Max Basin Elevation in m	1,701	1,890	1,823	1,890
Max – Min elevation, in m	1,180	1,329	1,259	1,664
Mean basin slope in percent	34	40	29	24
% area slope > 30 percent	57	68	43	36
% area slope >30 percent and facing North	17	18	12	10
% area covered by forest	39	44	30	21
Mean annual precipitation, in cm	67	76	70	58

Although intense summer thunderstorms and rain on snow events are relatively rare events, they are geomorphically very significant. The restoration project should be designed not just for the regular floods (e.g., 1.5 to 2 year return interval), but also for these major floods which have been shown to completely reshape the channel and riparian environments. The largest flow on record in the Asotin Creek was 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). For the Asotin USGS gage at the mouth of the creek, a long-term record does exist. Based on the existing flow gauge data there is at least a 15% probability of flows exceeding 1000 cfs on the mainstem of Asotin Creek (Figure 10).

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

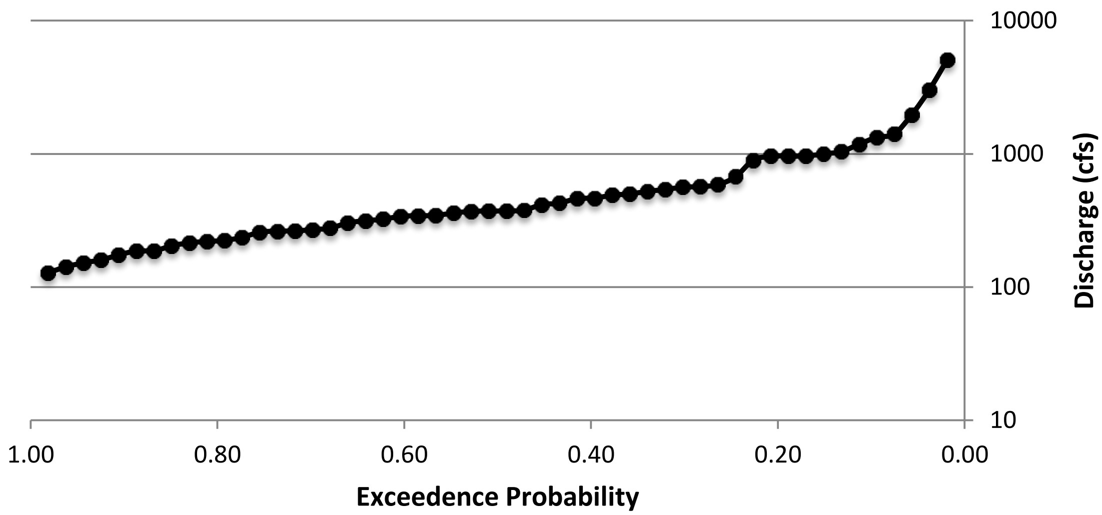

Figure 10. Log Pearson exceedence probability curve based on 52 years of combined peak discharge data from historic (# 13334500; 1904 – 1959) and current (gauge # 13335050; 1991 - present) USGS flow gauges near the mouth of Asotin Creek.

2.4 Stream Morphology and Classification

We used existing PACFISH/INFISH Biological Opinion Effectiveness Monitoring Program (PIBO) data sets to help describe the stream morphology of the study creeks. Two years of PIBO data (Heitke et al. 2008) were summarized to compare the condition of each study creek. The study creeks are small to medium sized with relatively simple channel form and have low sinuosity and bankfull widths that range from 5.1 – 9.3 m (Table 5). The study creeks have coarse substrates dominated by cobble. Charley Creek has the finest sediment of the three study creeks and smallest average substrate size. All of the study creeks have low frequencies of LWD and pools and where pools are present they have an average residual pool depth of less than 0.4 m.

Table 5. Summary statistics for Charley Creek, North Fork, and South Fork in the Asotin Creek IMW project*.

Stream	Sinuosity	% Slope	D_{50} *(mm)*	% fines <2 mm	% fines <6 mm	BFW *(m)*	W:D	Pools/ 100 m	RPD *(m)*	LWD/ 100 m
Charley	1.2	2.7	49.8	6.2	8.9	5.1	16.9	4.3	0.25	20.9
North Fork	1.3	1.9	96.1	2.1	2.9	9.3	21.2	2.3	0.38	13.7
South Fork	1.3	2.5	63.7	2.1	3	6.1	18	3.1	0.24	14.7

* All data summarized from habitat sampling at 1-2 sites per site using PIBO habitat protocols in 2008 and 2009 (Heitke et al. 2008) unless otherwise stated. D_{50} 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 Freq = number of pieces >= 1.0 m long and >= 0.1 m in diameter/100 m.

The lower reaches of the study creeks have a relatively steep gradient and flow through narrow, u-shaped valleys with very steep walls. NRCS (2001) used the Rosgen (1996) stream classification approach to assess Asotin Creek and classified the common channel types in the study creeks as Rosgen “G and B” (Charley and South Fork) and Rosgen “C” (North Fork). We will use a provisional GIS layer developed for the entire Columbia Basin that predicts the historical channel pattern of mountain streams (Beechie and Imaki *in Press*). The Beechie and Imaki classification roughly captures the reach level floodplain dynamics of the study creeks and provide an indication of the relative amount of lateral movement of the channel and age of floodplain surfaces. The primary geomorphological processes acting at the reach scale to produce lateral migration are erosion and deposition of sediment. Please note that this classification scheme uses common accepted terms to describe channel pattern but the GIS data layer that has been developed by Beechie and Imaki (*In* Press) is provisional. However, we are using these data to roughly assess the reach types in the study creeks prior to completion of our own more detailed description of reach types based on field data collection and extensive GIS resources (e.g., aerial LiDAR).

Streams that are less than 8 m bankfull width are classified using the Montgomery and Buffington (1997) channel classification and streams with > 8 m bankfull width are classified using selected terms from the literature (Beechie et al. 2006). The dominant channel morphologies range from plane-bed to step-pool in Charley Creek and South Fork Creeks to straight and island braided in the North Fork (Figure 11, Table 6)

Table 6. Definition of channel patterns as described by Montgomery and Buffington (1997) for streams less than 8 m bankfull width (BFW) and Beechie et al. (2006) for streams > 8 m BFW.

Channel Pattern	BFW Category	Definition
Cascade	< 8	Primarily single thread confined channel, dominated by boulder substrate, and fluvial, hillslope, and debris flow sediment sources
Plane bed	< 8	Primarily single thread variable channel, dominated by gravel and cobble substrate, and fluvial, bank failure, and debris flow sediment sources
Pool riffle	< 8	Multiple thread, unconfined channel, dominated by gravel substrate, and fluvial and bank failure sediment sources
Step pool	< 8	Primarily single thread confined channel, dominated by cobble and boulder substrate, and fluvial, bank failure, and debris flow sediment sources
Straight	> 8	Primarily single thread channel, sinuosity < 1.5
Meandering	> 8	Primarily single thread channel, sinuosity > 1.5
Island-braided	> 8	Multiple channels, mainly separated by vegetated islands
Braided	> 8	Multiple channels, mainly separated by unvegetated gravel bars

* confined channels = floodplain width to channel width ratio < 4; unconfined channels = floodplain width to channel width ratio >4 (Beechie et al. 2006).

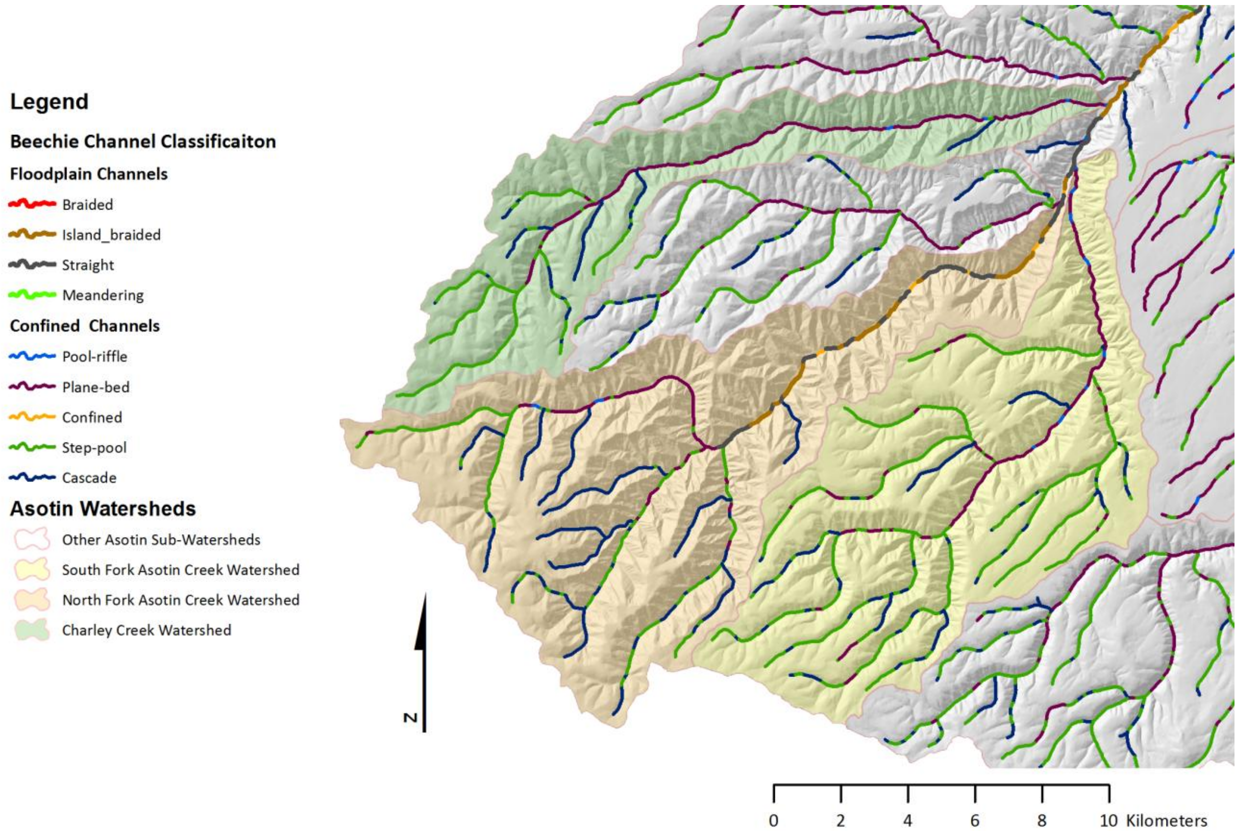

Figure 11. Assumed historic stream channel types in the Asotin Creek Intensively Monitored Watershed project area as classified by Beechie and Imaki (In Press).

2.4.1 Biophysical River Styles Classification

Although the existing PIBO and Beechie channel methods are a useful starting point for classification, they separate stream reaches based on either biologic or geomorphic characteristics. Here we seek to develop a classification framework which brings the two approaches together, thus separating channel reaches based on their geomorphic suitability for salmonids. Additionally, many classification approaches focus on a snapshot of channel condition – the developed classification framework will take into account natural geomorphic variability and stream dynamism through time.

The biophysical classification framework, which is currently under development, is based on the River Styles Framework (Figure 12; Brierley and Fryirs 2005). In brief, River Styles follows four steps aimed at gaining a mechanistic understanding and a general classification of channel types within a catchment:

1. Collection and analysis of GIS data with the goal of classifying reach types in a catchment on the basis of their physical character and geomorphic behavior. It is of note that River Styles does not constrain its classification to a set number of categories (e.g., Rosgen, 1994; Montgomery and Buffington, 1997), but instead allows the observer to develop styles which are suited to channel types found in their watershed; for example, river styles might be called “Confined Bedrock Cascade Channel,” or “Low-Slope Meandering Alluvial Channel.” Implementing this stage

within GIS can be viewed as a more comprehensive, in-depth and finer-resolution application of Beechie et al.'s (Beechie et al. 2006, Hiroo Imaki 2008) work in the Columbia River Basin.

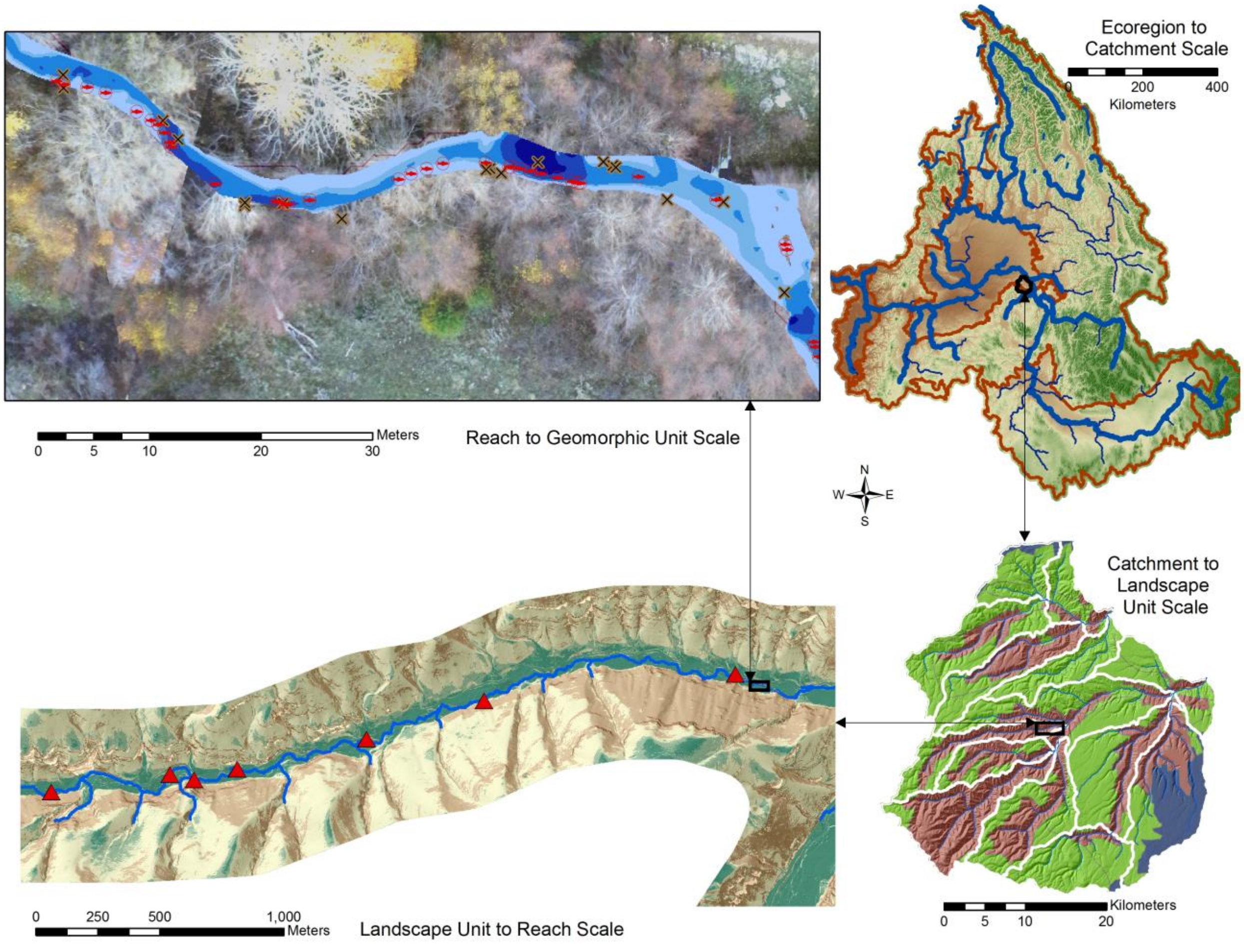

Figure 12. Example of preliminary application of River Styles Framework in the Columbia River Basin to contextualize the Asotin IMW at multiple scales. Red triangles at landscape scale represent fish sites; red fish at the reach scale represent detections of PIT tagged juvenile steelhead, and X's represent LWD geo-referenced during rapid habitat surveys. Bathymetry depicted at reach scale as pools (dark blue) and riffles (light blue).

2. The development of a 'condition assessment,' which places the current appearance of the channel in terms of what behaviors can be expected given its natural dynamism, and/or those characteristics which result from anthropogenic disturbance.

3. An analysis of recovery potential describing what trajectory a channel is likely to take in the future. Put simply, if a currently degraded channel is left to its own devices, will it (a) recover naturally over time, or (b) has a threshold been crossed whereby the channel is fundamentally changed by anthropogenic disturbance and therefore can never return to its natural state without intervention.

4. An analysis of 'what can be done' to return impaired channels to their natural conditions. In reality, this stage may treat 'natural conditions' as 'best achievable' conditions, given the degree of eco-geomorphic degradation seen today and the logistical restraints on conducting a complete restoration.

One of the major advantages of incorporating the River Styles Framework into our biophysical classification system is that it takes into account the numerous scales at which salmonid habitat is determined. For example, watershed-wide geology may influence the size and mobility of bed substrate that fish require for spawning. Simultaneously, the occurrence of fine-scale features such as undercut banks and eddies behind LWD may create essential cover for these fish. As such, implementing the River Styles Framework will allow us to develop a channel classification system that examines this range of scales with regard to their biological significance (e.g., spawning gravels, resting pools, stream bank shade) along with their physical influence (e.g., substrate mobility, bank erosion, channel slope and velocity) resulting in a true biophysical classification of channel types and habitat quality.

3 METHODS FOR DEVELOPING A RESTORATION PLAN

We used a variety of information sources and on-the-ground surveys to better understanding the fluvial processes and restoration options for the study creeks and help develop a restoration plan. Specifically, we reviewed previous watershed assessments, consulted local experts, collected site level and stream wide habitat data, and conducted a trial restoration installation. Below we discuss the specific methodologies used to collect and interpret information that was used to develop the restoration plan.

3.1 Review of Previous Assessments and Field Visits in Asotin Creek

During the development of the restoration design, we reviewed past restoration and habitat assessments coordinated by the Asotin County Conservation District (ACCD 1995, NRCS 2001, ACCD 2004) and the Snake River Salmon Recovery Board (SRSRB 2006). We also reviewed individual field reports and habitat data collected by the USFS and WDFW. We sought to glean from these past assessments which treatments have been effective, which treatments had either unknown or undetermined effects, and what lessons learned could be applied to the current effort. We also consulted the Regional Technical Team (RTT), local, and regional experts in restoration during a series of site visits and workshops. During these visits and workshops, the limiting factors identified in Asotin Creek were reviewed and options for restoration were discussed. Reviews of the background assessment data and field visits are summarized in the Asotin IMW annual reports (Bennett and Bouwes 2009, Bennett et al. 2010, 2012 *in preparation*) and highlights are provided in the results section below.

3.2 IMW Habitat Sampling

As part of the IMW monitoring design we conducted annual habitat sampling at permanent sites within the study creeks from 2008 to 2011 (Figure 13). The habitat sites are approximately 200 m long and there are three habitat sites within each fish survey site (Figure 3 and 4). The monitoring plan is reported in Bennett and Bouwes (2009) as well as revised monitoring plans in Bennett et al. (2010) and Bennett et al. (2012 *in preparation*). The habitat sampling provides site level assessments of the amount of LWD, pools, and substrate composition using standardized protocols (Heitke et al. 2008, Bouwes et al. 2011a). We compared the habitat attributes of the study creeks to reference conditions within the Umatilla National Forest and from published reports on streams east of the Cascade Mountains.

In 2011, we began implementing more intensive habitat sampling under the CHaMP (Columbia Habitat Monitoring Protocol) developed by Bouwes et al. (2011b). Briefly, CHaMP surveys entail full topographic surveys of sites with total stations, as well as mapping of habitat units and collection of a suite of ancillary habitat metrics (e.g., LWD, substrate type, solar inputs, drift, temperature, discharge, etc.). Data from these surveys are available for download at http://champmonitoring.org. As part of the temporal design, 18 sites will be surveyed annually using the CHaMP protocol. In the trial year in 2011, 10 of the 12 permanent IMW habitat sites were surveyed using the CHaMP protocol (Table 7). In 2011, four CHaMP surveys spanning over 690 m of channel were surveyed in Charley Creek, and three CHaMP surveys each were completed for the North and South Fork Asotin Creeks spanning 633 and 503 m of channel respectively. In addition to the ten CHaMP sites, topographic surveys following the CHaMP protocol were conducted to cover all of the sites where trial DWS were installed (see §3.4). In total, roughly 2350 m of stream were topographically surveyed representing 6.5% of the 36 km within the IMW study area (Figure 13**).**

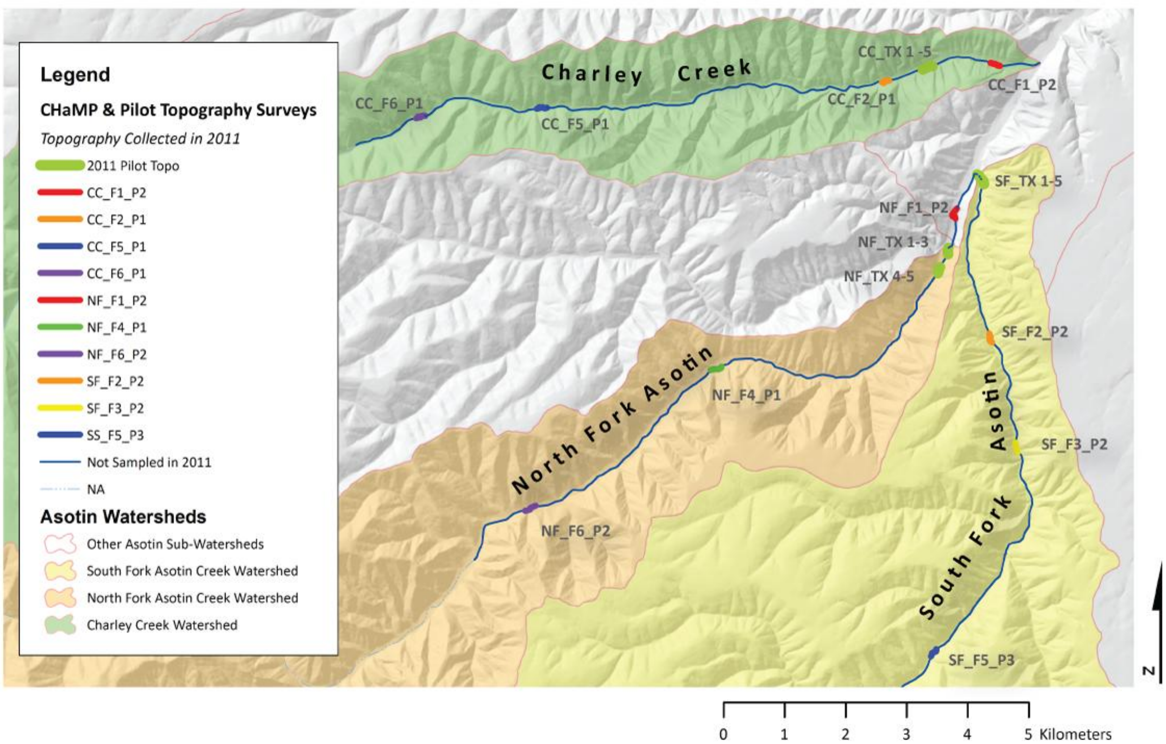

Figure 13. Locations of topographic surveys using the CHaMP protocol, conducted in 2011. CC = Charley Creek, NF = North Fork Creek, SF = South Fork Creek. Site labels are interpreted as: SF_F2_P2: Creek name (CC, NF, SF), Fish Site number (F1-6), and Habitat Site number (P1-3). TX refers to the trial structure locations (five/stream).

Table 7. Length of habitat and fish sampling and number of sites by stream at trial structures and permanent fish and habitat sites in Charley, North Fork, and South Fork Creeks in 2011. Surveys of DWS and CHaMP sites include topographic surveys and fluvial audits (i.e., rapid habitat surveys) to geo-reference key habitat features. IMW fish sites are surveyed using 2 pass mark-recapture methods with PIT tags to mark juvenile steelhead.

	Length of Stream Surveyed (m)				Number of Surveys		
	DWS trial Structures	CHaMP Sites	Fluvial Audit	IMW Fish Sites	DWS trial Structures	CHaMP Sites	IMW Fish Sites
Charley Creek	122	690	13,534	1,457	5	4	4
South Fork	188	503	12,730	983	5	3	3
North Fork	212	633	12,827	1,446	5	3	3
Total	522	1826	39,091	3,886	15	10	10

In addition to site level habitat sampling, several more extensive (in terms of spatial extent and resolution) baseline monitoring efforts have been undertaken. Ground-based LiDAR and aerial photography (by blimp) were collected in 2009 along roughly 4.5 km of Charley Creek (Wheaton and DeMeurichy 2009). In September, 2011 to augment these surveys, the entire length of Asotin Creek and the first 15 km of each of the study creeks aerial LiDAR and photography was collected by Watershed Sciences, Inc.. The LiDaR and aerial photography will be used to assess the current condition and changes in channel form, riparian cover, geomorphic reach types, valley width, gradient, tributary junction form, and provide context for the overall IMW project.

3.3 Fluvial Audits

To complement the site level habitat sampling and aerial LiDAR and photography surveys, we also completed more rapid habitat surveys we are referring to as “fluvial audits”. Fluvial audits are a rapid assessment inventory of the stream channel network, which involve both a desktop GIS analysis and a field based mapping effort (Newson and Sear 1997, Sear et al. 2003). Fluvial audits tend to focus on inventorying and mapping the primary controls on fluvial behavior and defining reach breaks based on where a different assemblage of processes and control lead to a different character in the reach. We used fluvial audits to rapidly assess and geo-reference specific features that were identified as important for i) determining if our annual habitat sites are representative of the continuum of conditions found in the study creeks, and ii) determine geomorphic reach types within the study creeks and compare to existing GIS layers (Beechie and Imaki *In press*), and iii) provide spatially extensive census data on LWD and pools for developing the restoration plan.

We conducted fluvial audits on the first 12 km of each study creek starting at the mouth (Figure 14). Each audit consisted of one to two people walking the stream with a mapgrade GPS and geo-referencing the following attributes: LWD (by size class), pools (and the forcing mechanisms), alluvial sediment sources, and significant features (e.g., springs, eroding banks, islands and side-channels, confluence with tributaries, etc.). During the audit the stream was divided into geomorphic reach types (riffle-pool, rapid, plane-bed, cascade, step-pool) based on gradient, substrate composition, sinuosity and valley confinement. Definitions of the attributes we geo-referenced are provided in Table 8.

Table 8. Definitions of the habitat attributes that were collected during fluvial audits of the lower 12 km of Charley Creek and South Fork Creek in 2010 and North Fork Creek in 2011. See Table 5 for definitions of LWD and Bouwes et al. (2011) for definitions of pools.

Attribute	Type	Description
POOL	POOL_LWD	pool forced by wood
	POOL_Boulder	pool forced by rocks
	POOL_Bar	pool forced by gravel bar
	POOL_Bedrock	pool forced by bedrock
	POOL _ROOTS	pool forced by tree roots
REACH	REACH_Break	start of new reach
SEDIMENT	BAR_Lateral	lateral deposited bar
	BAR_Mid	mid channel bar
	EROSION_Area	cut bank or eroding bank
STRUCTURE	LWD_Structure	existing restoration structure
	BOULDER_Structure	existing restoration structure
WOOD*	LWD_Small	10-<20 cm diameter
	LWD_Medium	20-30 cm diameter
	LWD_Large	>30 cm diameter
	LWD_Aggregate	>= 2 pieces >=10 cm diameter

The mapgrade GPS typically has a sub-meter accuracy which allows relatively precise location of the attributes. The GPS points were brought into ArcGIS and snapped to a digitized stream layer to allow calculation of distance between attributes and summarization of the data by reach type and length. These data will also be used as a baseline for comparison and a basis for planning where to install DWS.

3.4 Trial LWD Structure Placement Restoration

Although LWD is often used in a restoration context, the treatment methods prescribed here are rather different in both the spatial extent of their application and the relatively non-invasive installation techniques. We have experience installing 100’s of beaver dam support structures in Bridge Creek, Oregon, where the basic building materials are similar to here (i.e., wooden fence posts). In Bridge Creek, all the structures are channel-spanning, whereas in the Asotin we anticipate the structures will only occupy a portion (i.e., 40-70%) of active channel width. We will call these structures dynamic woody structures (DWS; see also §6.3) to emphasize the response we hope to produce (dynamic), the building materials (wooden fence posts and woody debris), and to recognize the fact these structures are constructed entirely with wood.

Although we have experience in Bridge Creek with structures requiring similar installation procedures, we have no past experience driving wooden fence posts into the bed of these particular study creeks. As such, we undertook a trial placement of five DWS in each of the three study creeks (i.e., 15 total trial DWS; Figure 15). The proposed LWD restoration design is described in §6 and its conceptual basis is presented in §5. The purpose of the trial placements were to i) test the feasibility of the installation of the treatment method and better constrain the time and costs associated with each structure, ii) highlight any unanticipated logistical constraints, and iii) ascertain how predictable the hydraulic and geomorphic responses associated with each structure were. We do not expect to learn about the broader restoration hypotheses associated with LWD density and fish population response from these small-scale trial treatments, but the monitoring methods are in place should such an opportunity present itself.

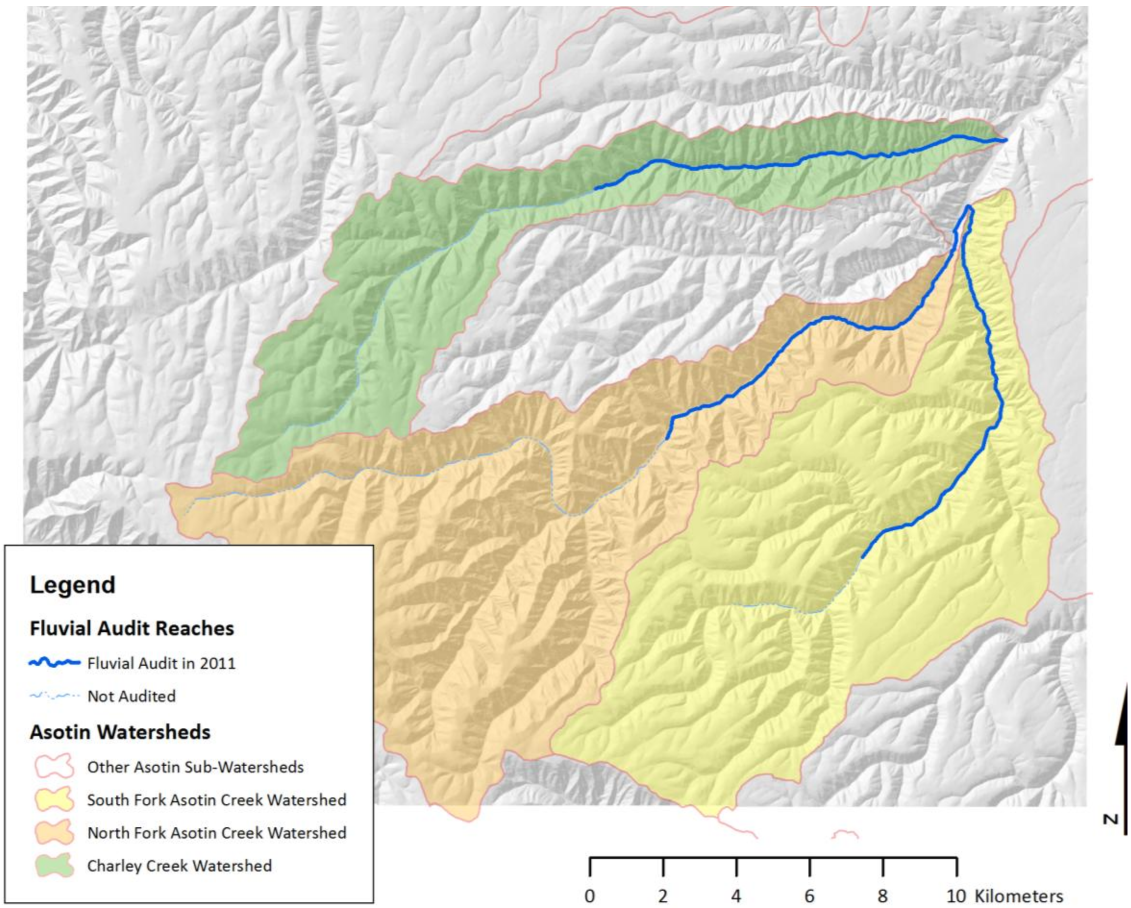

Figure 14. Extent of fluvial audits conducted in 2010 and 2011. The fluvial audits extended approximately 12 km from the mouth of each of the study creeks.

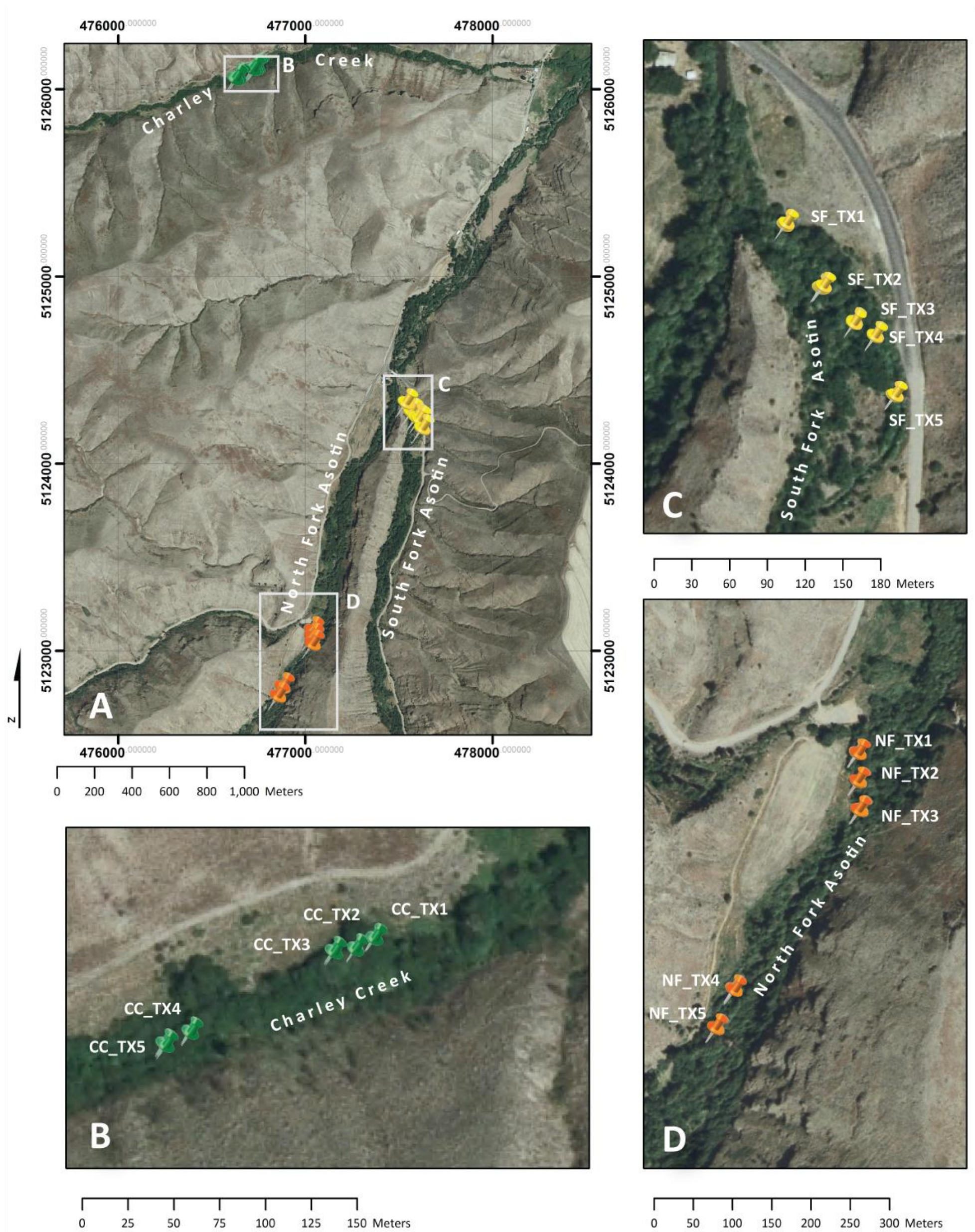

Figure 15. Location of implementation of trial dynamic woody structures (DWS) within Charley (B), South Fork Asotin (C) and North Fork Asotin (D) Creeks. Five structures were placed in each trial treatment section, and were generally placed in close proximity to each other as they were designed to work in concert with one another.

In August 2011, we installed 15 trial DWS with 97 posts. Each structure consisted of between four and nine posts. Installation was accomplished with a hydraulic post driver (Figure 16). Each set of five DWS were grouped within 100-200 m of stream length in the following arrangement: the two most upstream DWS were left as posts only (i.e., no LWD added) whereas LWD was added to the three most downstream DWS. The intent of this layout was to help us assess whether the DWS (posts only) are effective at collecting debris and causing the same predicted channel changes compared to DWS that start with LWD placed on them.

The three trial treatment sections were all located outside any of our established fish or habitat survey sites so as to not confound the ongoing fish and habitat monitoring (Figure 3). The extent of the trial treatment sections was defined to extend at least 25 m upstream of the uppermost DWS and 25 m downstream of the lowermost trial DWS. We collected detailed topographic data of each trial treatment section using the CHaMP protocol prior to installation of the DWS (Bouwes et al. 2011b). Using the protocol for the fluvial audit, we counted LWD, pools, and sediment sources 25 m above and below the trial sites to document these attributes pre-treatment. We also recorded the number and location of the posts (surveyed in with the total station), anticipated response of the channel (i.e., design hypotheses), complexity and orientation of the structure (i.e., whether posts were driven in straight line or offset), and the number of pieces of LWD added to each structure. Finally a detailed photographic record was collected at each structure and loaded in Microsoft's online software package, Photosynth (http://photosynth.net/userprofilepage.aspx?user=Asotin_IMW). Several dozen to over a hundred photos were taken of the structures and surrounding area and loaded in to Photosynth to create a 360° photo-mosaic of each trial restoration site (see Section 8 – Monitoring for more description about Photosynth). These mosaics will be recreated annually after high flow events and used to assess changes to the structures and surrounding areas.

The trial restoration sites will be resurveyed after the 2012 spring runoff to assess the structures performance at higher flows (See Section 8 – Monitoring). This resurvey and subsequent analysis will provide a learning opportunity and feedback as part of the adaptive management approach prior to the beginning of the full-scale implementation (Figure 2).

a)

b)

Figure 16. Example of a) the installation of posts and trial structure using a hydraulic post driver and b) the completed structure with LWD added in South Fork Creek trial site TX-2. Yellow arrow indicates location of completed structure. Posts cut to average high flow level after installation.

4 RESULTS OF ASSESSMENTS AND SURVEYS

4.1 Review of Previous Assessments and Field Visits

Past assessments identified increased sedimentation, substrate embeddedness, water temperature, and decreased riparian function, floodplain connectivity, habitat diversity, pool and LWD habitat as limiting factors to salmonid production (ACCD 1995, 2004, HDR 2006, SRSRB 2006). The degradation of salmon and steelhead habitat was caused by over-grazing, flooding and flood control efforts (e.g., channel straightening), road building, agriculture, and forest harvesting. Implementation of improved management practices starting in 1980's and numerous restoration activities mostly due to the adoption of the Asotin County Model Watershed Plan (ACCD 1995) are thought to have removed many of the past stressors on the stream habitat and upland drainage areas.

After summarizing the existing assessments and performing some of our own assessments of stream and riparian habitat, we concluded that riparian function and lack of habitat diversity were still a limiting factor to salmon and steelhead production (Bennett and Bouwes 2009). We developed a preliminary restoration plan to introduce LWD to the study creeks to increase habitat diversity in the short-term and restore riparian function via planting, fencing, and invasive weed control as a long-term objective. On September 15-17, 2010, we then invited a group of stream restoration specialists to visit the Asotin IMW study area with the intent of aiding in the development of a more detailed restoration plan. The primary goals of this field visit were to assess our conceptual understanding that i) the study creeks have less pool habitat than historic conditions, and ii) if LWD treatments are appropriate, iii) develop a restoration design, and iv) develop design hypotheses to test within the IMW. The general consensus from this field trip was that pool habitat is limited in the study creeks and that a LWD treatment could be an appropriate restoration option. However, concerns were raised regarding the amount of LWD that could be added (i.e., number of pieces/km) and the specific reach types that were appropriate for LWD additions. We have tried to develop a restoration plan that will be able to explicitly test some of these reservations.

4.2 IMW Habitat Sampling Results

Based on four years of monitoring LWD and pool abundance, 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 reference sites (Figure 17). Comparable reference sites in the Umatilla National Forest (UNF) and other eastern Washington locations consistently had more pieces of LWD ≥ 25 cm diameter compared to Asotin Creek IMW sites. Of particular note was that pieces of LWD 30-75 cm diameter were 3-4 times more abundant in reference 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 (Figure 18). 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 (see Bennett and Bouwes 2009, Bennett et al. 2010, and Bennett et al. 2012 in preparation for more analysis of LWD and pools).

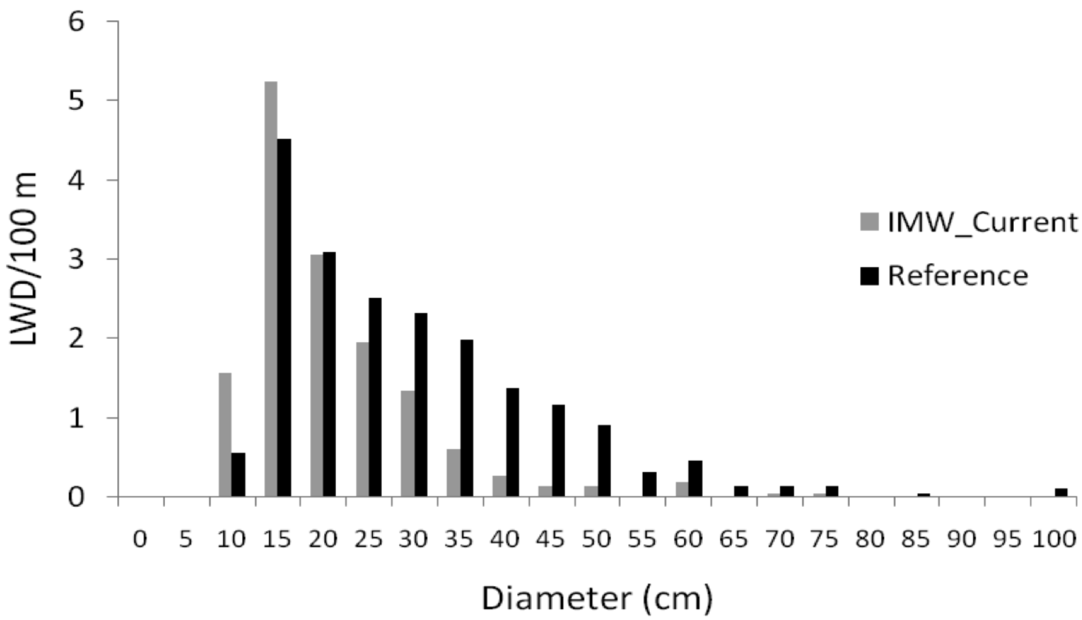

Figure 17. The size class distribution of LWD in Asotin Creek (Charley Creek, North Fork, and South Fork combined) based on sampling 2,153 m of stream habitat monitoring sites (n = 11) in July and August 2008 (total number of LWD counted = 314) versus Umatilla National Forest reference sites (n = 24) that sampled 4,284 m of habitat (total number of LWD counted = 853) .

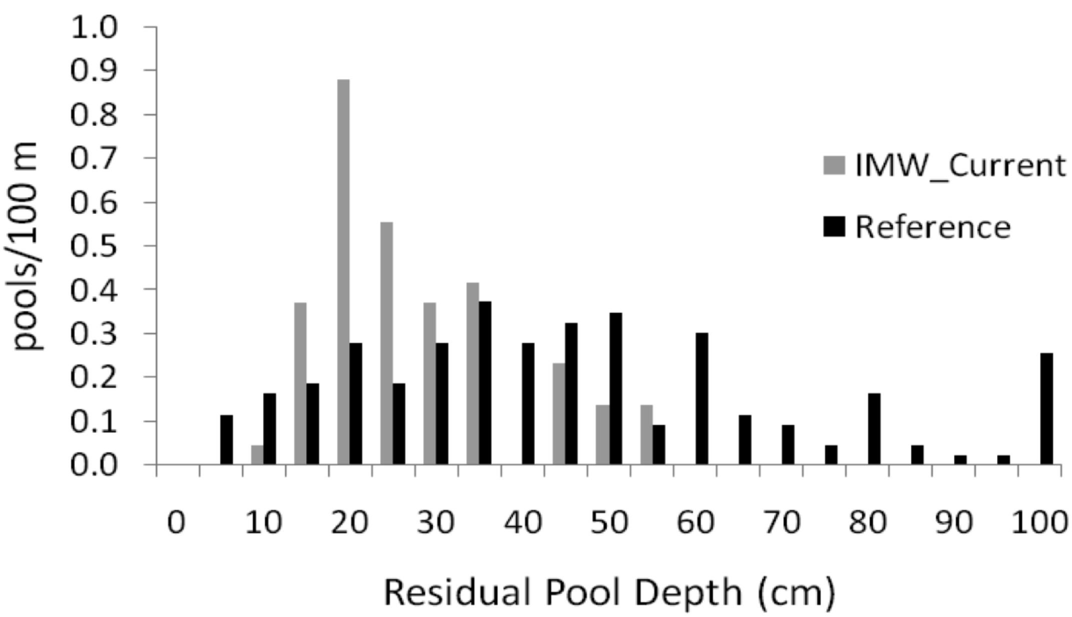

Figure 18. The size class distribution of residual pool depths in Charley Creek, North Fork, and South Fork (combined) based on sampling 2,153 m of stream habitat monitoring sites (n = 11) in July and August 2008 (total number of pools = 68) versus Umatilla National Forest reference sites that sampled 4,284 m of habitat (total number of pools = 159) .

We began monitoring stream habitat in 2008 using the PIBO stream habitat protocol (Heitke et al. 2008). We continued to use the PIBO protocol in 2009 and then transitioned to the CHaMP protocol in 2010 and 2011 (Bouwes et al. 2011). Both protocols use the same definitions of LWD and pool habitat and the majority of the attributes measured with these protocols are comparable. The CHaMP protocol will be used for the remainder of the IMW monitoring program for stream habitat. The CHaMP protocol provides a greater resolution of data than PIBO and other similar stream protocols because it uses a habitat unit based approach to measure attributes (as opposed to a reach or transect scale approach) and CHaMP utilizes a total station and GPS bench marks to map the stream habitat and geo-reference the location of habitat attributes. Channel units will be classified based on Hawkins et al. (1993) classification system. This hierarchical classification scheme allows for summarization of channel units at different levels of resolution depending on the question asked, and allows comparison to other habitat classification schemes that may be used by other protocols (e.g., pools and non-pools). Perimeters of channel units will be delineated and recorded using a total station to create a planform view of the site that depicts the arrangement of channel units. With this information, areas and volumes of channel unit types can be estimated. In addition, habitat attributes (e.g., LWD, substrate composition, etc.) are collected as they occur within specific channel units, providing distributional information and allowing interactions between channel morphology and structural attributes to be identified. For example, Senter and Pasternack (2010) found that Chinook prefer to spawn in riffles located near large wood cover rather than in riffles with similar substrate characteristics but without cover.

The total station survey will also be used to generate a high resolution digital elevation model (DEM) of the site. A total station survey requires two people; one person operates the total station instrument while the other person delineates topographic features using a stadia rod and reflective prism. The spatial information collected during the total station survey is referenced to a known point (collected from GPS) established by the surveyors and compass-derived orientation. This allows sites to be mapped for further watershed spatial analyses in a geographic information system (GIS).

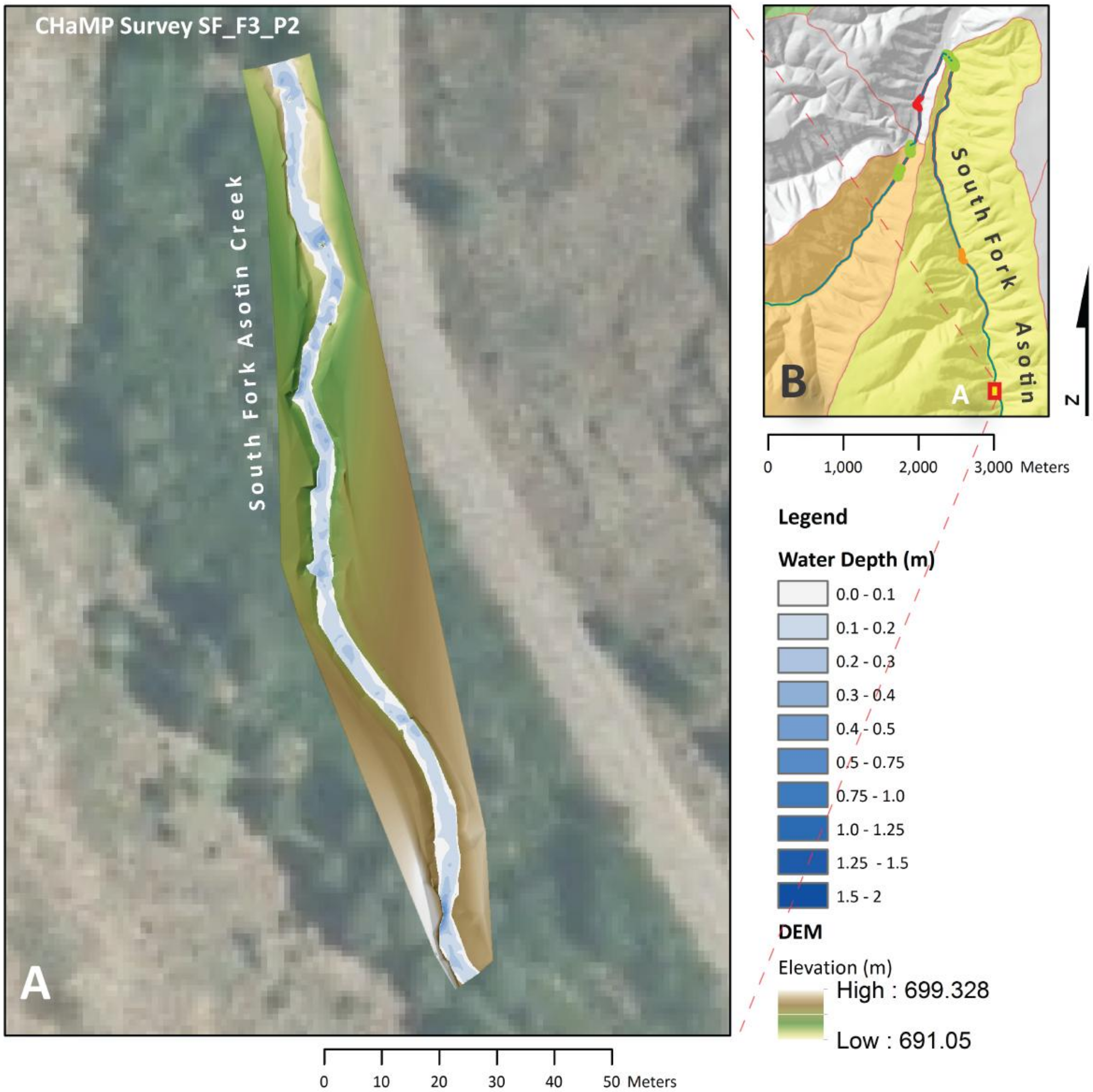

Figure 19 provides an example of a CHaMP total station survey for a habitat monitoring site in South Fork Asotin Creek. In this example, the topographic survey has been analyzed using GIS tools developed by the Integrated Status and Effectiveness Monitoring Program (ISEMP). The GIS tools convert the DEM data into water surface, water depth, and stream bank layers that can be used to view pool habitat and channel form. ISEMP and the CHaMP program are also promoting the further development of the River Bathymetry Toolkit (RBT) developed by the USFS and ESSA Technologies as means to evaluate DEMs. The RBT will be able to conduct several types of analyses associated with DEMs, including geomorphic change detection (DoD), uncertainty analyses, user-defined density of cross-sections, and longitudinal profiles. These tools can extract hydrologic parameters such as wetted area, bankfull width, water depths, hydraulic radius, gradient, sinuosity (McKean et al. 2009), erosion and depositional patterns and budgets, and uncertainty in the DEM (Wheaton et al. 2010). For further details go to www.champmonitoring.org. Refer to Appendix A for full inventory of all ten of the CHaMP total station survey results from the 2010 IMW surveys.

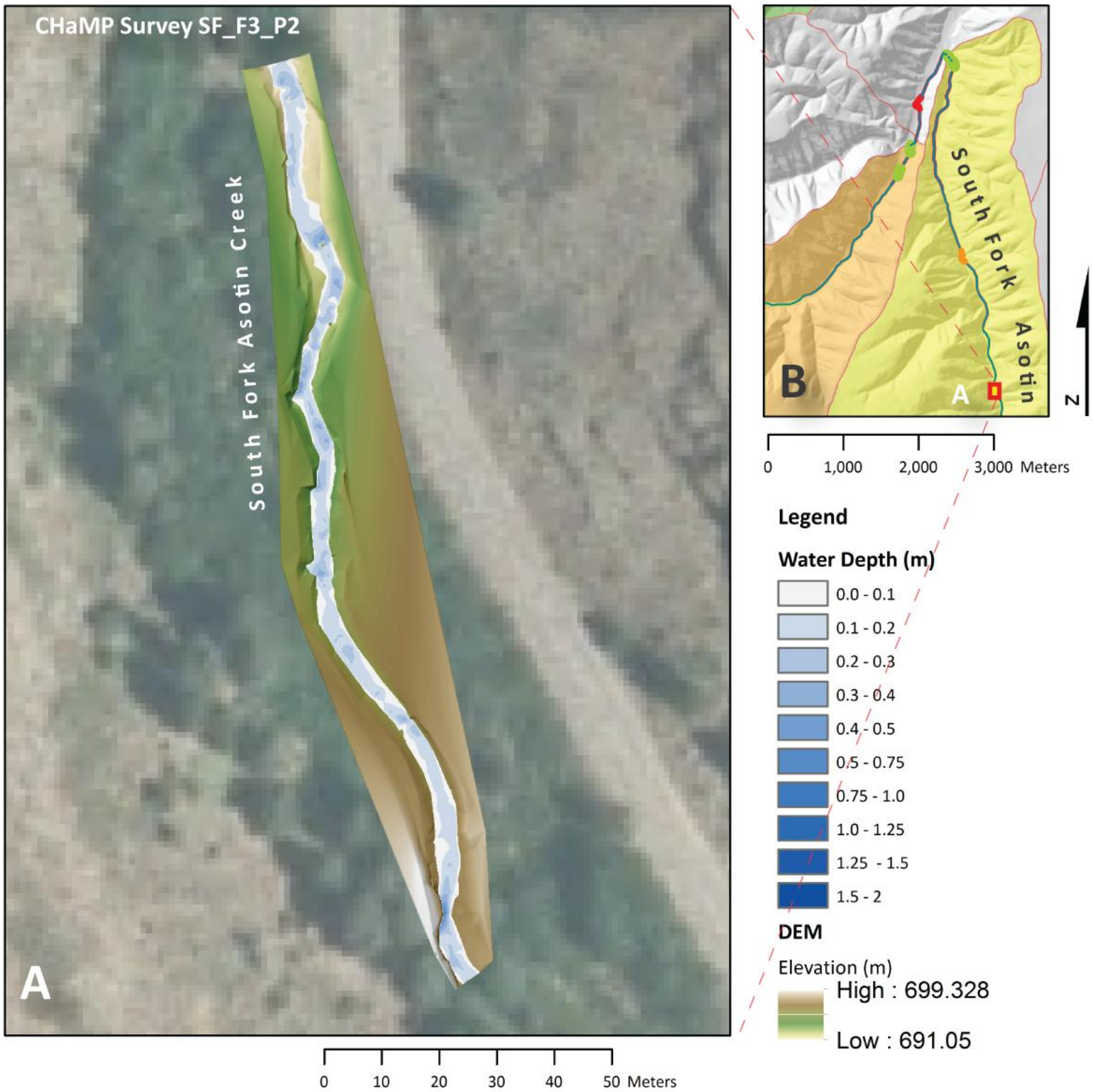

Figure 19. Example of a CHaMP habitat topographic survey from the South Fork Asotin Creek, Site F3_P2. This 165 m site typifies habitat conditions with relatively few pools and those that are present rarely exceeding 30-40 cm in depth. This site is part of a broader 4 km treatment section (South Fork Section 2) slated for treatment in 2012. See Appendix A for the other nine CHaMP surveys conducted in 2011.

4.3 Fluvial Audit Results

In the fall of 2010 we completed a fluvial audit of the lower 12 kilometers of Charley Creek and the South Fork of Asotin Creek. Using a map-grade GPS we marked and inventoried LWD, pools and sediment sources, and geo-referenced each attribute to sub meter accuracy. We recorded LWD as small (10-20 cm diameter), medium (20-30 cm diameter) or large (>30 cm diameter) and recorded the total number of LWD in each aggregate (Table 8). We inventoried pools based on the forcing mechanism causing the pool, whether it was by LWD, boulders, bedrock or roots. In addition, we marked man made habitat structures from past projects and fences crossing the stream. In summer of 2011, we conducted a fluvial audit on North Fork using the same protocol.

GIS was used to determine the spatial distribution of the habitat attributes that were collected via fluvial audits (Figure 20). This data can also be summarized by reach type and helped to identify common forcing mechanisms of pools. These data ultimately helped to confirm that our PIBO and CHaMP habitat surveys at the site scale were representative of the study creeks and provide another scale to assess the IMW restoration treatments.

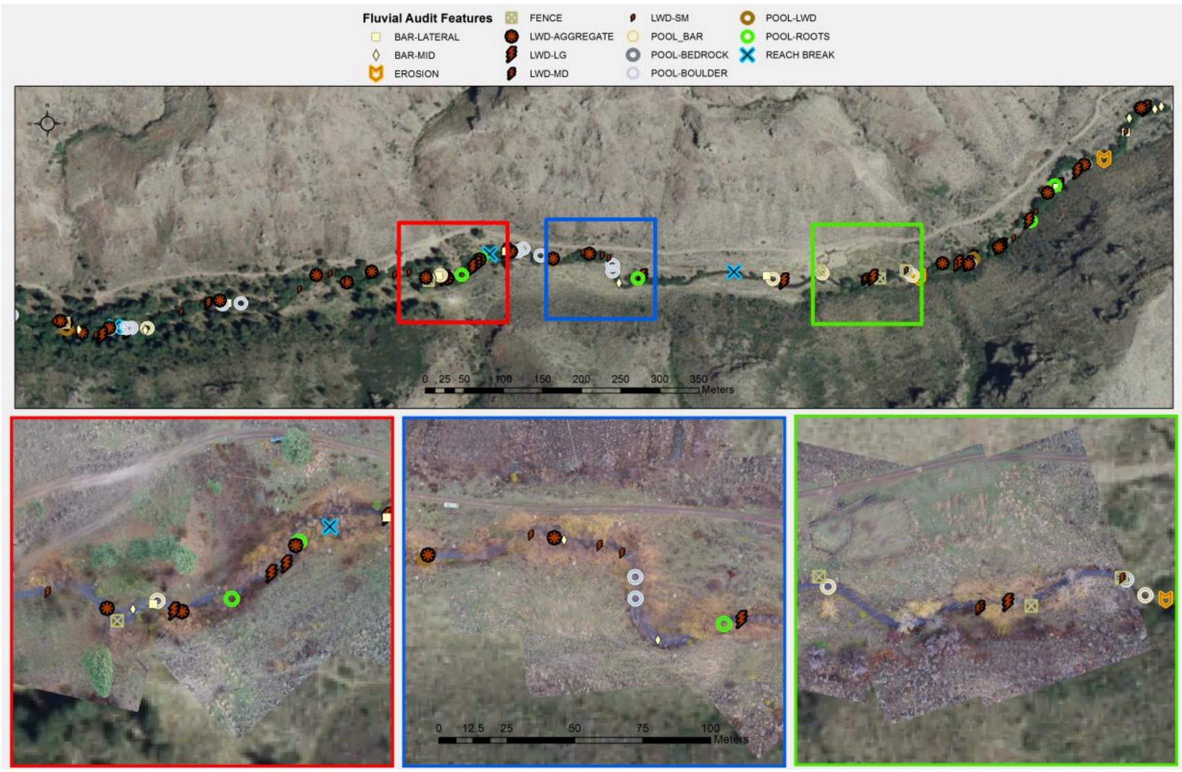

Figure 20. Example of the spatial data collected during fluvial audit (i.e., rapid habitat assessments) of the lower 12 km of each study creek. These panels show the habitat data overlain on 2009 low elevation aerial photo imagery collected using a small blimp along Section 1 of Charley Creek.

4.3.1 Reach types

The fluvial audit confirmed that the common reach type in study creeks is plane bed (§4.3). We compared the proportion of reach types by length calculated from our audit to the GIS based reach typing of Beechie and Imaki (In Press; Figure 11) and found they were similar with a few exceptions. Beechie and Imaki identified very little riffle-pool habitat and step-pool habitat compared to our audits. The differences between the two findings are likely due to the approaches (field based versus GIS) and the context of the studies. Beechie and Imaki identified "historic" reach types which may have been subsequently altered by land use activities. The reach assessments (field and GIS) show that Charley and South Fork Creeks are more similar than North Fork Creek which tends to be less confined and flatter.

Table 9. Percent of stream length classified by reach type based on A) field derived fluvial audit data and B) GIS derived data using Beechie and Imaki (In press) stream reach classifications.

A) Fluvial Audit

Stream	Braided	Plane bed	Riffle pool	Step pool
CC	0	57	22	21
NF	52	30	18	0
SF	0	25	21	54

B) Beechie and Imaki

Stream	Braided	Plane bed	Riffle pool	Step pool
CC	**0**	**89**	**7**	**4**
NF	**38**	**62**	**0**	**0**
SF	**0**	**82**	**15**	**4**

4.3.2 Sediment Types, Sources & Sinks

Initial impressions of the study creeks are that the bed is scoured, embedded, heavily armored, and dominated by coarse and angular sediment that is relatively poor substrate for fish spawning habitat. Large portions of the homogenized sections of the study creeks are dominated with substrate that appeared to be mainly coarse, colluvium (i.e., angular sediment derived directly from hillslopes) in origin. However, given how brittle this basaltic/andesitic bed material is, its angularity suggests that much of this material is not that mobile (i.e., embedded) otherwise it would round quickly. These observations may also suggest that there is a limited sediment supply to the study creeks. However, during the fluvial audit numerous small active bars with well-rounded alluvial sediments were observed throughout the lower 12 km of each study creek. There was ample evidence of an active sediment supply in all three creeks, mainly in the form of hillslope inputs from mass wasting (high degree of channel-hillslope coupling in most places), and to a lesser extent some lateral bank erosion into alluvial valley fill. Although the overall number of active bars and habitat complexity were both relatively low, active bars formed virtually anywhere there was increased variability in channel width. Typically, a flow width expansion downstream of a constriction was where active bars formed in the increased accommodation space (Figure 21). We also observed an active alluvial fan with fresh sediment deposits at the mouth of Charley Creek, as well as larger active bar deposits downstream of the confluence of the North and South Forks where valley width was greater. Collectively, these observations suggest that the study creeks are neither supply limited nor transport limited with respect to sediment. Reasonable quantities of sediment are moving through these streams (as evidenced by the temporary storage anywhere hydraulic conditions facilitate it), but this active bed load appears to have relatively short residence times and relatively few places to accumulate as it moves downstream. We attribute this largely to the relative lack of heterogeneity in channel width and hydraulic patterns. A large length of these creeks behaves as sediment conveyors, with no roughness elements to encourage deposition or lateral floodplain exchange. These observations lead to the hypotheses that increasing variation in channel width could allow increased temporary storage of gravels in active bars, promote better sorting, and more regular exchange with valley floors.

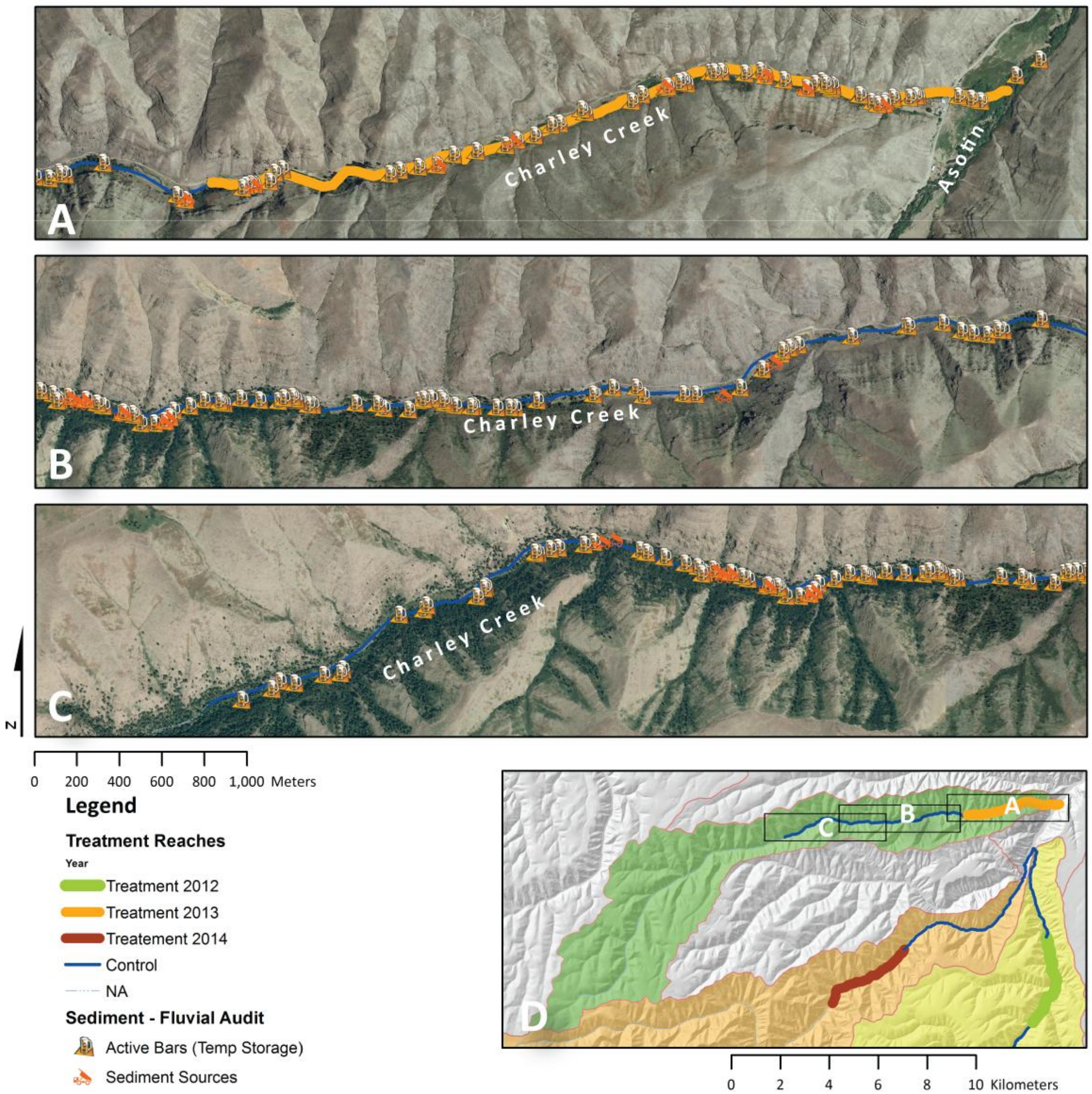

Figure 21. Example of sediment sources and sinks observed during fluvial audits in Charley Creek. Note that these reaches are relatively homogenous with limited bar development but the figure suggests there are a high density of sediment sources and sinks due to the scale of plotting. See Table 10 for fluvial audit results.

4.3.3 LWD and Pools

The fluvial audits confirmed that the abundance of LWD and pools was low (Table 10, Figure 22) compared to conditions in reference streams (Section 4.2). There were long straight sections in each of the study creeks that had little habitat complexity or cover and uniform fast flow (i.e., plane bed). Deep pools (> 0.5 m residual pool depth) were almost absent in Charley Creek and the South Fork; and were rare in North Fork. Large woody debris, when present, was often of a small diameter and mainly alder < 0.3 m diameter. The fluvial audit results were consistent with the annual habitat sampling with all study creeks having less LWD than reference streams and less pieces > 30 cm diameter especially.

However, where wood or large boulders were present they often forced local pools with quality fish cover (Table 10, Figure 23). Most pools were oriented longitudinally and associated with convergent flow patterns induced by the flow width constriction the boulders and/or LWD produced. Boulders, LWD, and roots were the most common causes of convergent flow that appeared to be scouring pools (Table 10). Some pools may be maintained more by routing of sediment around pools (and lack of deposition) rather than active scour (MacWilliams et al. 2006). Where LWD was present, LWD-forced flow-width constrictions at the heads of pools (e.g., Figure 24) were common, similar to patterns observed by Thompson and Hoffman (2001) in other streams. Even in Charley Creek, which exhibits the lowest and most stable flows and has width constrictions due to boulders, LWD and root-wads did occur occasionally and were generally associated with pool formation, bar deposition, variable channel width, and generally heterogeneous habitat. Although the number of these occurrences in the study creeks was relatively low, the rare instances of heterogeneous habitat and evidence of their formative processes gives an important insight into what is possible in these streams. These data from fluvial audits informed the development of the restoration design and also will be used to assess associations between PIT tagged juvenile steelhead and habitat attributes during different seasons and using GIS.

Table 10. Summary of fluvial audit survey results in Charley, North Fork, and South Fork Creeks. See Table 8 for definitions of each attribute.

								Proportion of pools forced by different features				
Stream	Length Surveyed (m)	LWD Aggregates/ 100m	LWD/ 100m	LWD ≥ 0.3 m diameter/ 100m	Past Restoration Structures /100m	Sediment Bar Area/ 100m2	Pools/ 100m	Sediment Bar	Bedrock	Boulder	LWD	Tree Roots
Charley	13,534	1.9	13.4	0.7	0.6	16.5	3.1	19.0	10.1	22.8	27.8	20.3
North Fork	12,730	3.6	11.4	0.8	0.5	18.7	2.7	1.1	5.1	36.9	46.9	10.0
South Fork	12,827	0.7	5.1	0.5	0.7	20.6	2.3	1.9	5.7	58.0	21.8	12.5
Average	**13,030**	**2.1**	**10.0**	**0.7**	**0.6**	**18.6**	**2.7**	**7.3**	**7.0**	**39.2**	**32.2**	**14.3**

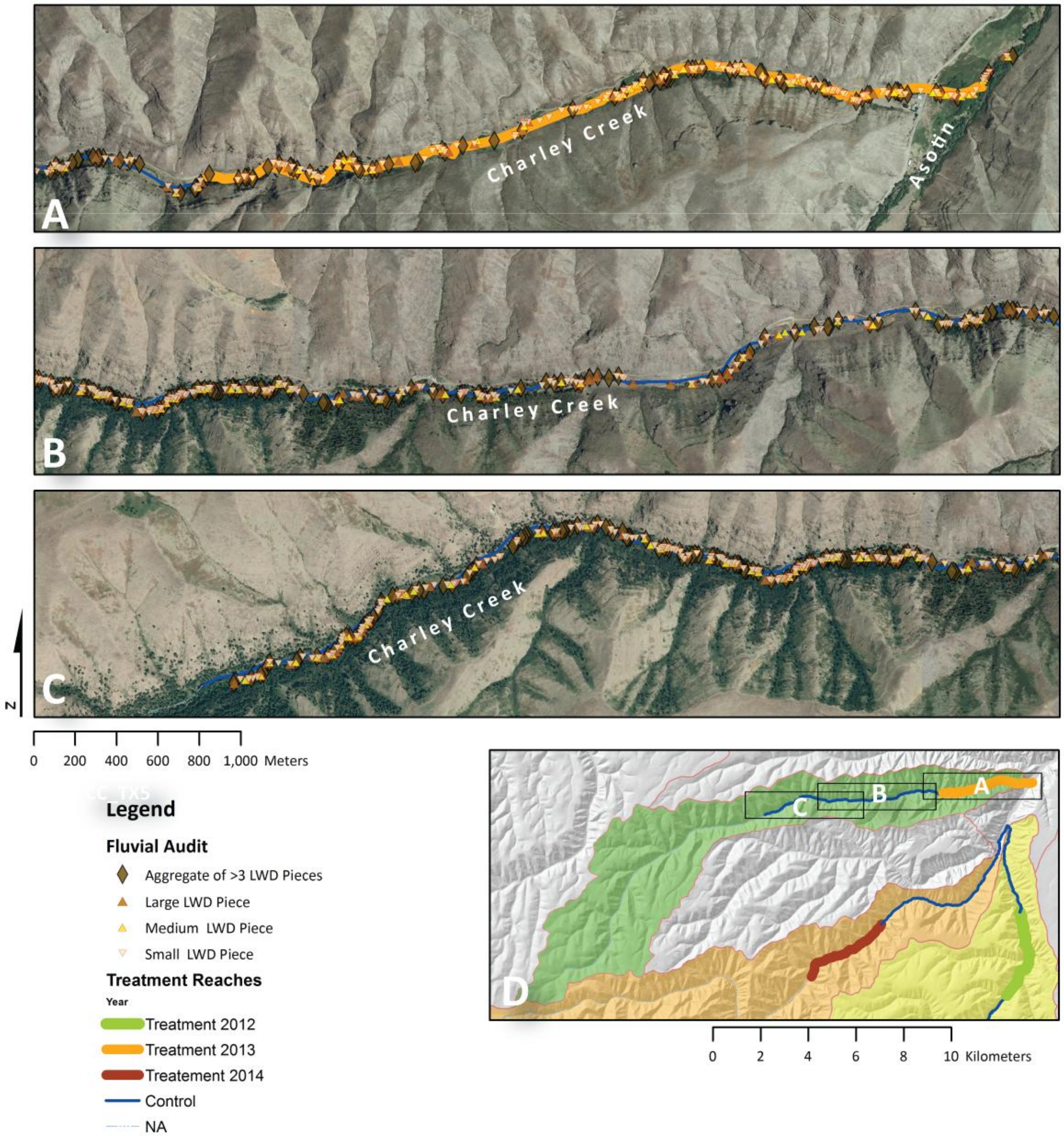

Figure 22. Example of fluvial audit results for LWD Charley Creek by size class of LWD. Note that these reaches are relatively homogenous with limited LWD but the figure suggests there is a high density of wood due to the scale of plotting. See Table 10 for fluvial audit results.

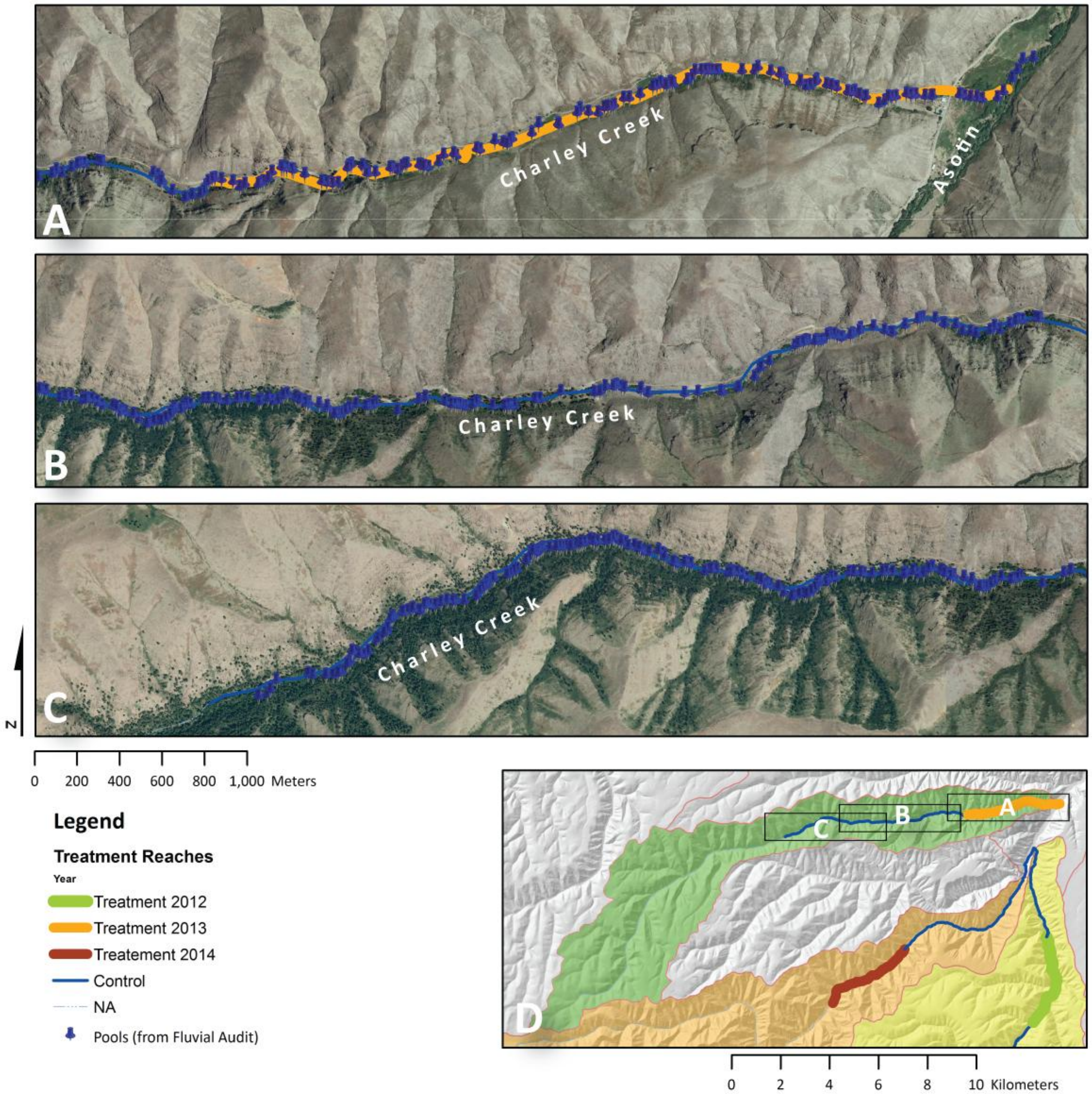

Figure 23. Example of the fluvial audit results for pools in Charley Creek. Note that these reaches are relatively homogenous with limited pools but the figure suggests there is a high density of pools due to the scale of plotting. See Table 10 for fluvial audit results.

Figure 24. Example of a width constriction on North Fork Creek. Note the debris pile on river-right that is forcing the flow towards the left bank, creating a pool downstream, and the vegetated sediment bar upstream of the width constriction.

Whereas the fluvial audit data cover the first 12 km of each stream (36 km in total), the CHaMP surveys were focused in 200 m long sites. We used the CHaMP topography and water depth maps to validate the presence of pools and bars that were recorded during the fluvial audits (Figure 25). Overall, there was agreement between the fluvial audits and CHaMP data. When viewed at the scale of the whole study creek (e.g., Figure 23), the fluvial audits give a false impression of a relatively high abundance of pools. A closer look at the fluvial audit reveals the pool densities are low relative to reference conditions, and many of the pools identified are relatively minor (e.g., < 0.3 m depth). When zoomed in to a habitat site, as in Figure 25, we see only two pools identified by the fluvial audit and a potential additional two minor pools identified in the CHaMP survey (all with max depths < 0.4 m). The same site exhibits only one aggregate accumulation of two or more picces of LWD, and not surprisingly the only active point bar in the entire site is immediately downstream of the aggregate and the bar seems to be forcing a small pool laterally on the outside bend. The same site has one small piece of LWD and two medium pieces of LWD, neither signficant enough to produce major variations in the hydraulics nor to force bars or pools. This situtation is typical through much of the study creeks, as confirmed by the fluvial audits.

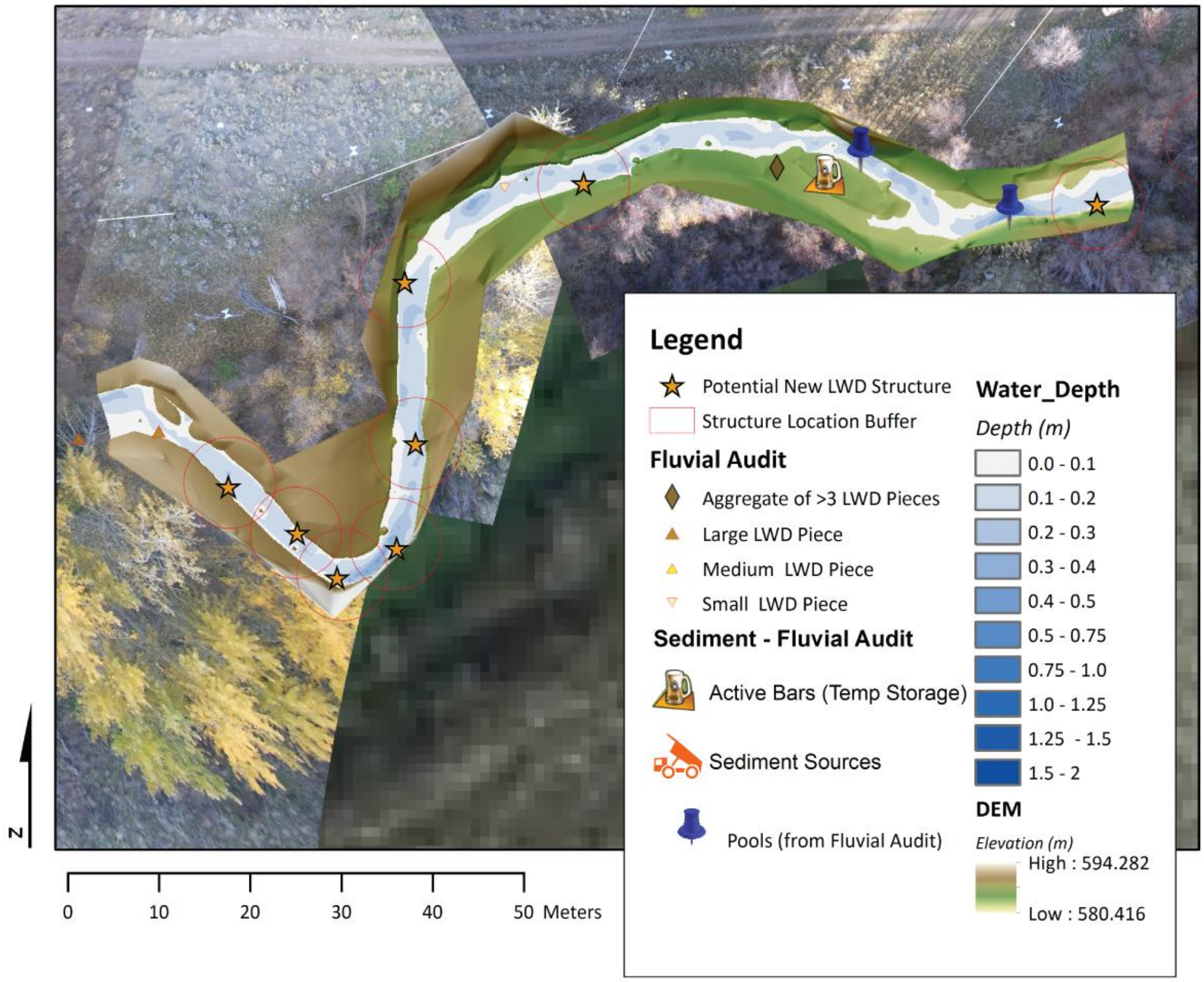

Figure 25. Overlay of fluvial audit and CHaMP 2011 habitat survey site CC_F2_P1 which is within Section 1 of Charley Creek and proposed for restoration in 2013. Potential new structure locations refer to where we may install a dynamic woody structure based on the CHaMP and fluvial audit results. Further ground truthing would be required to select the exact location and design of the structures.

Table 11. Structure type and configuration of 15 Dynamic Woody Structures installed in August 2011 as a trial project of the proposed restoration treatment for the Asotin IMW.

Stream	Site Name	No. Posts	Post Alignment	No. LWD	Existing Condition
Charley Creek	CC-TX1	6	Simple	2	RL directing flow to RR; just upstream from meander bend to RR with active erosion and large deposits of exposed alluvium; uniform depth and width upstream
	CC-TX2	4	Simple	2	RR direction flow to RL; uniform depth and width upstream and downstream; overhanging alder roots RR acting as enhancement point
	CC-TX3	4	Simple	1	RL directing flow to RR; at the downstream end of meander bend to RR; active erosion upstream (cattle may be accessing stream here); small debris pile RL acting as enhancement point
	CC-TX4	5	Simple	0	RR directing flow to RL; uniform depth and width upstream and downstream; rotten birch log partially enhancing structure
	CC-TX5	7	Complex	0	RL directing flow to RR; uniform depth and width downstream, upstream meander bend RL; channel widens upstream and overhanging roots RL act as enhancement point
North Fork	NF-TX1	9	Complex	3	RL direction flow to RR; meander bend to RR downstream; uniform depth and width upstream and downstream; small alder trees falling in the channel act as enhancement point RL
	NF-TX2	7	Complex	3	RR direction flow to RL; shallow scour pool already formed on RL from overhanging alder roots; uniform depth and width upstream and downstream
	NF-TX3	8	Complex	3	RL directing flow to RR; meander bend to RR upstream; uniform depth and width upstream and downstream
	NF-TX4	9	Complex	0	RL direction flow to RR; side channel formed by large debris jam on the mainstem (upstream 100 m); two large boulders acting as an enhancement point; bars and alluvial deposits present RR; uniform depth and width upstream
	NF-TX5	7	Complex	0	RL direction flow to RR; side channel formed by large debris jam on the mainstem (upstream 20 m); overhanging roots acting as an enhancement point; bars and alluvial deposits present RR; uniform depth and width downstream
South Fork	SF-TX1	4	Complex	3	RR directing flow to RL; meander bend to RR 20 m upstream; uniform depth/width upstream and downstream; at base of 3-4 m high bank
	SF-TX2	6	Complex	3	RR directing flow to RL; meander bend to RR 20 m downstream; large boulders upstream; uniform depth/width upstream and downstream; RL bank eroding and large cobble and boulders falling into stream
	SF-TX3	5	Complex	1	RL directing flow to RL; uniform depth and width upstream and downstream; simple channel
	SF-TX4	8	Simple	0	RR directing flow to RL; meander bend to RR 20 m upstream; some large boulders upstream from road rip rap; small live and dead trees fallen on river of RR acting as enhancement point; shallow scour pool
	SF-TX5	7	Simple	0	RL directing flow to RR; meander bend to RR 30 m downstream; some rip rap upstream near road; armored bank RR

*No. Posts = number of posts used to build dynamic woody structure; Post alignment = posts were installed in a straight line (simple) or an alternating pattern (complex); No. LWD = the total number of pieces of LWD added to the structure. LWD pieces were 2-4 m long, 20-40 cm diameter, and had branches and needles still intact.

4.4 Trial LWD/DWS Restoration Treatment Results

Fifteen trial dynamic woody structures (DWS) were installed, five in each study creek using the design criteria specified (see § 6). We were able to demonstrate that it is logistically feasible and cost effective to create DWS in the study creeks by driving wooden posts with a hydraulic post driver. At each DWS, 4-9 posts (regular 10 cm diameter fence posts, 1.8-2.4 m tall) were driven into the stream bottom using a hydraulic post driver. In almost all instances we were able to drive the posts 0.6-1.0 m into the substrate, which was a conservative depth we predicted would minimize the potential for the posts to be undermined and scoured away during spring high flows. The structures turned out to be very easy to install by hand and took on average 2 hours to construct with a crew of two to four people.

4.4.1 Charley Creek Restoration Trial

We installed five DWS in Charley Creek on private property approximately 2 km upstream from the mouth (Figure 26 and Figure 27). This trial treatment section had very few pools or LWD and no side channels were present. This section is also what has been typically described as "incised" in previous assessments (NRCS 2001). The channel is straight and the banks are high (0.3-1.5 m) and composed of coarse deposits. The lower three trial DWS (CC-TX1-3) have only a very narrow strip of riparian forest (0-3 m) on river left and frequent evidence of cattle accessing the stream and trampling vegetation (Figure 28). The upper two DWS had more riparian cover on river left (20-30 m) and had less evidence of cattle accessing the stream. We used less posts on average to create each DWS (mean 4.6 posts/structure, range 4-7) and posts were easily driven in 0.6-1.0 m. A road along Charley Creek and the lack of riparian vegetation at the site allowed easy access to this trial treatment section. The LWD and post materials were stockpiled within a few hundred meters of the trial restoration section, which allowed rapid construction of the structures. We estimate it took 1-2 hours to complete the construction of each structure.

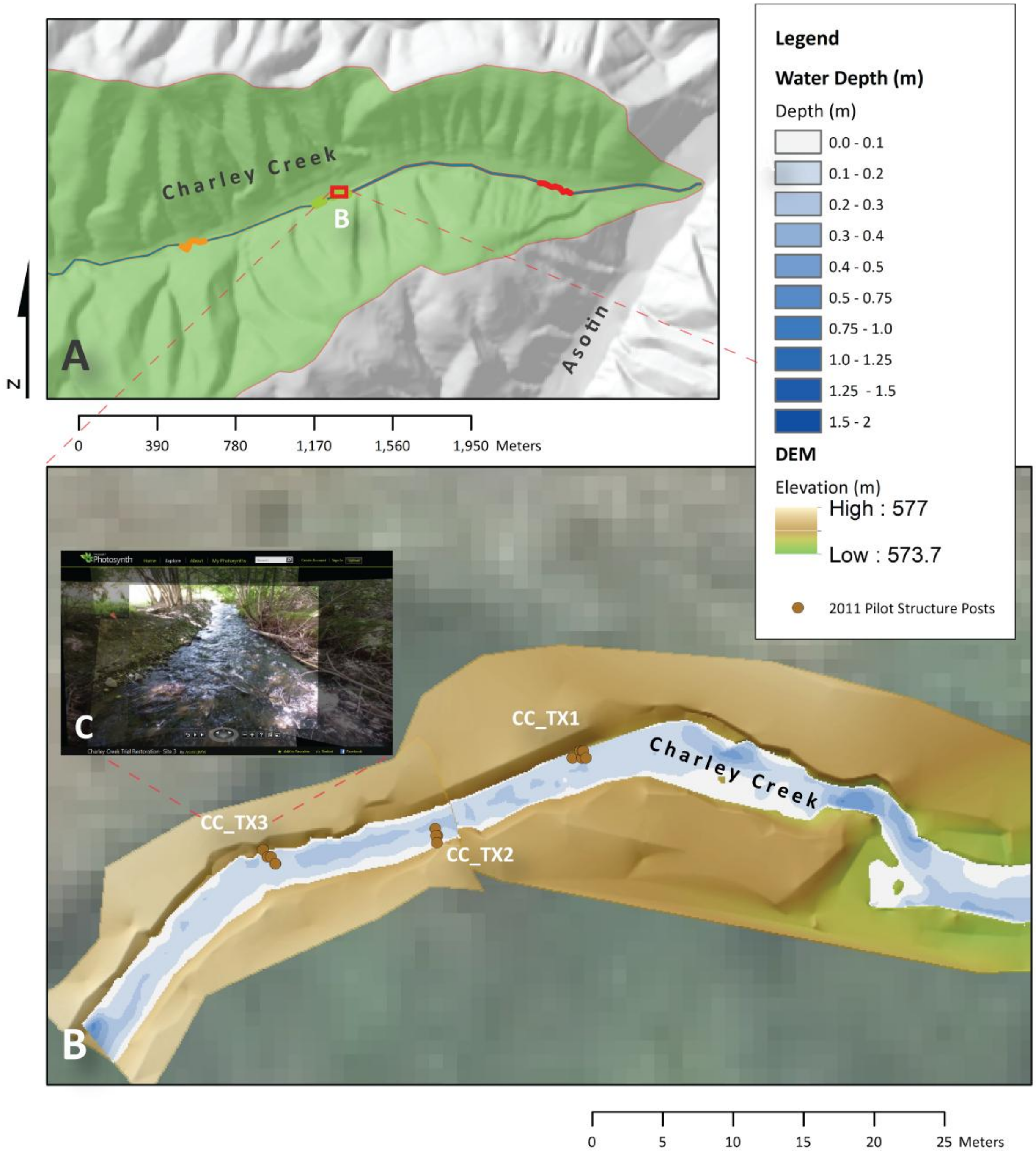

Figure 26. A) Location of lower trial treatment section within Charley Creek, B) as-Built topographic and habitat survey of trial structure installation in Charley Creek, and C) Photosynth of CC_TX3 shown (available at: http://photosynth.net/userprofilepage.aspx?user=Asotin_IMW). Trial structures CC_TX1, CC_TX2 & CC_TX3 are shown.

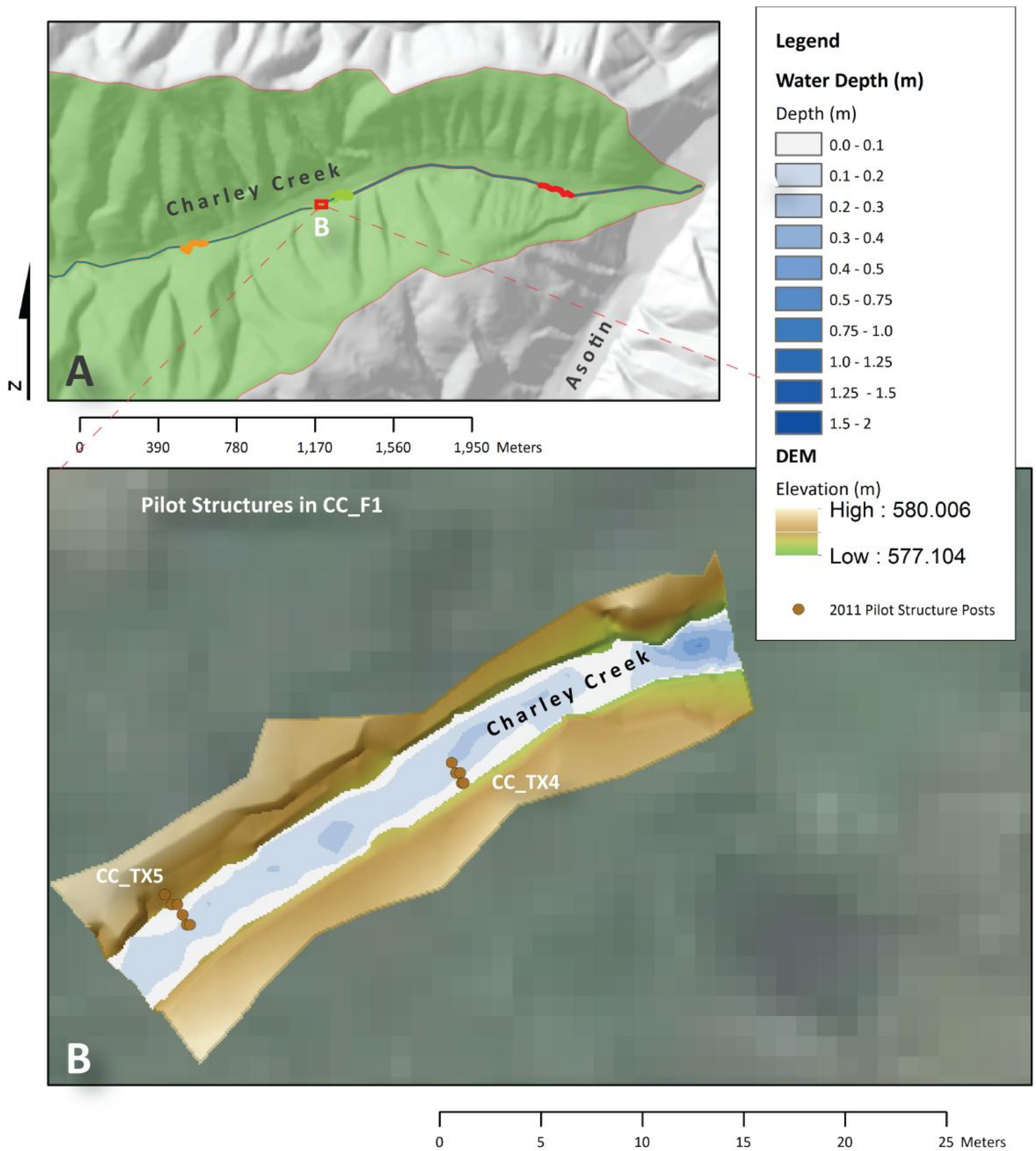

Figure 27. A) Location of upper trial treatment section within Charley Creek and B) as-built topographic and habitat survey of trial structure installation in Charley Creek. Trial structures CC_TX4 & CC_TX5 are shown.

Figure 28. Example of a trial restoration structure on Charley Creek (CC-TX1). A root wad was added to this DWS to aid in forcing a width constriction to this straight and homogenous portion of channel (flow is towards the reader, structure is placed on river left). Note the steep banks and coarse material. CC-TX2 and CC-TX3 can be seen 25 m and 50 m upstream from CC-TX1.

4.4.2 South Fork Restoration Trial

We installed five DWS in South Fork Creek on WDFW property starting approximately 0.1 km upstream from the mouth and confluence with the North Fork (Figure 29). This trial treatment section had very few pools or LWD and no side channels were present. This section is not as incised as Charley Creek but one high bank (3-4 m) is present at SF-TX1 on river right. The stream channel is generally wide and shallow (Figure 30). Near SF-TX4 and 5 there is a road and a considerable amount of large rip-rap borders the stream on river left. The riparian forest is extensive (20-30 m) and composed of mature conifers and cottonwoods at all of the DWS except SF-TX5 which has only a narrow (2-3 m) wide strip on river right due to impingement by the South Fork Forest Road. Posts were most difficult to drive at the South Fork sites and we attribute this to large substrate (mostly cobble and boulders), rip-rap from road building, and more embedded substrate (possibly due to the location of these sites near the bottom of the watershed). On average we used six posts (range 4-8) per structure and drove the posts 0.5-0.6 m into the substrate.

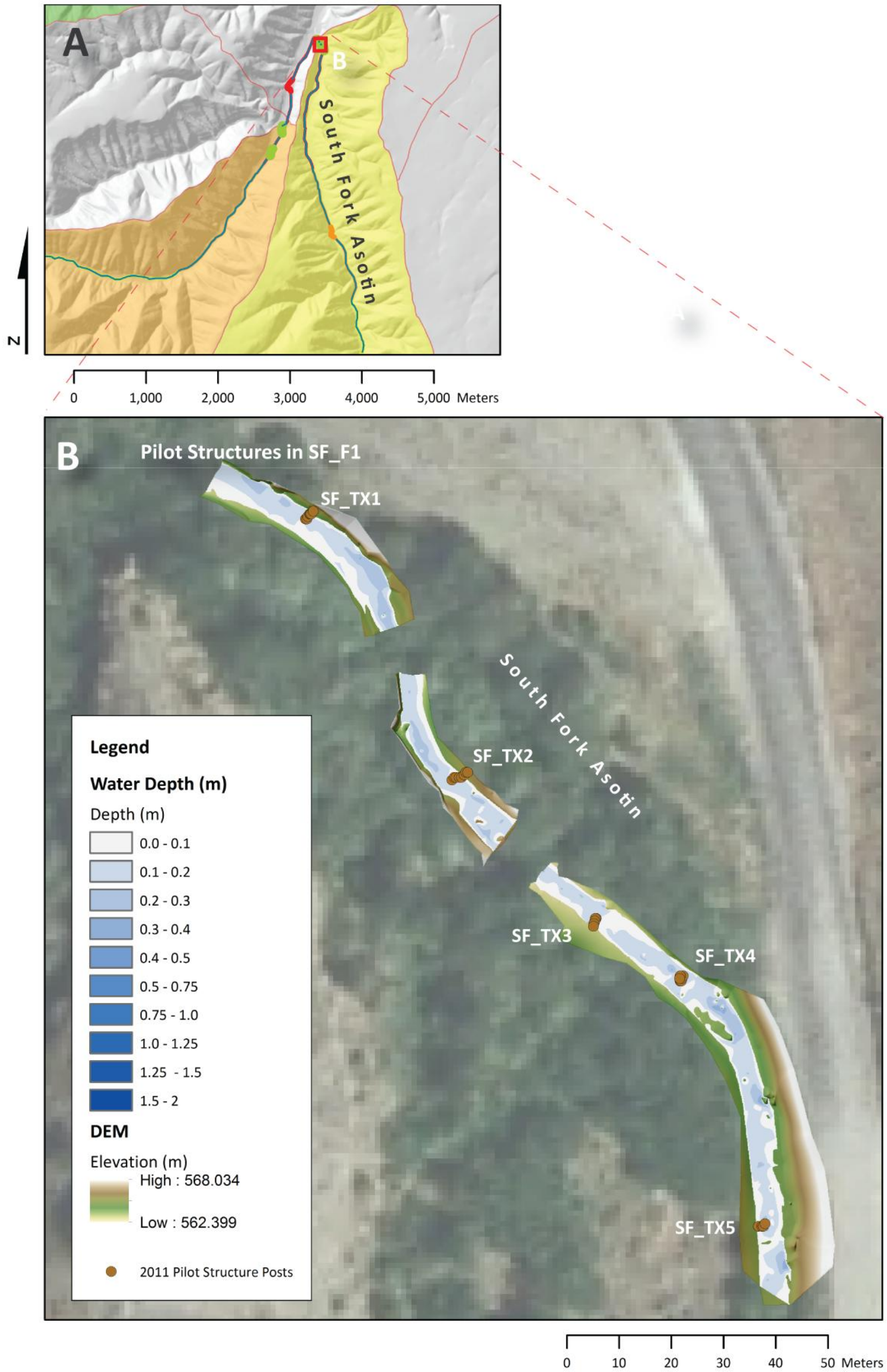

Figure 29. A) Location of trial restoration section within South Fork Asotin Watershed and B) as-Built topographic and habitat survey of trial structure installation in South Fork Asotin Creek. Trial structures SF_TX1, SF_TX2, SF_TX3, and SF_TX4 & SF_TX5 are shown.

Figure 30. Example of a trial DWS on South Fork Creek (SF-TX3). A green piece of LWD with branches was added to this structure to increase the likelihood it will trap other debris washed downstream. Flow is towards the reader and structure is placed on river left. Note the extensive riparian vegetation, wide and shallow channel, and large substrate of cobble and boulders. Yellow arrow points to SF-TX4 50 m upstream on river right from SF-TX3.

4.4.3 North Fork Restoration Trial

We installed five DWS in North Fork Creek on WDFW property approximately 2 km upstream from the mouth (Figure 31 and Figure 32). The lower three DWS were installed on the mainstem North Fork Creek (Figure 31) and the upper two DWS were installed on a side channel along the mainstem (Figure 32). The North Fork has a more multi-threaded channel form and thus we wanted to assess how the structures would perform in both mainstem and side channel situations. The valley is much wider at these trial sites compared to Charley Creek or South Fork sites and the riparian vegetation is extensive because there is no road along this section of river. We used the most posts on average to create each structure (mean 8.0 posts/structure, range 7-9), the structures were more complex, and posts were easy to drive in 0.6-1.0 m (Figure 33). Access to this site was moderate because there was no road along the creek, but a well-used trail follows the creek on river right. The LWD and post materials were stockpiled at the confluence of the South Fork and North Fork approximately 2 km downstream. Construction materials were transported to the site from the stockpile during construction. We estimate it took 1-2 hours to complete the construction of each structure.

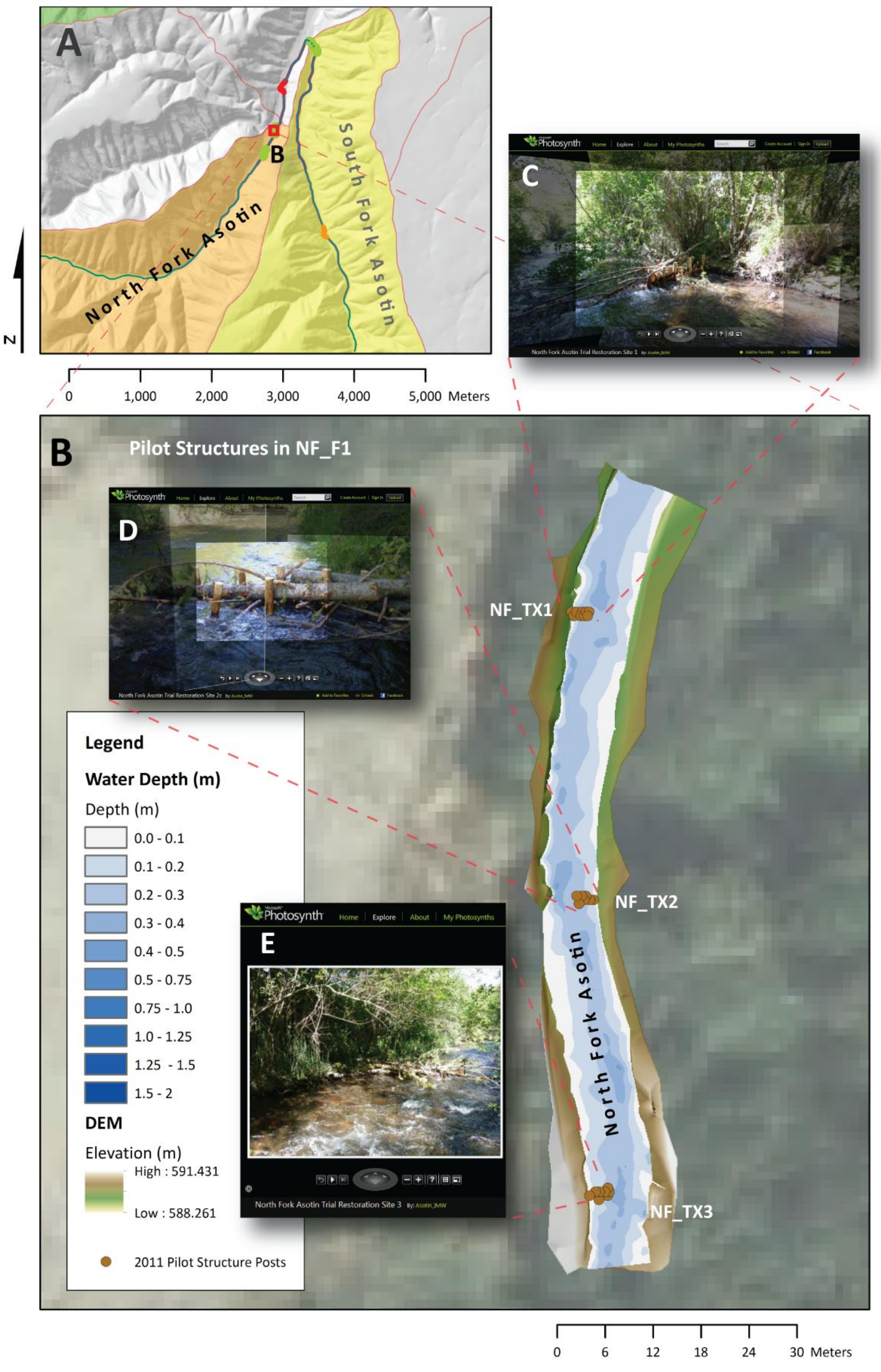

Figure 31. A) Location of lower trial treatment section within North Fork Asotin Watershed, B) as-built topographic and habitat survey of trial structure installation in North Fork Asotin Creek, and C) example Photosynth of NF-TX3 shown (available at: http://photosynth.net/userprofilepage.aspx?user=Asotin_IMW). Trial structures NF-TX1-3 are shown.

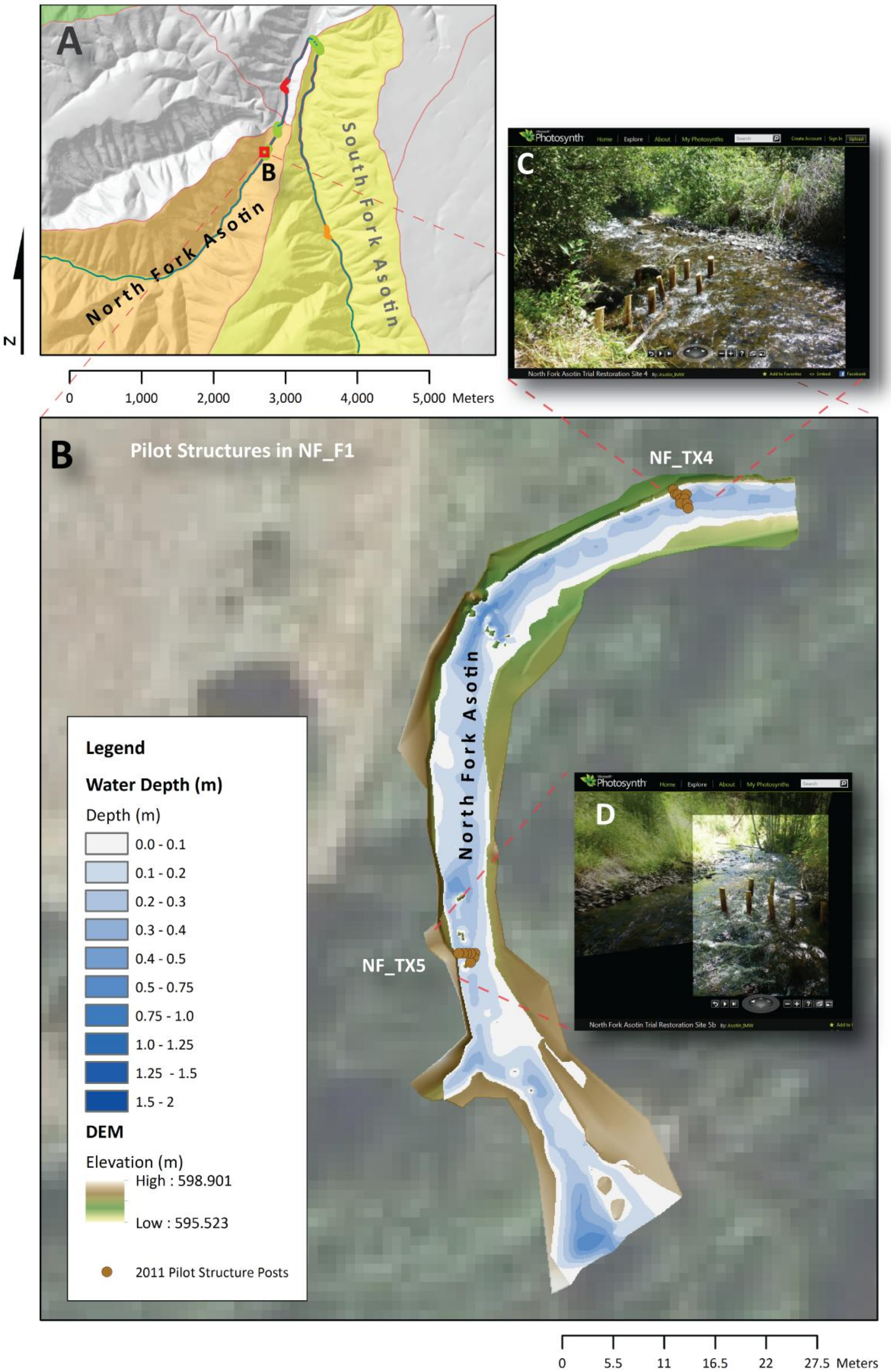

Figure 32. A) Location of upper trial treatment section (side-channel) within North Fork Creek, B) as-built topographic and habitat survey of trial structure installation in North Fork Creek, and C, D) Photosynth picture of NF-TX4 and 5. Trial structures NF-TX4 & NF-TX5 are shown. Photosynth's of NF_TX4 (C) & NF_TX5 (D) shown (available at: http://photosynth.net/userprofilepage.aspx?user=Asotin_IMW).

Figure 33. Example of a trial DWS on North Fork Creek (NF-TX1). This is an example of a more complex structure as the posts were driven in an off-set pattern. LWD was then added diagonally between the posts to lock the pieces together. Flow is towards the reader and structure is placed on river left. Note the extensive riparian vegetation, wide and shallow channel, and LWD extended beyond the posts to constrict flow.

4.4.4 Spring 2012 Flood Results

We were fortunate to have two large spring flow events in March 2012 that allowed us to observe how the trial restoration structures performed under high flows. On March 16, 2012 the USGS gauge just downstream of the confluence between the North Fork and South Fork Creeks measured an increase in flow from ~ 50 cfs to a peak of 579 cfs (Figure 34; Gauge # 13334450). Then on March 31, 2012 the same USGS gauge measured a peak flow of 1330 cfs. These floods were larger than the average annual peak discharge recorded at this gauge and the second flood was the largest recorded in the 12 years the gauge has been in operation (Figure 35). Intense rain, rapidly warming air temperature, and recent snow fall all contributed to a very rapid increase in discharge.

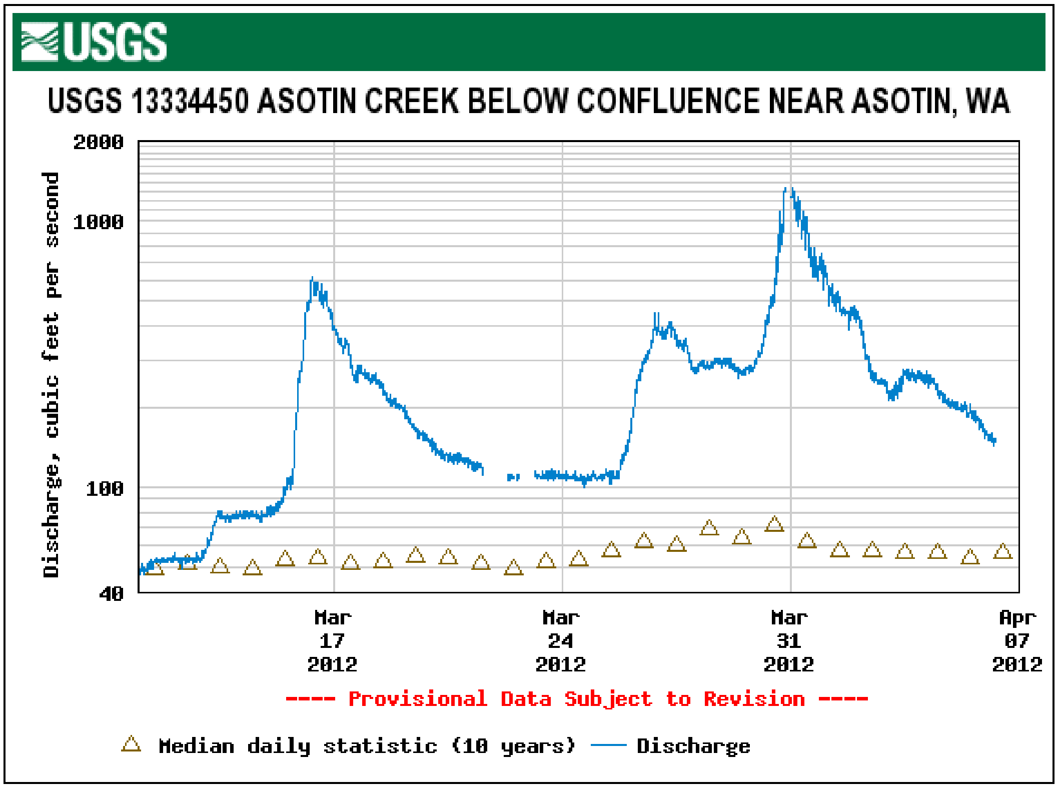

Figure 34. Discharge record for USGS gauge # 13334450 downstream of the confluence of the North Fork and South Fork Asotin Creeks for the period of March 15, 2012 to April 7, 2012.

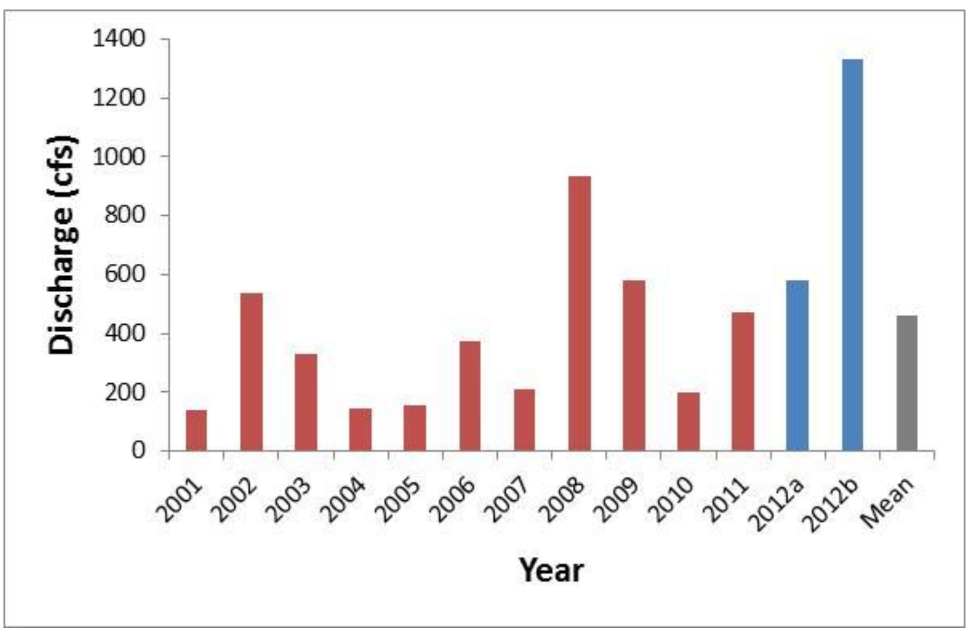

Figure 35. Annual peak discharge by year (red bars) at USGS gauge # 13334450 downstream of the confluence of the North Fork and South Fork Asotin Creeks. Blue bars are two large flows in March 2012 and the gray bar represents the average annual peak flow at the site.

We were able to take pictures and video of the pre-flood, flood, and post flood conditions at all 15 trial structures and make some preliminary observations about i) the response of the structures to high flows, and ii) hydraulic and geomorphic responses to the structures under a variety of flow conditions (Appendix B). During and after the first flood on March 16th, all 15 structures remained intact and we observed many of the hypothesized responses including: flow width constriction, increased velocity at the width constriction, collection of natural debris on the posts, scouring of substrate downstream of the structures, erosion of the bank across from the structures, and formation of sediment bars upstream and downstream of the structures (see section 6.5, hypotheses E-P). The structures also provided refugia from high flows in the form of back-eddy pools (downstream of structures) and dam pools (upstream of structures). During and after the second and larger flood, most of the posts in three structures in the South Fork washed out (SF-TX1, SF-TX3, and SF-TX4) washed out. The partial loss of a portion of these structures was a hypothesized response in the design report, and in the full treatment with a higher concentration of structures the posts and debris that washed away from these structures may have re-accumulated in downstream structures. All of the structures in the North Fork and Charley Creek remained completely intact after both floods. These results suggest that the majority of the structures can withstand even large floods in each of the study creeks and that the structures are providing some of the hypothesized benefits within less than one year of placement. We will complete repeat topographic surveys of the all the trial structures in June 2012 to quantify the geomorphic response as a result of the structures and the subsequent changes to physical habitat.

5 CONCEPTUAL MODELS ARISING FROM ASSESSMENTS, SURVEYS, AND TRIAL RESTORATIONS

There are at least two working conceptual models that arise from our assessments and surveys (§4). One is a conceptual model of the current state of the study creeks; which infers how this condition came to be, but more importantly focuses on what about the current condition is limiting geomorphic processes from sustaining better habitat conditions that could lead to increased fish production. The second is a conceptual model of how we think the study creeks will function after the treatments, and explicitly articulates the attributes which will help support fish production and the physical mechanisms by which we hypothesize these conditions could be self-sustaining. We articulate both conceptual models here as they help transparently distinguish the things we know from that which we infer and create better opportunities for testing, learning, adapting treatments and refining these conceptual models through the IMW adaptive management process as the project continues (see §1.3).

5.1 Current Condition

Our assessments (§4) and other regional assessments (ACCD 1995, ACCD 2004, SRSRB 2006, Bennett and Bouwes 2009) support the conclusion that there is less LWD in the stream channel of Asotin Creek and its tributaries than historically. The lack of LWD, combined with a history of land use that has included extensive logging in the upper reaches of the study creeks, over-grazing, channel straightening, and riparian degradation in the lower reaches, has led to straighter, shallower, and more homogeneous channels with relatively few deep pools. A cursory inspection of riparian conditions along the study creeks suggests a relatively healthy riparian corridor 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 have a fairly stable, rather homogenous riparian age and species structure, which likely reflects a steady recovery following cessation and/or reduction in some of the previous land uses (e.g., logging, grazing). Unfortunately, this recovery has taken place around a relatively homogenized channel, and has acted to stabilize the degraded condition of the channel. The majority of the stream consists of homogenous 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. However, there are encouraging remnants of the feasibility of a more diverse age and species structure in the riparian corridor (especially in the North Fork) and in these areas the channel is often more diverse.

The ball and cup diagram on the left hand side of Figure 36 illustrates the fate of the current condition in the study creeks. The study creeks are currently locked 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 streams into a different state and/or to modify the system parameters. Even when rare large floods do occur, as noted by the historical discharge record of Asotin Creek, the streams quickly revert back to degraded conditions. Despite this current scenario, the fluvial audit highlighted that the study creeks are capable of a higher degree of complexity and complexity 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 present.

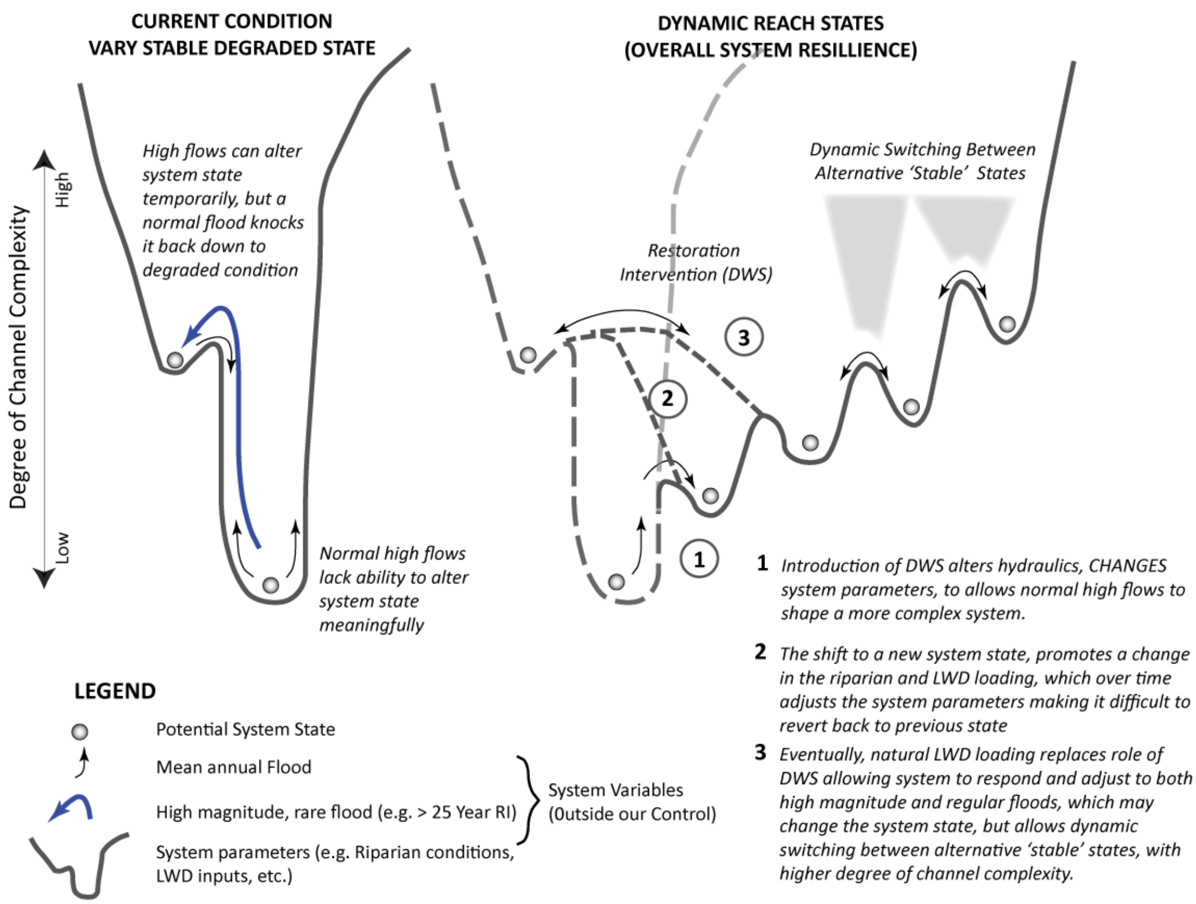

Figure 36. Conceptual model of current condition (left) and envisioned condition (right) post restoration in response to the introduction of DWS. In this instance, we can't change the system variables (e.g., hydrology), but we can change the system parameters by increasing the loading of LWD, which we hypothesize will shift the stream into more complex system states, which can dynamically switch between alternative stable states.

5.2 Envisioned Condition

Our vision for the treated sections of the three study Creeks is one of a dynamic and complex mix of habitat with a high concentration of naturally recruited LWD, active bars, small side-channels and more regular exchange of wood, sediment and water with adjacent riparian forests. In short, this envisioned condition is an expansion of the remnant pockets of historical conditions we found evidence for in the fluvial audits. Although the restoration intervention we propose to achieve this artificially increases the density of LWD in the short-term, the design is explicitly to hand off the work that this active intervention promotes to the stream's own fluvial processes. This design is intended to directly produce a hydraulic response, which is exacerbated at high flows, and promotes fluvial processes of erosion and deposition to carve out and build more complex in-channel habitat as well as increase the exchange of materials with the riparian corridor. Figure 36 (right) illustrates the transition from active intervention to stream dynamic processes for creating desired changes. We start with the installation of DWS, which act to change the system parameters, such that the stream can shift to a new (more complex) system state even in response to small floods. A larger flood would likely produce a more dramatic response quicker. Through time, we hypothesize that the riparian dynamics will change such that LWD recruitment increases and the density of roughness elements is being maintained by natural recruitment and fluvial processes. At the local DWS scale, Figure 37 illustrates conceptually how a particular measurable metric (flow width) may be expected to change in response to the treatment. As with many metrics of potential interest, we are not necessarily looking for a shift in the mean value (difficult to detect), but rather for a shift in the variability of that metric. We should clarify that we do not expect to see a physical response from the restoration outside of the three 4 km treatment sections (i.e., in the control sections).

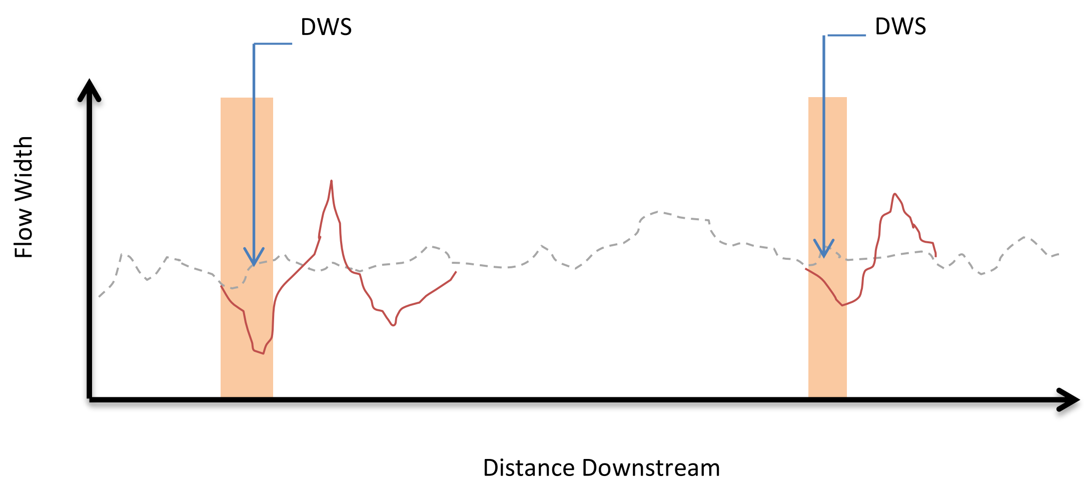

Figure 37. Conceptual diagram of the effect of dynamic woody structures on stream width variation in the study creeks. Gray dashed line represents existing stream width and the solid red line represents potential increase in stream width variation created by DWS.

6 PROPOSED RESTORATION DESIGN

6.1 Restoration Philosophy and Response Uncertainty

The basic philosophy we bring to this restoration plan 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 just 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 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 observed 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 field 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.

If an isolated structure 'fails' and washes out, the consequences of such an event are relatively insignificant. The cost of that structure in terms of raw materials is less than $100 for materials. The hydraulic and geomorphic influence of the structure may be lost, with the stream returning to its pre-treatment condition. However, if the structure is instead part of a complex network of hundreds of structures in series with each other, the consequences of a failure are actually part of a natural progression. The materials (wooden fence posts) and LWD that might have been part of that structure are likely to end up moving downstream to the next structure and becoming tangled up in that roughness element as a debris jam. Debris jams come and go in nature, inducing a consistent and roughly predictable cast of associated features (e.g., pools, bars, side channels, etc.). If there are enough debris jams, their transitory nature and the attributes associated with them are simply part of the overall character of the stream. By contrast, if there are only one or two mega features, their failure leads to the diffusion and dispersal of the material that built them into generally less effective forms.

One of the tenants of a healthy stream and fish populations is diverse habitat and complexity at multiple scales (Fausch et al. 2002). Such complexity is the product of dynamic processes, which means that the precise details of the arrangement of a reach are very difficult to predict. However, harnessing this inherent variability stochasticity can be a very effective restoration strategy (Wissmar and Bisson 2003). This philosophy not only accepts the inherent uncertainty of natural stream systems but also embraces it (Sear et al. 2008, Wheaton et al. 2008). Most restoration efforts conceptualize the outcomes as either desirable or undesirable with respect to project goals (top and bottom half of outcome space in Figure 38). However, there can be a host of other important, but unforeseen factors that maybe were not considered as part of the restoration planning. It is important to recognize that we cannot predict what other benefits and consequences may be associated with the project. There may be situations where a Type B response (undesired outcome with respect to original goals, but unforeseen benefits), may actually produce an outcome better than what was originally envisioned with the restoration. Our adaptive management plan and monitoring will allow us to evaluate how the project performs in response to our stated goals, as well as the surprises it presents. We will be looking to avoid risky situations that might produce a Type D response, but we will also need to accept the possibility of a Type C response where the unforeseen consequences may compete with a desired outcome. We obviously aim for a Type A response, but Type B or C responses may be perfectly acceptable. The main point that underlies our restoration philosophy here is that there are not only risks in what might be uncertain outcomes, but also opportunities. In §6.5 we synthesize the various hypothesized responses we have postulated throughout this design document, and we believe that these help us shift the plausible outcome space within the total outcome space of Figure 38.

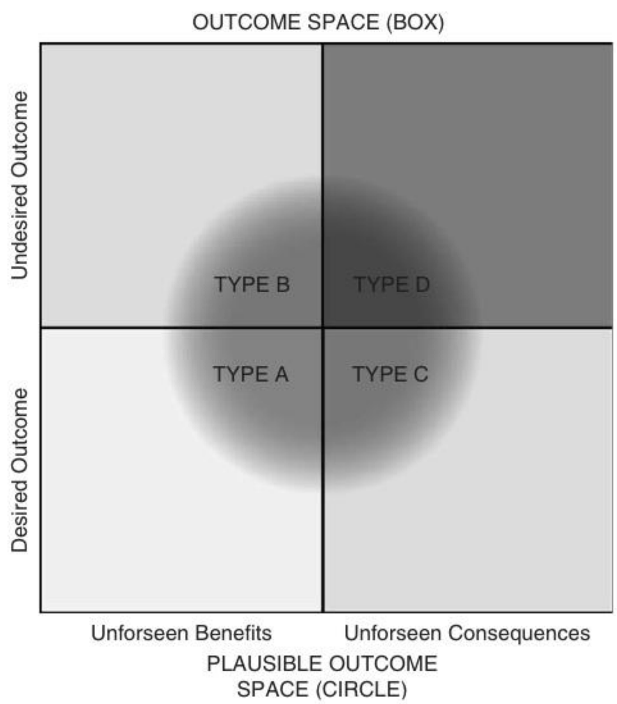

Figure 38. A mapping of the plausible outcome space as a result of a restoration action. The inner circle of plausible outcome space can be larger or smaller depending on the level of knowledge and types of uncertainty (Sear et al. 2008). In this diagram, the plausible outcome space gives equal weight to a Type A, B, C or D response. However, specific design strategies can be used to shift the bulk of this plausible outcome space at least towards the bottom half, if not also the left half.

We cannot predict when the next big flood (e.g., recurrence interval > 25 years) will occur in the Asotin. However, we hypothesize that a bigger flood might increase the heterogeneity of the study creeks. Moreover, we expect that unlike the current condition, the study creeks should be more dynamic and less likely to revert back to its current state. If the watershed were to experience a major flood with the DWS in place, the flood waters would encounter more roughness elements (slowing the flood wave and promoting more flooding of the riparian) and to the extent it scoured some DWS, it would have more tools to work with. Although it is plausible that a single flood could wipe out all the DWS structures, this is highly unlikely. It is more likely to rearrange them and potentially consolidate them into larger debris jams.

We do not need to predict the future exactly, instead we are relying explicitly on a dynamic design, which as Figure 36 suggests, makes it even more difficult for us to predict the precise system state in the future. However, by accepting a greater degree of variability in this response, and allowing the stream to behave more dynamically, we maintain that this is another means by which we can constrain and shift that plausible outcome space (circle in Figure 38) down into the lower left.

6.2 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. This forest will be dominated by native species, have a diversity of seral stages appropriate to the natural disturbance regime of the vegetation and ecosystem type types they represent, and provide a suite of attributes that will benefit the streams they border. Many of these goals will require coordination with landowners and management agencies and will take many decades to fully realize. However, the IMW project will attempt to initiate the process of riparian restoration with a series of activities designed to remove immediate stressors and promote long-term recovery. The main tools at our disposal to start this process are fencing, planting of native species, control of introduced species, and thinning of existing alder forests to promote conifer and cottonwood regeneration. The specifics of the riparian restoration design have not been articulated herein for two main reasons: 1) we have only recently acquired aerial imagery of the entire study area, and 2) the ownership and status of the riparian areas of Charley Creek are in a state of flux. We expect to be able to provide more detailed restoration planning once the aerial imagery has been assessed and the ownership status of Charley Creek is resolved (Note: there are negotiations underway to purchase private property in Charley Creek and other portions of private property in Charley Creek may be enrolled in the Conservation Reserve Enhancement Program which would change the need for the IMW to prescribe restoration actions).

The specific objectives of the riparian restoration actions of fencing, planting, weed control, and thinning are to:

1. Minimize grazing activity in riparian areas to allow natural recovery,
2. Speed up recovery by planting native species,
3. Remove competing non-native species to allow natural recovery, and
4. Create gaps in the alder forest to allow the re-establishment of conifers and cottonwood trees that will eventually be a source of LWD.

In the short-term, we propose to add LWD to the study creeks at densities similar to mean reference conditions. The goals of the DWS 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. Thus, we will be introducing Dynamic Woody Structures (DWS) to the stream.

The specific objectives of the LWD treatments are to:

5. Increase channel width variability (Figure 37),
6. Increase instream habitat diversity (e.g., fish cover, pool frequency and depth), and
7. Promote mobilization of and sorting of sediment by encouraging bar development, bed scour, bank erosion, and substrate sorting.

6.3 Proposed Restoration Treatments

6.3.1 Short-Term Restoration: Instream Dynamic Woody Structures Design and Location Criteria

To improve instream habitat in the short-term we propose to install Dynamic Woody Structures (DWS) at high densities within three 4 km treatment sections (Figure 3). The addition of DWS is intended to create a more complex array of habitat and provide the stream with the material necessary to "build" habitat. We will test three types of DWS variants to determine which structures are the most effective at creating pools and fish cover, and ultimately increasing fish production. The three basic designs we propose are:

1. DWS (wooden posts only)
2. DWS with LWD additions
3. Whole trees or LWD (no posts)

All three designs are expected to constrict the flow locally and induce the response shown in Figure 39. The exact location of these DWS will be determined in the field by a professional geomorphologist who flags each structure location ahead of the installation team, and uses a proforma to record critical placement elements and instructions to the installation team. The DWS locations will be flagged, their locations recorded via GPS, photographed, and a decision will be made in the field on placement type (1-3 above). This will take place approximately 1-4 weeks ahead of the installation effort as to allow adequate time to prepare and stage the installations. Although a detailed design of every structure is possible, a critical element of this IMW and treatment approach is to test to what extent a simple in-the-field design procedure can be successfully implemented. Detailed designs are very expensive, and the extent to which we can demonstrate that a simpler/cheaper design process is possible will help in the eventual transferability of results from this IMW. We believe that undue focus on a specific structure misses the point of this restoration project. While we can likely predict the plausible range of responses explicitly for each structure, the behavior around an individual DWS is nowhere near as important as how all these DWS function in concert. The instructions for placement summarized in the professional geomorphologist's proforma will include approximate guidelines on:

- The side of the channel on which the DWS will hinge
- Rough angle of DWS (i.e., 90° vs. 120°)
- Rough percentage of flow width to constrict

- Highlight any critical features to work with (e.g., anchoring off an existing boulder or root wad; directing flow at a bank with excellent alluvial source material to supply downstream bar development; directing flow at potentially recruitable trees).

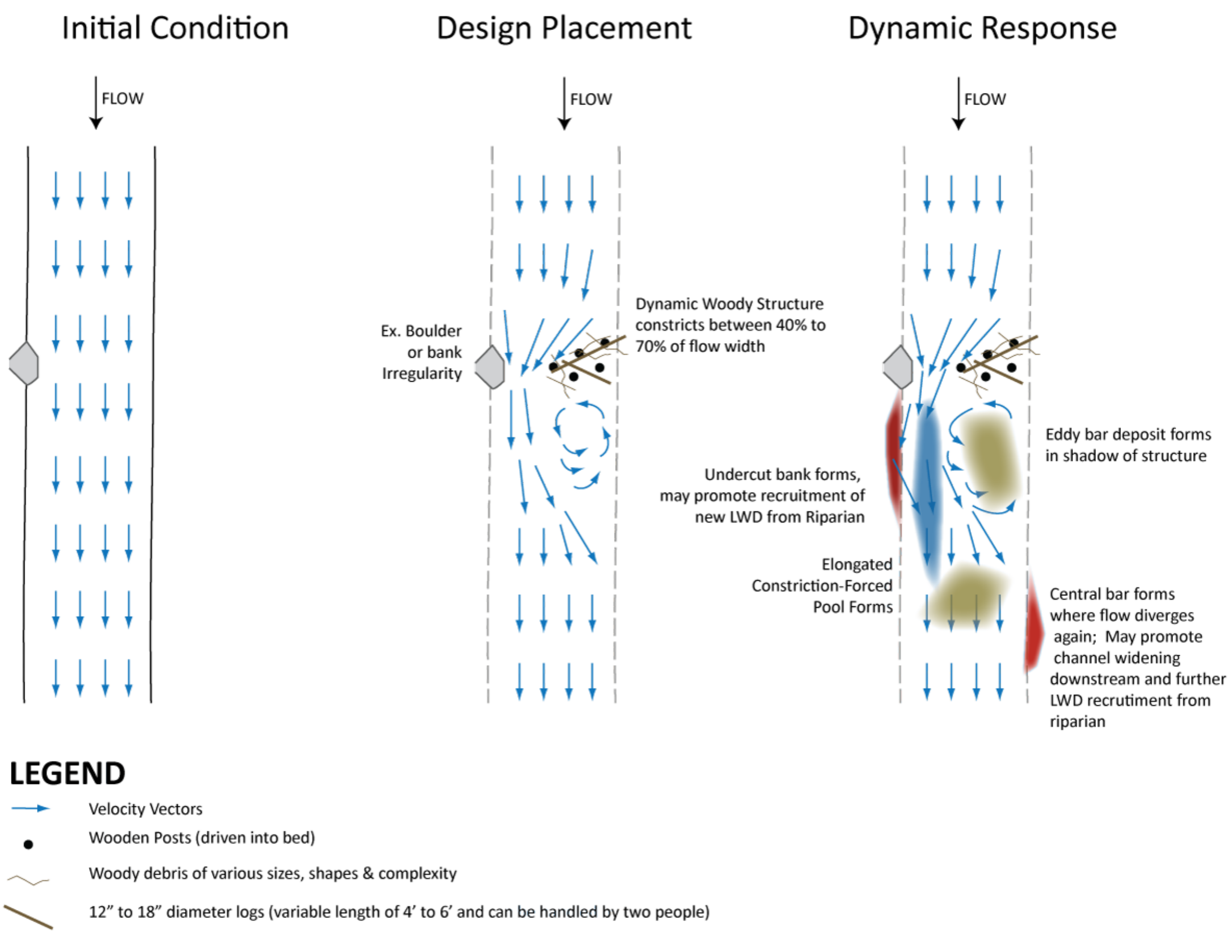

Figure 39. Schematic of the potential response to DWS placement or whole trees added to a relatively simple plane bed channel to constrict the flow. The constrictions in flow will be created by either post deflectors, post deflectors with LWD added to increase their complexity (pictured above), or whole trees.

The three different DWS designs are described in sub-sections below, and the judgment for where to place which will be based on a combination of i) logistical constraints, ii) natural opportunities, and iii) testing how different DWS might work in concert with each other. Additional criteria are more generic design guidelines provided in subsections §6.3.2.1 through §6.3.2.3 and in Figure 40.

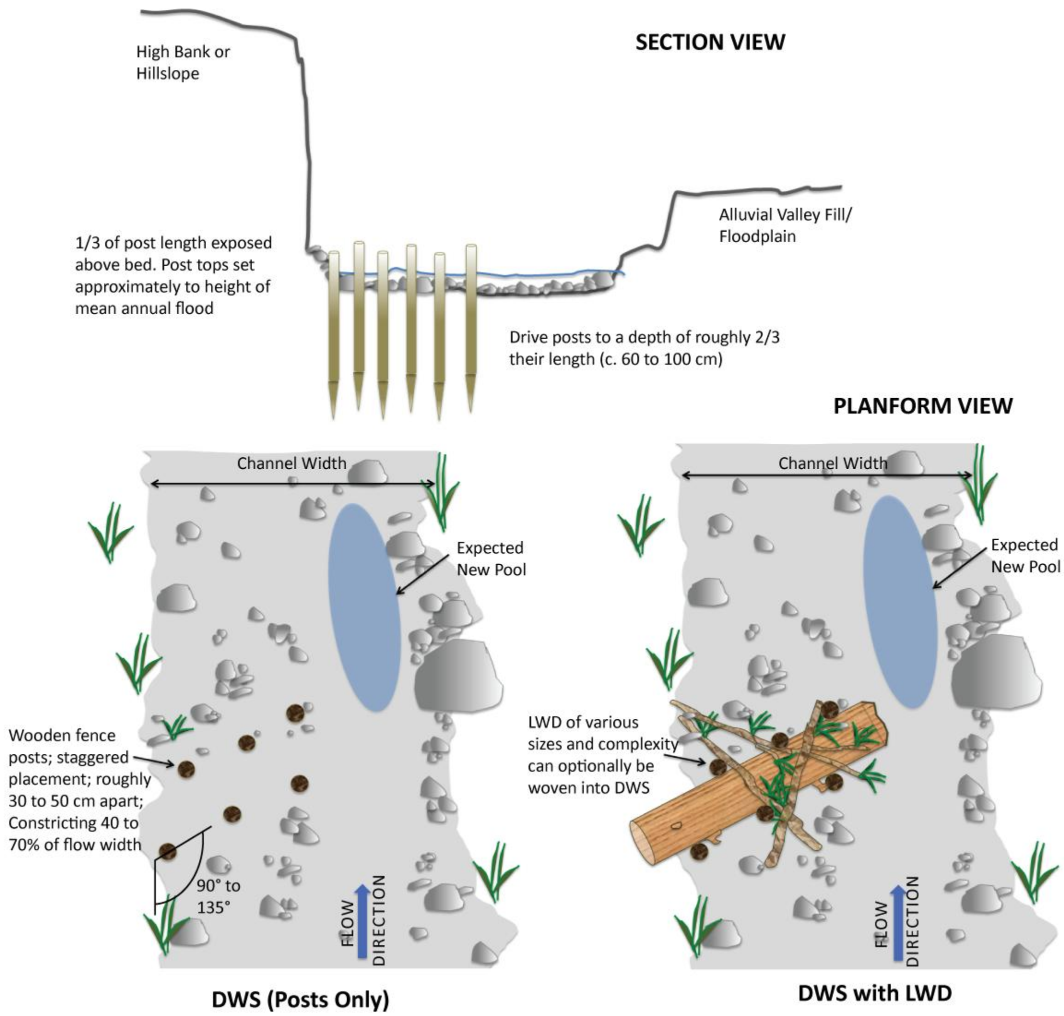

Figure 40. General design schematic for installation of dynamic woody structures (DWS).

6.3.1.1 Dynamic Woody Structures (wooden posts only)

DWS with only posts 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). In this restoration plan we are proposing the use of DWS to act primarily as surrogates for high concentrations of LWD and/or as temporary anchors for LWD (Montgomery et al., 2003). There overall functional roll at the section scale is to act as large-scale roughness elements that increase stream width variability, and promote higher degrees of habitat complexity. At the local scale they are designed to induce an immediate influence on the hydraulic flow field that forces convergent flow past the structure itself and subsequent divergent flow paths downstream of the structure (Figure 39).This is expected to be exacerbated at high flows to the point that it promotes a geomorphic response in terms of bed scour and/or bank erosion where flows are concentrated, and deposition of sediment and construction of bars where flows are divergent. Also at high flows we expect natural woody debris and LWD that we added to upstream structures to accumulate on some downstream structures. The dynamics of woody debris moving and being captured at some structures will further accentuate the hydraulic response at some structures. The geomorphic response is intended to increase the variability in channel width and depth and promote and sustain more complex habitat development and evolution. These structures are termed 'dynamic' because we fully expect them to evolve, wash-out, migrate, become part other structures, or reform in their own natural debris jams at places of the creek's choosing.

The basic design calls for 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 40). 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 are to be 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. 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 once the posts are driven in the stream substrate. While not catastrophic, the posts ought to last long enough to act as a trap for debris and kick start the geomorphic response we are seeking.

This installation method is designed to be possible with mostly hand tools and labor. The posts and LWD will be stockpiled near the installation areas. The LWD will be donated by the USFS from blow-down and beetle killed trees within the Asotin Creek watershed, and cut to 2-3 m lengths that can be loaded onto a trailer by 2-4 people and transported to the restoration sites (Figure 41). The only equipment required for installation is a hydraulic post driver to pound the posts into the stream bottom, a chainsaw to trim the posts, and an ATV to transport posts and equipment when the sites were not near a road (Figure 42).

Figure 41. Example of the transportation mode and size of LWD that will be used to build Dynamic Woody Structures during the Asotin Creek IMW restoration.

Figure 42. Example of the hydraulic post driver that will be used to install DWS in Asotin Creek.

The post driver can be manipulated by two people and has a 25 m hose connected to a gas engine power unit (Figure 43). 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 power unit can also be carried by 2-4 people when the terrain is too rough for wheeling.

Figure 43. Example of the hydraulic power unit used to power the post driver for installing DWS in the Asotin Creek Watershed.

Posts will be driven into the substrate using the general dimensions outlined in Figure 40. 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 we remove the post and attempt to drive it in another spot. We construct a structure with a relatively complex configuration of posts using an alternating arrangement of posts to enhance the likelihood that the structure catches woody debris moving downstream.

6.3.1.2 Dynamic Woody Structures with LWD

The DWS with LWD design is the same as the DWS (posts only) design except in this case we will add LWD to the structure (Figure 40). The addition of wood may produce a more immediate hydraulic response, and increase the amount of scour and bar development associated with the structure, and subsequently provide fish cover. When possible branches will be kept on the LWD and/or branches will be added to the structure to simulate natural LWD. We will also align the LWD to lock it in place on the post (i.e., cross several pieces within the spaces between the posts) to aid in securing the LWD in place temporarily (see successful examples of this in the trial installations in §4.4). The intent is not to permanently anchor the LWD (as is frequently done with cables), but instead to promote the likelihood that the LWD and structure remain in place long enough to produce a geomorphic response at flood flows. We will use pieces of LWD that can be handled set in place with 1-3 people to limit the disturbance to existing riparian vegetation.

6.3.1.3 Whole Trees

Whole trees are being used as a restoration treatment throughout the Snake River Salmon Recovery Region (S. Martin, Pers. Comm.). We will use whole trees as a part of the restoration where possible without causing significant damage to the existing riparian vegetation. Elsewhere, we may opportunistically harvest whole trees from thick areas of the riparian corridor and use them in the stream as close to the location of harvest as possible. In some cases, trees may be felled from the riparian corridor directly into the channel, in other areas they may be dragged by a crew of three to four laborers into the stream. The same criteria will be used to select sites for whole tree additions as for DWS. It is anticipated that the whole trees will be less mobile than DWS, as they will be anchored by large portions of the tree being on the bank and/or the overall size of the tree compared to bankfull width of the channel (Montgomery et al., 2003). We will only use heavy machinery to move whole trees into the stream if it can be done without damaging the existing riparian habitat.

6.3.2 Long-Term Riparian Restoration Approaches

Restoring riparian function can take many years due to the time it takes native vegetation to grow to maturity in previously disturbed areas. Large portions of the current riparian forests are dominated by young alder, water birch, and some willow, especially along Charley Creek. This woody vegetation likely provides adequate shading and organic and terrestrial invertebrate inputs tend to be higher in alder dominated streams relative to conifer dominated riparian areas (Wipfli 1997). However, the riparian forests in the study creeks appear to provide few larger LWD pieces (i.e.> 30 cm diameter). Smaller diameter LWD tends to decay faster than large pieces and may be transported from the reach by fluvial processes causing overall LWD abundance to remain low until mature conifers develop (Beechie et al. 2000). If the current riparian forests are not contributing sufficient amounts and sizes of LWD to the stream we would expect to observe fewer LWD pieces and resultant pools in the Asotin Creek Watershed than are predicted for similar streams in reference conditions (i.e., natural conditions unaltered by development). Indeed, our fluvial audits found that both LWD > 30 cm diameter and deep pools were substantially lower than reference conditions (Figure 17 and Figure 18).

Some of the most impacted sections of the study creeks are those areas where active cattle grazing still takes place (e.g., Charley Creek). Nearly the entire watershed was heavily grazed in the past; however, grazing pressure on the study creeks is much lower now. Private property along Charley Creek has the most active grazing and numerous horses are also wintered there. The riparian zone along the North Fork and South Fork is mostly intact and recovering due to improved management and current ownership by WDFW and the USFS. However, there are still portions of these two creeks that have highly disturbed riparian areas, or areas that are dominated by alder, and which are not providing LWD pieces to the stream. Further assessment of the condition of the study creeks riparian zones is necessary before we can develop detailed reach-by-reach prescriptions. A riparian assessment will be undertaken and a more detailed plan provided in the future (see below). Until then, we provide a general outline of which riparian restoration methods will likely be used.

The primary riparian restoration treatment is one of passive recovery, which will be facilitated by more regular exchange between the channel and the riparian environment as promoted by the more active restoration intervention with the DWS in the channel. Opperman and Merenlender (2004) showed that riparian restoration can be an effective means of restoring instream fish habitat, promoting LWD recruitment and encouraging fluvial processes to ‘do the work of restoration’. The passive treatments will be either direct fencing exclosures, or removal of grazing, depending on land ownership and management agencies requirements. The majority of the mainstem of Asotin is fenced, or cattle are managed to minimize disturbance (ACCD 1995, ACCD 2004). We will coordinate with local managers to develop an IMW specific riparian management plan.

The potential design of the fencing exclosure(s) would use the following design criteria:

- Only use a fence if absolutely necessary as they are expensive and can have unintended consequences. Reasonable alternatives include i) locating off-stream water troughs in areas easily accessible to the herds that deter them from needing to enter the stream, ii) effective management of herds (e.g., lower densities or shorter periods of access)
- The layout of the fencing should be such that it does not segment the riparian corridor and become an unintended barrier to wildlife migration
- Access gates should be provided to allow wildlife free passage when livestock are not present, and provide access for monitoring crews
- In areas where invasive plant species are or prove to be a major concern, the ‘exclosure fencing’ may be used as short-term, targeted, high-intensity ‘enclosures’ for using livestock to help knock back invasive plants at critical times of year.

Once the immediate stressor of grazing and/or land disturbance within riparian areas are removed, more active restoration activities will be initiated. These activities will include planting, non-native species control, and riparian thinning. In areas devoid of vegetation planting will be the most effective treatment if it is matched with measures designed to prevent wildlife damage to the seedlings during the first few seasons of growth and potentially watering or fertilizing to promote rapid establishment. Again, there is extensive knowledge of these treatments within the watershed from previous work on the Model Watershed Plan and we will draw heavily from past work (ACCD 1995, ACCD 2004).

There are some extensive areas of scotch thistle invasion along Charley Creek. The USFS has already begun a control program and has donated time and money to this issue. We will continue to work with the USFS, WDFW, Asotin County, and private landowners to develop and implement an invasive weed control program, especially where it relates to riparian vegetation reestablishment.

A final active treatment action that we are proposing is riparian thinning. We have noted that there are many areas of all the study creeks that have a well-established riparian community. However, a substantial amount of the established riparian zones are dominated by alder trees of 3-10 m in height. These alder stands are providing excellent shade and allochthonous inputs to the streams but may be preventing reestablishment of other tree species that would have been native to the riparian and floodplain zones (e.g., cottonwood, Douglas-fir, spruce, and ponderosa pine). Selective thinning (i.e., opening small gaps in the stands) could allow the creation of a more diverse riparian vegetation and larger trees species. This is analogous to gap theory in forest ecology and is well supported in the literature (Hartshorn 1989, Lertzman 1992). The purpose of the thinning is to disturb the currently stable and homogenous corridor, without robbing it of all its important structure and function, and to create opportunities for the diversity of the riparian zone to improve (in terms of both species and age structure). The thinning could also dove-tail nicely with LWD additions we are proposing by becoming a source for small and large woody debris on site. This proposed treatment will require discussions with local foresters to develop a more detailed prescription.

6.4 Extent of Restoration

The original hierarchical-staircase design was revised from a restoration of 12 km all in one stream to three 4 km sections (one in each stream) after extensive evaluation of the power of different experimental designs to detect changes in fish abundance (Loughin 2010). The revised experimental design has approximately 80% power to detect a 12-15% change in abundance based on the mean variance calculated from 15 years of historic juvenile abundance data. The revised design still had 80% power to detect a 30-35% change in abundance under a "worse-case" scenario where the upper limit of the 95% confidence intervals of the variance was used to estimate power. The proposed extent of restoration assumes that a 4 km treatment in each stream will be sufficient to cause a population response. If there is not a detectable response, we may choose to increase the extent of the treatments (i.e., > 4 km). We will review this each year to determine if a larger section needs to be treated, in line with our adaptive management strategy (Section 1.3).

We estimate that approximately 53 pieces of LWD/km would need to be added to each study creek to equal the mean reference conditions (Table 12). This equates to approximately 211 pieces of LWD for each 4 km proposed restoration section. The exact number of structures have not been determined but we expect approximately 200 structures/section to be installed with an average of two 2-3 m pieces of LWD per structure (we are using short pieces of LWD to allow hand placement of the structures). The spacing between structures will average 20-40 m apart depending on the stream. We propose to install 75-85% of the structures as DWS with LWD added and 10-15% of the structures as whole trees or very large complexes of LWD. The remaining DWS will be posts only, with no LWD added. This will allow us to inter-compare the effectiveness, time to response, and practical utility of slightly different installation techniques. All these DWS treatments are geared to increase the overall density of LWD and directly influence the local hydraulics.

Table 12. Approximate number of pieces of LWD by size class that would need to be added per km and restoration treatment section in the Asotin Creek IMW study creeks to equal the mean density of LWD in reference conditions.

LWD Size Class (cm)	LWD to add per km	LWD to add per 4 km section
<=30	0	0
30-40	25	99
40-50	18	72
>50	12	46
Total	53	211

6.5 Design Hypotheses and Expected Responses

Throughout this document we have introduced both explicit and implicit hypotheses about the expected response to the DWS treatments. Here we try to distill those down to a short list of explicit design hypotheses, which can be used to guide our monitoring efforts. 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 (See § 5.1). From this understanding of the current stream conditions we generated a vision of the restored condition (see § 5.2) that we then used to form specific, testable hypotheses, and a monitoring program to test those hypotheses.

It should be noted that hypotheses regarding the potential responses of the riparian habitat are not fully developed in this restoration plan because we are in the process of analyzing the aerial photography and LiDAR imagery that was collected by Watershed Sciences Inc. (WSI 2012) in September 2011. We expect to refine the riparian restoration hypotheses more once we have completed some more detailed assessments of their current condition and we may need to fine tune DWS hypotheses once we have the results (short-term) of the 15 trial structures that installed in August 2011.

We recognize two important plausible “responses” of the DWS 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.

6.5.1 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. 2008); however, the long-term effectiveness of this restoration approach has rarely been evaluated beyond determining a structures durability (Roper et al. 1998). This IMW has the unique ability track the function of DWS 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 (§6.5.1.1), how we expect different structures to work together in concert over the longer-term (§6.5.1.2), and finally how this will interact with the riparian zone and floodplain (§6.5.1.3).

6.5.1.1 Short-term response at individual structures

The individual DWS are designed to produce an immediate hydraulic response by constricting the flow width. Immediately following placement of the structure we hypothesize the following physical responses (summarized graphically in middle diagram of Figure 39):

A) Shift from uniform flow pattern to convergent flow pattern concentrated on opposite side of channel as structure and the main zone of convergence will be slightly downstream of the structure. The intensity of this convergent jet will scale roughly with the degree of blockage the DWS causes (i.e., bare posts vs. LWD woven in, vs. amount of channel restricted by the structure; e.g., Figure 28).
B) An eddy will form in the wake of the DWS and extend downstream on the same side of the DWS roughly as far as the jet from the convergent flow extends.
C) Downstream of the main zone of convergence and the eddy, the flow paths will strongly diverge.
D) We do not expect any significant geomorphic adjustment in response to these hydraulic changes at base-flows, however we do expect the overall hydraulic heterogeneity of the flow field to increase.

In response to high flows, we hypothesize the following potential responses (summarized graphically in right diagram of Figure 39):

E) If woody debris is transported by high flows, we expect some of it to accumulate on the DWS.
F) We expect scour and formation, accentuation, or maintenance of a longitudinally-elongated constriction-forced pool associated with the convergent flow patterns, and the deepest portion of the pool to form directly downstream of the main zone of convergence. The pool will likely persist as long as the DWS persists.
G) If any of the convergent flow is directed at the bank opposite of the DWS, and the bank is readily erodible, we expect bank erosion and/or an undercut bank to develop. We expect the fine fraction of this source material to be winnowed away quickly and coarse fraction to be deposited in the next 1-4 bars downstream (at the individual flood event time-scale), with most being deposited in the first bar.
H) Depending on the flow geometry and sediment load, the eddy may act as a pool, or may become a zone of finer sediment deposition. In the case of an ample sediment load, an eddy bar may form. The size of the eddy and development or persistence of any eddy bar deposit will depend very much on the porosity and configuration of any woody debris existing or racking on the DWS.
I) Where the flow path becomes highly divergent downstream of the convergent flow jet and eddy, we expect an active gravel bar to form. The flow and channel geometry will determine whether the bar is a mid-channel bar, a bank-attached bar, or riffle. If the local coarse sediment supply is adequate, and a riffle forms, the riffle crest may rise and accentuate the pool depth of the upstream pool.
J) Depending on the degree and geometry of the bar growth, this may promote strongly convergent flow patterns downstream of or adjacent to the bar, which may in turn form, accentuate and/or maintain a bar-forced pool.

We hypothesize that the high-flows will result in the following geomorphic changes:

K) Greater variability in channel & flow width.

L) A low-flow water depth distribution with at least a 2-3 fold increase in range, and potentially an 5-10 fold increase in the variability of water depth (i.e., change from a uniform depth profile to a highly variable depth profile with shallow riffles, moderately deep runs, and deep pools).
M) Greater diversity in the type of geomorphic units and a larger number of geomorphic units.
N) An increase in both the amount of erosion and deposition, without necessarily causing a change in the net sediment budget (i.e., relative balance of erosion and deposition).
O) An increase in the presence of structural cover for fish provided from deep pools, woody debris and undercut banks.
P) An increase in the number, size and proximity of shear zones to important habitat elements (e.g., pools and undercut banks), resulting from DWS, LWD, bank irregularities and variation in channel width.

The responses hypothesized above may vary significantly if the configuration or integrity of the DWS is undermined. A specific set of cases where this could happen are 1) if a significant portion of the high flow goes through the structures as opposed to around them, 2) flow is separated into strong convergent jets around both sides of the DWS, 3) if there is a significant lateral adjustment to the banks or an avulsion, and 4) if the structure is washed out entirely. If the DWS does not cause a convergence of flow (case 1) we expect the channel and flow conditions will remain unchanged. If flow splits around the DWS or the stream shifts laterally (case 2 and 3), it will be difficult to predict the precise response (i.e., hypotheses A – I), but the responses will likely be systematic and relatively easy to infer. In these situations, although our specific predicted responses will not be realized, the overall changes to the channel will likely be realized (i.e., hypotheses J through O). If, by contrast, the DWS are washed downstream (case 4), we expect the channel to either:

Q) Quickly revert back to the pre DWS condition; or
R) Follow a similar progression to hypotheses A-I, resulting in J-P, but focused spatially around wherever the DWS material we added accumulates downstream (i.e., on another DWS or natural location).

The above hypotheses outline a specific set of responses and alternative responses. Note that in the worse-case scenario, hypothesis Q is realized. Hypotheses A-D should be testable immediately following installation. Hypotheses E-R should be testable after the first competent flows. The trial DWS structures will have been in place roughly 9 months by the time we resurvey them. Our ability to test E-R has been increased by the large magnitude of the flows during March (see Section 4.4.4.).

6.5.1.2 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 DWS. We expect the DWS to be ephemeral on the time frame of 1-5 years). Our most fundamental hypothesis at the site-scale over the long-term is that:

S) The overall concentration of DWS will be so high that when an individual DWS 'fails' 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 DWS or LWD jam, or some distance likely not more then 1-4 DWS or LWD jams downstream. Those building blocks at their new location are then likely to result in conditions similar to those hypothesized in P-Q above.

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:

T) The LWD used in the initial placement of the DWS will break down, but the benefits of hypotheses P-Q will be self-sustaining if natural LWD recruitment roughly matches the rate of breakdown.

U) 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 (i.e., hypotheses E-J) is likely to have cumulative effects that help support hypotheses T & U. Specifically, we expect:

V) 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 (U). Also, woody debris will be recruited from the riparian areas during floods and some debris will be deposited in riparian areas.

In summary, the desired habitat conditions to increase the growth and survival of juvenile steelhead are largely reflected and predicted in hypotheses K-P. ***In the long term we expect the dynamic woody structures to become a part of the study creeks that is more dynamic, resilient, and regularly adjusts to switch between alternative stable states, which maintain a diversity of habitat types, and support increased steelhead production (i.e., Figure 36).***

6.5.1.3 Riparian Hypotheses and Expected Responses

We do not expect significant short-term responses to large amounts of the proposed riparian restoration due to the length of time it will take for the riparian forest to respond and the limited length of the IMW (e.g., expected completion of monitoring in 2018). The most immediate response may come from opening gaps in the existing stands of alder and planting cottonwood and native conifer species. Fencing, planting (in areas with little vegetation cover), and weed control will all be more long-term efforts that may show significant responses in several decades. 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 DWS, 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.
- 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.

6.5.2 Fish Hypotheses and Expected Responses

The goal of the restoration treatments are to increase the productivity of wild steelhead in Asotin Creek**.** We are most interested in the production of juveniles (pre-smolts) and smolts (presumed out-migrants) at the fish site, treatment/control section, stream scale, and watershed scale. Although there are interesting patterns of habitat utilization at the individual-structure scale that we could study, most of our hypotheses focus on processes and phenomena more commensurate with our fish sampling design at the fish site and stream scale. Fish production is a more informative 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). Measuring the juvenile and smolt production of salmon and steelhead 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 (Horton et al. 2009).

In streams west of the Cascades where steelhead coexist with coho salmon (*O. kisutch*), steelhead do not appear to respond to the addition of LWD during the summer, but do respond positively during the winter by both increased winter abundance of juveniles and increased smolt production from treated sites (Solazzi et al. 2000, Roni and Quinn 2001). By contrast, in early studies in Asotin Creek, steelhead abundance increased in the summer after the addition of LWD but winter abundance and smolt production were not measured (Viola et al. 1998). Asotin Creek is on the east side of the Cascades, and these streams are more likely to have low flows during the winter due to cold temperatures and more precipitation in the form of snow (although infrequent, but large flows can result from rain-on-snow events). These assessments of the effectiveness of LWD treatments suggest that the response of steelhead may vary depending on the stream type and the presence of other salmonid species. For example, steelhead are known to select riffle habitat in the summer and pool habitat in the winter when coexisting with coho (Hartman 1965, Bustard and Narver 1975, Bisson et al. 1982) which may explain the differences in study results in Asotin Creek where coho are absent.

To add to the complexity of predicting how production will be effected by the proposed restoration, there are multiple pathways by which changes in habitat conditions (predicted in previous section) can alter production (Figure 44). Our fish and habitat monitoring programs may help untangle some of these complex interactions, but we may not be able to fully describe all pathways.

Below we propose a set of specific fish response hypotheses that directly relate to the hypothesized habitat responses above. Our adaptive management approach and its monitoring will help refine these hypotheses further. In contrast to the predicted habitat responses, the fish responses are more appropriately differentiated by life stage and the spatial scale of our fish monitoring. For a brief outline of the fish monitoring program see Section 7 and for a complete description of the IMW fish monitoring methods see Bennett et al. (2012 in preparation).

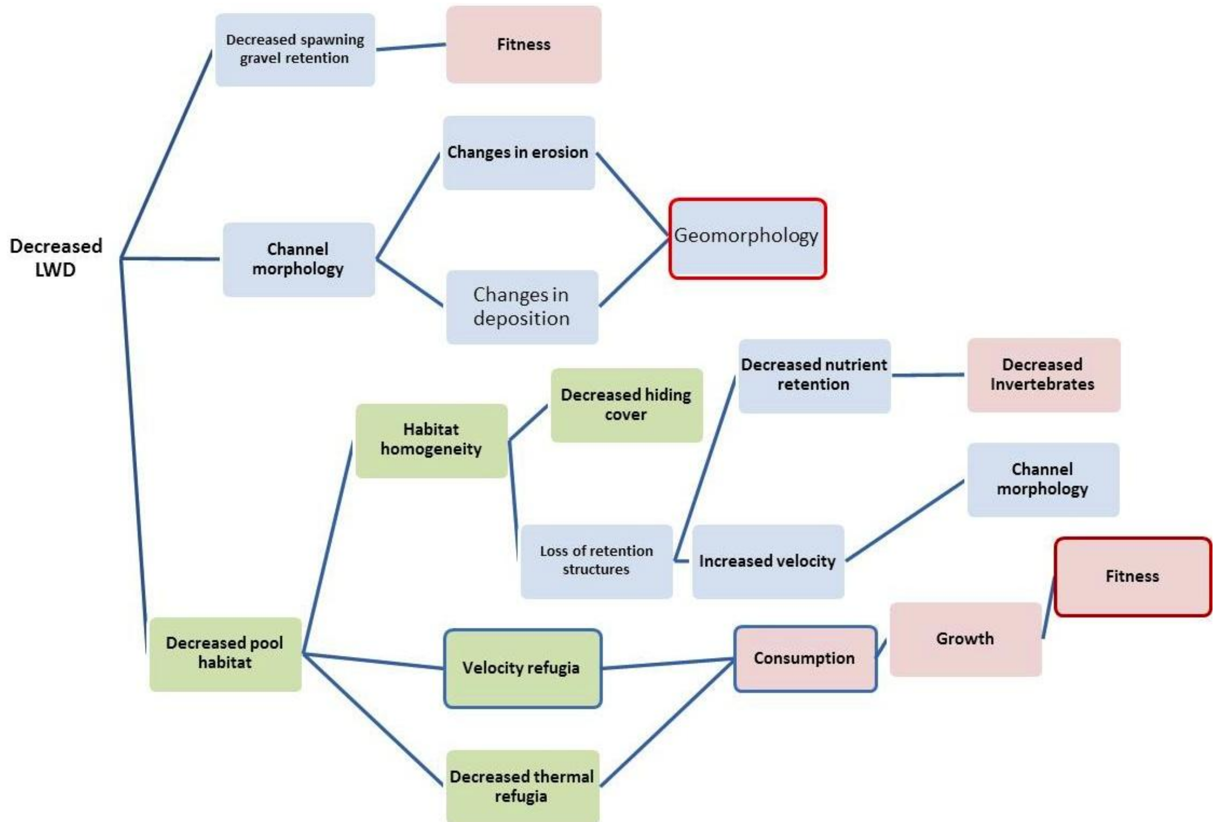

Figure 44. Conceptual framework of the consequences of decreased LWD supply on stream process and habitat types thought to be critical determinants of individual and population fitness and ultimately production. Reversing the effects of decreased LWD by installing dynamic woody structures can increase population fitness and production through multiple pathways and synergistic interactions.

6.5.2.1 Hypothesized site, section, and stream responses

The majority of our fish sampling occurs at the 12 permanent fish sites we have established (Figure 3**). At these sites we are estimating juvenile age, abundance, growth, and survival by cohort over all seasons (i.e., total biomass/period). 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 we are measuring are most likely to change. 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 13).**

Table 13. Hypothesized responses in juvenile and adult population parameters and the associated causal mechanisms and habitat changes from the installation of dynamic woody debris 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/m2	+	++	- predation, +survival	+ pools, cover	MR
Growth (G)	g/g/d	++	++	+ feeding efficiency	+ shear zones	MR
Survival (S)	%	+	++	- predation,+G	+ pools, cover	MR, PIT
Movement	m	-	-	- searching micro-habitats	+habitat diversity	MR, PIT
Production (Pj)	g/m2/month	+	++	+ A,G,S	+ carrying capacity	NREI modeling
Production (Ps)	recruits/spawner	+	++	+ Pj	+ carrying capacity	AW, MR, PIT, SS
Adults/Redds	count	N/A	++	+local hydraulics	+ bars, sediment sorting	AW, PIT, SS

* Responses are trending positive (+), significantly positive (++), trending negative (-), significantly negative (--), unknown (?); Pj = juvenile production (pre-smolt), Ps = smolt production; Monitoring methods are AW = adult weir, MR = mark-recapture, PIT = PIT tag detections due to capture, mobile surveys, and traps, SS = spawning surveys , TR = adult weir and smolt traps.

We hypothesize that at the scale of the fish site, treatment section, and stream juvenile production (pre-smolt) will increase. We expect the increase to occur more strongly during the winter and spring periods. Increases in growth and/or survival will result from i) an increase in shear zone refugia which enhances feeding efficiency; and/or ii) increases in fish cover which can increase survival due to decreased predation threat and refugia from high flow events. The increase in shear zone refugia, cover, and habitat diversity will lead to an overall increase in the carrying capacity of the treated sections. Based on observed increases in fish abundance from similar LWD treatments we predict that production could increase 25%-50% relative to the control sections after controlling for the number of spawners and other changes in habitat not accounted for by using the control watersheds (Viola et al. 1989, Roni et al. 2001). The positive increase in juvenile production should lead directly to an increase in smolt production as the survival and overall production from the juvenile to smolt stage should also increase as a result of juvenile production.

6.6 Cost Estimates

The DWS method will generally have lower costs than more engineered approaches and the installation of whole trees due to the use of hand tools and easier access to stream locations with minimal damage to existing riparian forests (Table 14).

Table 14. Comparison of implementation costs and logistics of dynamic woody structures (DWS), wholes trees, and typical engineered LWD structures.

Item	DWS	Whole Trees	Engineered Structures
Design (typically detailed)	Low	Moderate	high
Purchase of Wood	Low – high (depending on sources, small pieces can be used that are generally cheaper)	High	Moderate to high
Transport of Wood to site	Moderate	High	High
Onsite installation (i.e., excavator, crane, etc.)	N/A	Moderate to High	High
Onsite Access (i.e., cutting a road to get from road to stream bank)	N/A	Moderate to High	Moderate to High
Construction Observation	Low	Low – Moderate	High
Mitigation of Access through Riparian (e.g., erosion control, replanting, road removal)	N/A	Low – Moderate	High

Based on the trial restoration this summer, we estimated the actual costs of each element of the installation process (Table 15). The costs of the LWD and the post driver are currently being donated to the IMW project. If we have to purchase these items in the future it will increase the costs of the treatments, but the cost should still be relatively lower than whole-tree engineered approaches.

Table 15. Cost estimate of installing 150-200 dynamic woody structures (DWS) and LWD to a 4 km treatment section in South Fork Creek in 2012. Machinery for installing whole trees are not included in this budget.

Work Item	Description and Rational	Unit	No. Units	Cost/ Unit	Cost
Materials					
Peeler Logs	posts used to secure the LWD structure for a short period of time before they decompose	post 4" x 8'	1000	5	4,500
Large Woody Debris purchase*	the USFS will donate wood as a sponsor match as per SRFB requirements	Truck load/transport	200	80	16,000
Hydrualic Post Driver Rental*	rental of IMW post driver to install structures this will be donated as matching funds	Day	30	100	3,000
Misc equipment	misc equipment and supplies, equipment maintenance, driver adapters, chainsaws, etc. (< $1000 in value)	-	-	3,000	3,000
Subtotal Materials					26,500
Installation Costs					
Collection and transport of LWD and posts	rental or hiring of local contractor to collect and deliver LWD and peeler logs to the installation sites	truck and trailer - month	3	1,500	4,500
Vehicle Rental	rental of a 4x4 truck to access sites, carry supplies, transport wood and post pounder, and general use at the project site	truck - month	2	1,200	2,400
Vehicle Rental	rental of two ATV's to access sites, carry supplies, transport wood and post pounder, and general use at the project site	ATVs - month	4	250	1,000
Site selection and flagging	using fluvial audit results to pre-flag areas for structure installation prior to installation crews arriving	Biologist/Fluvial Hydrologist - day	10	743	7,430
Structure Installation	crew of four people to drive posts, cut and transport LWD, and install structures (sr tech and 3 jr techs plus 10/day per diem)	4 person crew day	50	995	49,725
Implementation Monitoring	daily onsite inspections and assessment of implementatioin effectiveness, design review and trouble shooting	Biologist/Fluvial Hydrologist - day	10	743	7,430
Project management	IMW coordinator time to manage project, meet with landowners, coordinate activities, secure permits, reporting	Biologist - day	40	743	29,722
Travel and Accomodation	IMW coordinator travel to the site from Logan Utah (airfare, accommodation, food)	-	2	750	1,500
Subtotal Installation					**103,707**
Subtotal Total Installation					**130,207**
Contract Administration		year	1	0.15	19,531
TOTAL Restoration Cost					**$ 149,739**

* Donations by USFS (wood donations) and NOAA (rental of post driver) to project

6.7 Implementation Plan

We developed the basic steps required to implement the restoration from the trial restoration and will synthesize those further after a review of the structures during the spring of 2012. We have outlined the steps and the approximate timing of the implementation activities in an annual schedule that can be repeated for each of the three sections that are proposed to be restored starting in 2012 (Table 16).

Table 16. Schedule for the annual implementation of a restoration treatment in one of the study creeks in the Asotin Intensively Monitored Watershed. The first 4 km treatment will be implemented in 2012 and the next two treatments are expected in 2013 and 2014.

Task	Date	Description
Apply for restoration funding	November – December year prior to installation	Submit a proposal to the Salmon Recovery Funding Board or other entity for restoration funds.
Identify and secure source of LWD	January – March 6 months prior to installation	Acquire source of LWD (USFS has already indicated a supply is available from Umatilla National Forest).
Stage LWD near site	January – March 6 months prior to installation	Transport LWD to staging area near restoration site (WDFW owns land in area and has agreed to allow storage of LWD).
Permit Application	January – March 6 months prior to installation	Apply for federal, state, and county permits to conduct the instream restoration.
Supplies and field crew	May - June 2 months prior to installation	Purchase supplies and hire crew for restoration activities.
Resurvey & Assess Performance of Past Structures	May – June 1-3 months prior to installation	Assessing the hydraulic and geomorphic responses to structures installed previously will be an important part of the adaptive management plan.
Structure Placement Reconnaissance & Field Design	June – July One month prior to installation	Conduct site visits prior to installation to flag areas for installation of structures using the GIS data collected during the fluvial audit and further stream assessments based on design criteria.
Prepare structure material	June – July 1 month prior to installation	Stage posts and LWD at treatment section.
Install structures	June – Sept Based on permitting (e.g., Section 10)	a. Use a post driver to install posts as necessary at each flagged installation site. b. Add LWD and branches posts structures.
Assess structures	Year round Effectiveness monitoring will be completed as part of the IMW monitoring program (e.g., CHaMP)	a. Monitor structures to assess safety and property. b. Monitor structures to insure they were appropriately installed according to the restoration design. c. Monitor structures to assess performance.

7 MONITORING PLAN

As part of the overall Asotin IMW, we have a comprehensive monitoring plan for assessing both stream habitat and fish responses to the restoration treatments (Wheaton et al. 2012, Bennett et al. 2012 *In preparation*). Below we outline the main monitoring types we will use to assess physical and biological responses to the restoration. We refer the reader to the above cited overall IMW design report for more details on the IMW monitoring plan.

In the context of our adaptive management approach (§1.3), it is important that the monitoring is driven explicitly by our design hypotheses (§6.5). This creates better opportunities for us to learn from the project, revise implementation and monitoring as needed, and increases the potential for useful transferable scientific knowledge and practical restoration techniques to be shared from this project. We describe our monitoring efforts in terms of those geared to test the habitat response design hypotheses (§7.2) and those geared toward testing the fish response hypotheses (§7.3).

7.1 Monitoring Infrastructure and Methods

The monitoring design is composed of four components: fish, stream habitat, riparian habitat, and stream channel/floodplain monitoring. We are using a set of monitoring protocols for the different components that are either regionally recognized protocols, or monitoring methods that are well supported in the literature, that will allow efficient and precise data collection, data sharing between various agencies, and detection of biological and geomorphological significant changes due to restoration actions. Most monitoring activities are focused on the three study creeks: Charley Creek, North Fork, and South Fork Creeks (Figure 3). All monitoring activities will be integrated with ongoing WDFW's Asotin Creek Assessment Project (Crawford et al. 2011).

Considerations of fish and habitat responses to restoration activities will be most informative if appraised within the appropriate spatio-temporal context of their natural and impacted environments (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. While extensive GIS data are available through various sources, they are not readily applicable to this specific purpose, (i.e., they typically require intermediate to advanced GIS skills to prepare for application specific analyses). To support this end, ELR is in the process of developing the Columbia River Basin (CRB) Biophysical Framework. The ELR CRB Biophysical Framework is an ArcGIS based geo-database, customized map document, and geo-processing toolbox, which combined, provides a user friendly, live mapping utility that can be used to identify, describe and explain the biophysical context for any location in the Columbia River Basin. It is presently being developed specifically for ELR project areas, but can be easily expanded. Development of this framework and its application are based on the River Styles Framework (Brierley and Fryirs 2005) which provides both the conceptual model that places streams into location specific, biophysical context and a set of procedures that can be followed to develop geo-spatial data describing this context for a given reach.

7.2 Habitat Monitoring

To test to what extent habitat hypotheses A-V are supported will require monitoring over a range of spatial scales. We will rely on a targeted blend of detailed, habitat monitoring at local nested sites combined with coarser-grained rapid assessment inventories and remote sensing at the broader project-wide 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 upscale these understandings to the stream and watershed 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.

7.2.1 Monitoring at Habitat Site Scale

At habitat sites we will continue to implement detailed instream topographic and habitat surveys as per the CHaMP protocol (Figure 3; Bouwes et al. 2011). We are proposing to sample 18 CHaMP sites and 18 rapid survey sites each year (Bennett et al. 2012 *in preparation*). A minimum of four CHaMP sites will be surveyed in each treatment section. This equates to 2.4 km of CHaMP surveys and 9.6 km of rapid surveys within the proposed 12 km of treatments, or 20% and 80% sampling effort respectively. Assuming 200 structures will be installed in each treatment section (total of 600), this means we should have direct, detailed monitoring evidence from a sample size of roughly 120 structures. This level of effort will allow us to detect geomorphic change, infer mechanistic responses, and test design hypotheses A-J (Bangen and Wheaton 2012). Moreover, we will be able to derive metrics within the first three years of monitoring that help us test hypotheses K-P explicitly by comparing them with baseline CHaMP monitoring data and ongoing monitoring at control sites (Figure 3). This will afford us a high degree of power to detect significant differences between treatment and control sites. Through time, this will also allow us to mechanistically test design hypotheses Q-V.

7.2.2 Monitoring at Treatment & Control Section Scale

To augment the detailed CHaMP sampling above, we will rely on a rapid assessment inventory performed every year post-treatment, over the entire lower 12 km of each study creek. These rapid assessments should take roughly 1 day for each 4 km section, and will be conducted in a style very similar to the fluvial audits (§3.3). A mix of map-grade GPS with a digital pro-forma and geo-tagged imagery taken with a digital camera will be used to produce a categorical census of DWS performance and fate with respect to design hypotheses A-V. The quality of the data from this rapid assessment will be sufficient to help test most of the hypotheses, and highlight if we're missing anything taking place outside the 18 CHaMP habitat treatment sites. Moreover, the accuracy of the inferences from this data can be independently checked and verified at the CHaMP habitat treatment sites.

- Hypotheses A –D are short-term hypotheses, which only need to be tested during an as-built survey and inventory following installation. By contrast, hypotheses E-J are post-flood hypotheses, which can be categorically and qualitatively tested at each structure each year. Not all of design hypotheses K-P can be tested numerically but some can:
- Greater variability in channel & flow width – *Qualitatively confirmed.*
- A low-flow water depth distribution with at least a 2-3 fold increase in range, and potentially a 5-10 fold increase in the variability of water depth – *Qualitatively confirmed.*
- Greater diversity in the type of geomorphic units and a larger number of geomorphic units – *Counted explicitly. Tested Numerically.*

- An increase in both the amount of erosion and deposition, without necessarily causing a change in the net sediment budget (i.e., relative balance of erosion and deposition) – *Qualitatively Confirmed*
- An increase in the presence of structural cover for fish provided from deep pools, woody debris and undercut banks – *Counted explicitly. Tested Numerically.*
- An increase in the number, size and proximity of shear zones to important habitat elements, resulting from DWS, LWD, bank irregularities and variation in channel width – *Counted explicitly. Tested Numerically.*

Metrics relating to design hypotheses K-P will need to be collected in the baseline monitoring effort at treatment sections as well as at control sections. Fluvial audits every 2-3 years will be used in 12 km of the 24 km control sections, to track these metrics in control areas.

Finally, design hypotheses S, T and V will be easier to test (categorically and semi-quantitatively) at the scale of the entire treatment section as opposed to the habitat sites. These hypotheses will only need to be compared to baseline conditions at the treatment sections to test them. Design hypothesis U will not be readily testable from the rapid assessment data.

7.2.3 Monitoring Trial Dynamic Woody Structures

Our first opportunity to assess the effectiveness of the proposed structures will be a review of the 15 trial DWS. We propose to complete a pre-treatment and post-treatment habitat and topographic survey of each trial structure using components of the CHaMP protocol (Bouwes et al. 2011). We completed the pre-treatment habitat and topographic surveys in August 2011. We recorded the number of posts, alignment of the posts, and the number of pieces of LWD added to each structure. The pre-treatment topographic surveys were completed 25 m upstream and 25 m downstream of each structure (e.g., Figure 19). These data provide a DEM that can be imported into GIS and converted into a water depth layer, stream bottom, and bank height layer that create a 3 dimensional representation of the site. Working in cooperation with ISEMP, the USFS and ESSA we can now use the River Bathymetry Toolkit to quickly generate a host of stream attributes such as W:D, cross-sectional areas, water depths, define pool volume based on different flows. Further analyses such as DEM differencing will allow us to calculate sediment budgets at the site or reach scale. We also used the definitions of LWD and pool habitat outlined in Bouwes et al. (2011) to enumerate all piece of LWD and all pools above and below the structures pre-treatment. Using our fluvial audit methodology (Section 4.3), we also identified all sediment sources and bars at the 15 pre-treatment sites. And finally, we collected multiple photos of each site and created 360 ° Photosynths of each structure (http://photosynth.net/userprofilepage.aspx?user=Asotin_IMW). We will repeat the topographic, LWD and pool, sediment, and photographic surveys as soon as possible after the spring runoff in 2012. Results of these analyses will help inform the full implementation of the restoration in the summer of 2012.

7.3 Fish Monitoring

There are three basic levels of fish monitoring infrastructure: watershed scale, stream scale, and site scale (Figure 45). The WDFW conducts fish-in fish out monitoring for Asotin Creek using smolt trap, adult weir, and indexed redd counts (Crawford et al. 2011). These data have been collected yearly since 2004 and can be used to provide context for the IMW sampling and assess if the production at the watershed scale changes, although the power to detect change at this scale may be low. At the stream scale we have an extensive set of PIT tag arrays, tagging programs, and mobile PIT tag surveys that can be used in conjunction with the WDFW Assessment program to assess stream production (i.e., smolt production from each study creek). And finally, we have individual fish sites within each treatment and control section that will be used to estimate specific population parameters such as abundance, growth, and survival. Methods for the watershed scale WDFW monitoring are described in Crawford et al. (2011). Below we describe the methods for monitoring fish responses at the stream and site level.

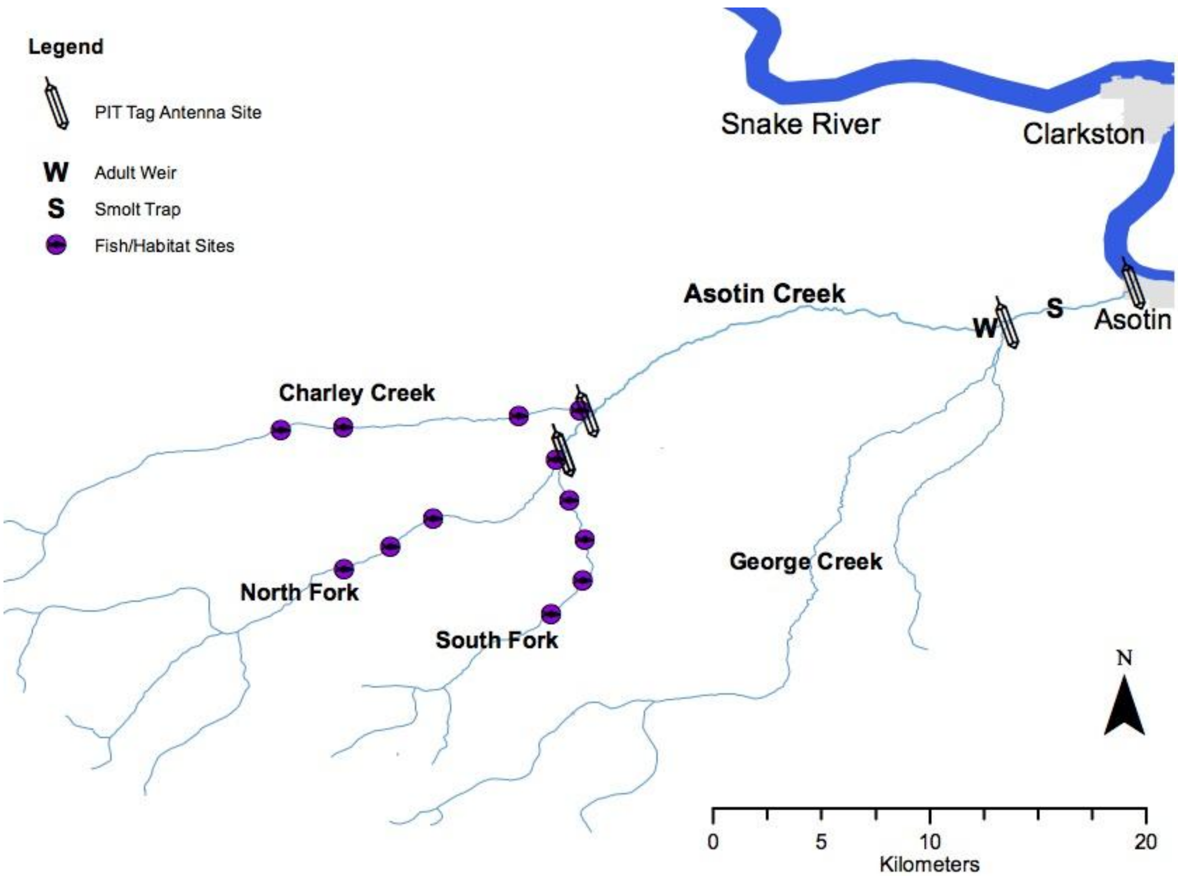

Figure 45. Fish monitoring infrastructure for the Asotin Creek IMW.

7.3.1 Stream Fish Monitoring

Four PIT tag interrogation sites are arranged to detect tagged fish leaving or entering Asotin Creek, Charley Creek, North Fork Creek, and South Fork Creek (Figure 45). The arrays at Charley Creek, the confluence of North Fork and South Fork, and at the mouth of Asotin Creek provide the direction of travel so that the migration/movement path and timing of each tagged fish can be determined. WDFW also PIT tag all adult wild steelhead captured at the adult weir which allows determination of the proportion of the adult escapement entering each of the IMW study creeks.

7.3.2 Fish Site Monitoring

We need to determine juvenile abundance, growth, movement, and survival pre and post restoration to fully assess how restoration is affecting juvenile production. To acquire this information requires the capture and PIT tagging of juvenile steelhead within the treatment and control sections of the study creeks. We have established 12 permanent fish sample sites to capture and tag juvenile steelhead. There are four fish sites in each study creek to ensure replication of sample sites within the treatment sections (Figure 3). Each fish site is visited twice a year during a summer tagging session (July) and a fall tagging session (September to October). We also conduct mobile PIT tag surveys at each site in the late summer, fall, winter, and spring where we detect PIT tag fish with a hand held mobile wand. The two tagging sessions and mobile surveys provide data on abundance, growth, and survival at each site over relatively short time periods (i.e., summer to fall, fall to winter, etc.). With these data we will be able to better determine which parameters and periods are most likely contributing to changes in production pre and post restoration. See Bennett et al. (2012 in preparation) for a complete description of all monitoring and analyses methods.

7.3.2.1 Net Rate of Energy Intake modeling

Although we will not be focusing our monitoring efforts at the level of individual structures, we are using a process-based modeling approach to help us understand how the habitat currently available to juvenile steelhead supports their populations and how changes to habitat might influence their production. To accomplish this, we are adapting a modeling approach (Hayes et al. 2007) developed for large, slow-moving pools, to work on sections of stream with both fast- and slow-moving habitats. The modeling approach involves four main components: a 2D hydraulic model to approximate flow patterns through a section of stream, a model to predict the paths of invertebrates drifting in the water, a foraging model to predict which drifting invertebrates are available to fish, and an energetic model that subtracts the metabolic costs of swimming in the stream from the energy gained by foraging to estimate the net energy flux for fish in the modeled stream section (Figure 46). The modeling approach predicts net rates of energy intake (NREI) for drift-feeding fish throughout the entire modeled stream section at a user-defined set of locations. By using a fine prediction resolution (predicting NREI at many locations throughout the stream section), we are able to illustrate which areas of a stream section are energetically profitable (fish would be able to meet their survival and growth requirements) and which areas are energetically deficient (fish would lose weight or not be able to meet their survival requirements). After accounting for depletion of drifting invertebrate food items by foraging fish, we can use the number of locations where fish meet their survival requirements as a rough estimate of carrying capacity.

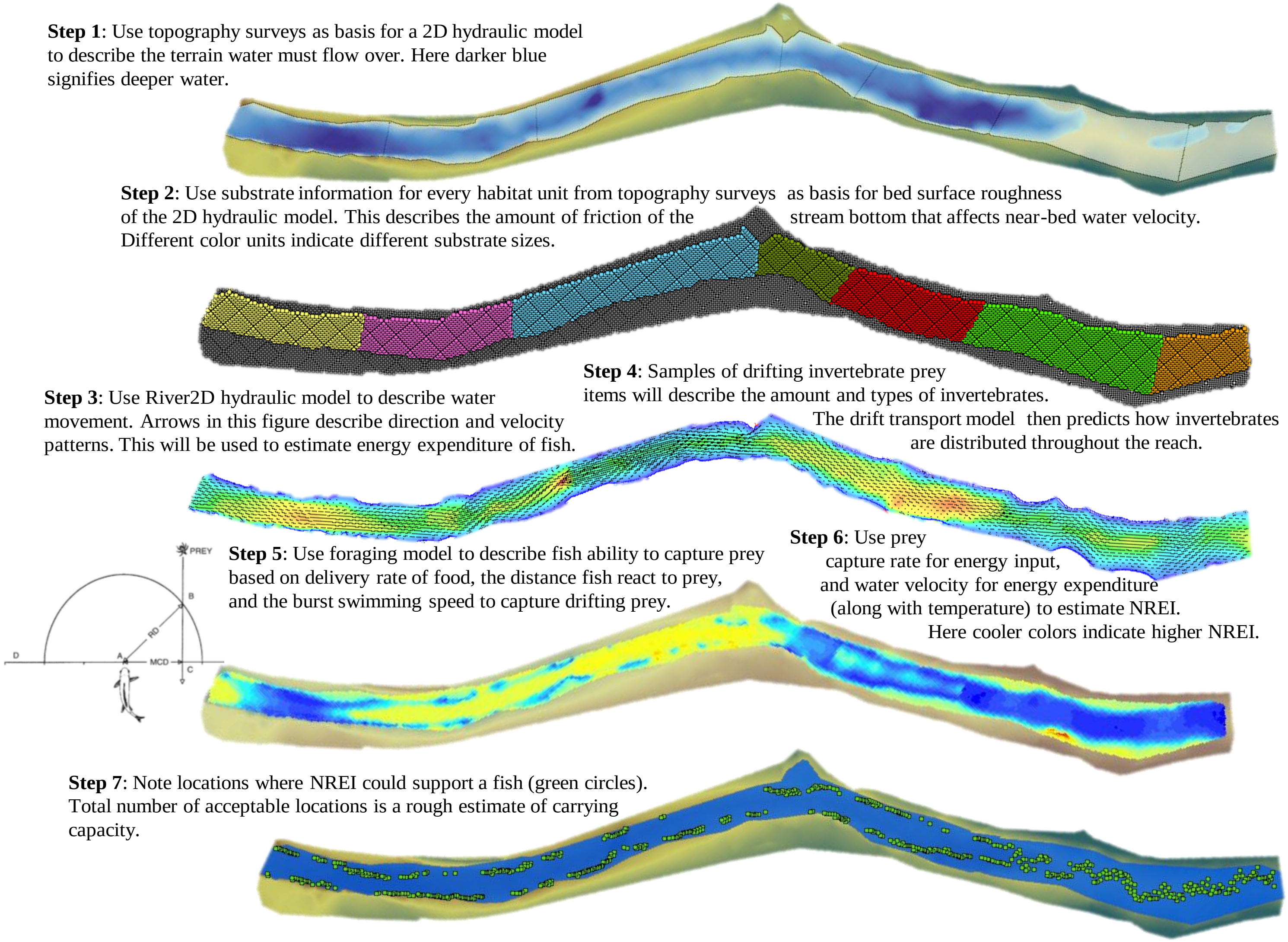

Figure 46. An overview of the modeling process to predict profitable foraging locations and carrying capacity for a stream section using the Net Rate of Energy Intake (NREI) approach based on Hayes et al. (2007).

8 CONCLUSIONS

We have developed a conceptual model of the current and future ecogeomorphic condition of Asotin Creek and its tributaries from a large set of assessments and field surveys. The models we have developed indicate riparian function is currently degraded but is providing some key functions such as shading. Instream conditions are simplified and lack sufficient LWD inputs required to create a dynamic channel that can produce and maintain habitat complexity required by steelhead. Within the context of an Intensively Monitored Watershed experimental framework, we have proposed a restoration technique that differs significantly from traditional restoration approaches in its cost of implementation (low) and the spatial extents over which it can be applied (entire stream reaches). We believe that by creating dynamic woody structures (DWS) using wood posts driven into the substrate and augmented by LWD, we can promote the creation of key fish habitat attributes that will result in increased juvenile production of steelhead that can be detected at the site, stream, and possibly the watershed scale. The restoration technique also has the added advantage of being a potentially transferable method for restoring LWD and roughness elements over the broad range of steelhead habitat with the use of hand labor that causes minimal disturbance to existing riparian vegetation and stream banks. Our monitoring design includes detailed measurements of the pre and post locations of 20% of the proposed 600 DWS's and rapid assessments of every DWS plus detailed fish monitoring at the treatment site, stream, and watershed scale. This intensive and extensive monitoring will help determine the underlining casual mechanism of any fish response and allow these results to improve the design and implementation of future restoration projects.

9 LITERATURE CITED

ACCD. 1995. Asotin Creek model watershed plan. Prepared by the Landowner Steering Committee. Prepared for the Asotin County Conservation District.

ACCD. 2004. Asotin subbasin plan. Prepared by the Asotin County Conservation District. Prepared for the Northwest Power and Conservation Council. Appendix B: Asotin subbasin plan aquatic assessment.

Almodóvar, A., G. G. Nicola, and B. Elvira. 2006. Spatial Variation in Brown Trout Production: The Role of Environmental Factors. Transactions of the American Fisheries Society **135**:1348-1360.

Bangen, S. G. and J. M. Wheaton. 2012. CHaMP Crew Variability: Influence on Topographic Surfaces & Derived Metrics. Report to Eco Logical Research, Inc. and the Columbia Habitat Moniotirng Program, Logan, Utah.

Beechie, T. and H. Imaki. In Press. Predicting natural channel patterns based on landscape and geomorphic controls in the Columbia River basin, USA. Water Resources Research.

Beechie, T. J., M. Liermann, M. M. Pollock, S. Baker, and J. Davies. 2006. Channel pattern and river-floodplain dynamics in forested mountain river systems. Geomorphology **78**:124-141.

Beechie, T. J., G. R. Pess, P. Kennard, R. E. Bilby, and S. Bolton. 2000. Modeling recovery rates and pathways for woody debris recruitment in Northwestern Washington streams. North American Journal of Fisheries Management **20**:436–452.

Beechie, T. J. and T. H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams Transactions of the American Fisheries Society **126**:217-229.

Bennett, S. and N. Bouwes. 2009. Southeast Washington Intensively Monitored Watershed Project: Selection Process and Proposed Experimental and Monitoring Design for Asotin Creek. State of Washington, Recreation and Conservation Office, Olympia, Washington.

Bennett, S., N. Bouwes, and E. Wall. 2010. Southeast Washington Intensively Monitored Watershed Project in Asotin Creek: Year Two Pretreatment Monitoring Annual Report. Eco Logical Research, Inc. for State of Washington Recreation and Conservation Office.

Bennett, S., R. Camp, B. Bouwes, and E. Wall. 2012 *In preparation*. Southeast Washington Intensively Monitored Watershed Project in Asotin Creek: year 4 pretreatment monitoring summary report. Prepared for the State of Washington Recreation and Conservation Office, Olympia, WA. Prepared by Eco Logical Research Ltd. .

Bilby, R. E. and P. A. Bisson. 1998. Function and distribution of LWD. Pages 324-346 in R.J. Naiman and R.E. Bilby, editors. River ecology and management: lessons from the Pacific coastal ecoregion. Springer-Verlag, New York.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with exam- ples of habitat utilization by salmonids during low stream flows. In Acquisition and utilization of aquatic habitat inventory infor- mation. Edited by N.B. Armantrout. American Fisheries Society, Bethesda, MD.62–73.

Bouwes, N., J. Moberg, N. Weber, B. Bouwes, C. Beasley, S. Bennett, A. Hill, C. Jordan, R. Miller, P. Nelle, M. Polino, S. Rentmeester, B. Semmens, C. Volk, M. B. Ward, G. Wathen, and J. White. 2011a. Scientific protocol for salmonid habitat surveys within the Columbia Habitat Monitoring Program. Prepared by the Integrated Status and Effectiveness Monitoring Program and published by Terraqua, Inc., Wauconda, WA.

Bouwes, N., J. Moberg, N. Weber, B. Bouwes, S. Bennett, C. Beasley, C. E. Jordan, P. Nelle, S. Polino, S. Rentmeester, B. Semmens, C. Volk, M. B. Ward, and J. White. 2011b. Scientific Protocol for Salmonid Habitat Survyes within the Columbia Habiat Monitoring Program. Prepared by the Integrated Status and Effectiveness Monitoring Program and published by Terraqua, Inc., Wauconda, WA.

Brierley, G. J. and K. A. Fryirs. 2005. Geomorphology and River Management: Applications of the River Styles Framework. Blackwell Publishing, Malden, MA.

Bustard, D. R. and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Board Can. **32**:667-680.

Cederholm, C., R. E. Bilby, P. A. Bisson, T. W. Bumstead, B. R. Fransen, W. J. Scarlett, and J. W. Ward. 1997. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington stream. North American Journal of Fisheries Management **17**:947-963.

Clarke, S. 1995. Hierarchical subdivisions of the Columbia Plateau and Blue Mountains Ecoregion, Oregon and Washington. USFS, General Technical Report, PNW-GTR-395.

Crawford, E., M. Schuck, and M. Herr. 2011. Assess salmonids in the Asotin Creek watershed: 2010 annual report. Prepared for US Department of Energy, Bonneville POwer Administration, Environment, Fish, and Wildlife, Portland, OR. Prepared by WDFW, Fish Program, Science Division, Clarkston, WA.

Downes, B. J., L. A. Barmuta, P. G. Fairweather, D. P. Faith, M. J. Keough, P. S. Lake, B. D. Mapstone, and G. P. Quinn. 2002. Monitoring ecological impacts: concepts and practice in flowing waters. Cambridge University Press, Cambridge, UK.

Gentry, H. R. 1991. Soil survey of Asotin County Area, Washington, parts of Asotin and Garfield Counties. USDA, Soil Conservation Service.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. Bioscience **41**:540-551.

Hallock, D. and G. Mendel. 1985. Instream habitat improvement in southeastern Washington: 1984 annual report (phase III). Washington Department of Game, Dayton, WA.

Harmon, M. E., F. J.F., S. F.J., S. P., G. S.V., L. J.D., N. H. Anderson, C. S.P., N. G. Aumen, S. J.R., L. G.W., J. K. Cromack, and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research **15**:133-302.

Hartman, G. F. 1965. The role of behavior in the ecology and interact ion of under yearling coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Journal of Fisheries Research Board of Canada **22**:1035-1081.

Hartshorn, G. S. 1989. Application of gap theory to tropical forest management: natural regeneration on strip clear-cuts in the Peruvian Amazon. Ecology **70**:567-569.

Hawkins, C. P., J. L. Kershner, P. A. Bisson, M. D. Bryant, L. M. Decker, S. V. Gregory, D. A. McCullough, C. K. Overton, G. H. Reeves, R. J. Steedman, and M. K. Young. 1993. A hierarchical approach to classifying stream habitat features. Fisheries **18**:3-12.

Hayes, J. W., N. F. Hughes, and L. H. Kelly. 2007. Process-based modelling of invertebrate drift transport, net energy intake and reach carrying capacity for drift-feeding salmonids. Ecological Modelling **207**:171-188.

HDR. 2006. Middle Snake River watershe plan: planning unit draft. Pasco, WA.

Heitke, J. D., E. Archer, D. Dugaw, B. Bouwes, E. A. Archer, R. C. Henderson, and J. L. Kershner. 2008. Effectiveness monitoring for streams and riparian areas: sampling protocol for stream channel attributes. Unpublished paper on file at: http://www.fs.fed.us/biology/fishecology/emp.

Hemstad, N. A. and R. M. Newman. 2006. Local and landscape effects of past forest harvest on stream habitat and fish assemblages. American Fisheries Society Symposium **2006**:413-427.

Hinrichsen, R. 2010. Before-After Control-Impact (BACI) Power Analysis For Several Related Populations. Draft report. Hinrichsen Environmental Services, Seattle, WA.

Hiroo Imaki, T. B. 2008. GIS Approaches for Channel Typing in the Columbia River Basin: Carrying Fine Resolution Data to a Large Geographic Extent. AGU. Northwest Fisheries Science Center, NOAA Fisheries and The Macaulay Land Use Research Institute, Seattle.

Holling, C. S. 1978. Adaptive Environmental Assessment and Management. Wiley, Chichester, U.K.

Horton, G. E., B. H. Letcher, M. M. Bailey, and M. T. Kinnison. 2009. Atlantic salmon (Salmo salar) smolt production: the relative importance of survival and body growth. Canadian Journal of Fisheries and Aquatic Sciences **66**:471-483.

Keller, E. A. and F. J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes **4**:361-380.

Kondolf, G. M. 2000. Some suggested guidelines for geomorphic aspects of anadromous salmonid habitat restoration proposals. Restoration Ecology **8**:48-56.

Koski, K. V. 1992. Restoring stream habitats affected by logging activities. Pages 343-401 *in* G.W. Thayer (ed.) Restoring the nation's marine environment. Maryland Sea Grant, University of Maryland. College Park.

LANDFIRE. 2010. Landscape Fire and Resource Management Planning Tools. Department of Agriculture, Forest Service; U.S. Department of Interior. Available: http://www.landfire.gov/index.php.

Lertzman, K. P. 1992. Patterns of gap-phase replacement in a subalpine, old-growth forest. Ecology **73**:657-669.

Loughin, T. 2010. Comparison of the statistical power of BACI and hierarchical-staircase experimental designs to detect changes in fish abundance and habitat change within the framework of the Asotin Creek Intensively Monitored Watershed Project: Progress Report. September 30, 2010. Prepared by T. Loughin, Statistics and Actuarial Science, Simon Fraser University, Surrey, BC. Prepared for Eco Logical Research Inc. Providence, Utah.

Loughin, T. M. 2006. Improved experimental design and analysis for long-term experiments. Crop Science **46**:2492-2502.

Loughin, T. M., M. P. Roediger, G. A. Milliken, and J. P. Schmidt. 2007. On the analysis of long-term experiments. Journal of the Royal Statistical Society: Series A (Statistics in Society) **170**:29–42.

MacWilliams, M., J. M. Wheaton, G. B. Pasternack, P. K. Kitanidis, and R. L. Street. 2006. The Flow Convergence-Routing Hypothesis for Pool-Riffle Maintenance in Alluvial Rivers. Water Resources Research **42**:W10427: doi 10410.11029/12005WR004391.

McAllister, L. S. 2008. Reconstructing historical riparian conditions of two river basins in eastern Oregon, USA. ENVIRONMENTAL MANAGEMENT **42**:412-425.

McKean, J., D. Nagel, D. Tonina, P. Bailey, C. W. Wright, C. Bohn, and A. Nayegandhi. 2009. Remote Sensing of Channels and Riparian Zones with a Narrow-Beam Aquatic-Terrestrial LIDAR. Remote Sensing **1**:1065-1096.

Mendel, G. 1984. Instream habitat improvement in southeastern Washington. Washington Department of Game, Dayton, WA.

Montgomery, D. R. 2003. Wood in rivers: interactions with channel morphology and processes. Geomorphology **51**:1-5.

Montgomery, D. R. and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin **109**:596-611.

Montgomery, D. R., J. M. Buffington, R. D. Smith, K. M. Schmidt, and G. Pess. 1995. Pool spacing in forest channels. Water Resources Research **31**:1097-1105.

Montgomery, D. R., B. D. Collins, J. M. Buffington, and T. B. Abbe. 2003. Geomorphic effects of wood in rivers. American Fisheries Society Symposium.

Naiman, R. J., H. Decamps, and M. McClain. 2005. Riparia: ecology, conservation, and management of streamside communities.

Newson, M. D. and D. Sear. 1997. The role of geomorphology in monitoring and managing river sediment systems (vol 11, pg 265, 1997). Journal of the Chartered Institution of Water and Environmental Management **11**:385-385.

NRCS. 2001. Asotin Creek inventory and assessment report. Prepared by USDA Natural Resources Conservation Service.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Map (scale 1:7,500,000). Annals of the Association of American Geographers **77**:118-125.

Omernik, J. M. 1995. Ecoregions: A Spatial Framework for Environmental Management. In Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making, W. S. Davis and T. P. Simon, eds., Lewis Publishers, Boca Raton, FL, 49-62.

Opperman, J. J. and A. M. Merenlender. 2004. The effectiveness of riparian restoration for improving instream fish habitat in four hardwood-dominated California streams. North American Journal of Fisheries Management **24**:822-834.

Pollock, M., J. M. Wheaton, N. Bouwes, and C. E. Jordan. 2011. Working with Beaver to Restore Salmon Habitat in the Bridge Creek Intensively Monitored Watershed: Design Rationale and Hypotheses, Interim Report. NOAA Northwest Fisheries Science Center, Seattle, WA.

Roni, P., K. Hanson, and T. Beechie. 2008. Global review of physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management **28**:856-890.

Roni, P., G. Pess, T. Beechie, and S. Morley. 2010. Estimating Changes in Coho Salmon and Steelhead Abundance from Watershed Restoration: How Much Restoration Is Needed to Measurably Increase Smolt Production? North American Journal of Fisheries Management **30**:1469-1484.

Roni, P. and T. P. Quinn. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences **58**:282-292.

Roper, B. B., D. Konnoff, D. Heller, and K. Wieman. 1998. Durability of Pacific Northwest instream structures following floods. North American Journal of Fisheries Management **18**:686-693.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Schuster, J. E. 1993. Geologic map of the CLarkston 1: 100,000 quadrangle, Washington - Idaho, and the Washington portion of the Orofino 1: 100,00 quadrangle. Washington State Department of Natural Resources, Division of Geology and Earth Resources **Open file report 93-4**.

SCS. 1984. Southeast Washington cooperative river basin study USDA Soil Conservation Service, Economic Research Service.

Sear, D., C. L. Newson, and C. R. Thorne. 2003. Guidebook of Applied Fluvial Geomorphology. R and D Technical Report FD1914, DEFRA: Flood Management Division, London, UK.

Sear, D. A., J. M. Wheaton, and S. E. Darby. 2008. Uncertain restoration of gravel-bed rivers and the role of geomorphology. Pages 739-760 *in* H. Habersack, H. Piegay, and M. Rinaldi, editors. Gravel-Bed Rivers VI: From Process Understanding to River Restoration. Elseiver.

Senter, A. E. and G. B. Pasternack. 2010. Large wood aids spawning Chinook salmon (Oncorhynchus tshawytscha) in marginal habitat on a regulated river in California. River Research and Applications.

Slaney, P., R. Finnigan, and R. Millar. 1997. Accelerating the recovery of log-jam habitats: large woody debris-boulder complexes. Pages 9-1 to 9-24 *In* Slaney and Zaldokas (eds.) Fish Habitat Rehabilitaiton Procedures. Watershed Restroation Techniocal Circular No. 9. Ministry of Environment, Lands, and Parks, Vancouver, BC.

Slaney, P. and D. Zaldokas, Minore. 1997. Fish habitat rehabilitation procedures. Watershed Restoration Technical Circular No. 9, Watershed Restoration Program, MELP, Vancouver.

Solazzi, M. F., T. E. Nickelson, S. L. Johnson, and J. D. Rodgers. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences **57**:906–914.

SRSRB. 2006. Snake River salmon recovery plan for SE Washington. Prepared by Snake River Salmon Recovery Board for the Washington Governor's Salmon Recovery Office.

Thompson, D. M. and K. S. Hoffman. 2001. Equilibrium pool dimensions and sediment-sorting patterns in coarse-grained, New England channels. Geomorphology **38**:301-316.

Underwood, A. J. 1994. Beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications **4**:3-15.

Viola, A. E., M. L. Schuck, and S. A. Nostrant. 1989. An evaluation of instream habitat alterations in southeast Washington, 1983-1989. Washington Department of Wildlife, Olympia, WA.

Walters, C. J. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology [online] **1**:1. Available from the Internet. URL: \url{http://www.consecol.org/vol1/iss2/art1}.

Walters, C. J., J. S. Collie, and T. Webb. 1988. Experimental designs for estimating transient responses to management disturbances. Canadian Journal of Fisheries and Aquatic Sciences **45**:530-538.

Waters, T. F. 1999. Long-Term Trout Production Dynamics inValley Creek, Minnesota. Transactions of the American Fisheries Society **128**:1151-1162.

Wheaton, J., S. Bennett, B. Bouwes, and R. Camp. 2012. Asotin Creek Intensively Monitored Watershed: Restoration plan for Charley Creek, North Fork Asotin, and South Fork Asotin Creeks. DRAFT: April 7, 2012. Prepared for the State of Washington Recreation and Conservation Office, Olympia, WA. Prepared by Eco Logical Research Ltd. .

Wheaton, J. and K. D. DeMeurichy. 2009. Asotin IMW, 2009 Deliverables. Ecogeomorphology and Topographic Analysis Lab, Utah State University, Prepared for Eco Logical Research, Logan, UT.

Wheaton, J. M., J. Brasington, S. E. Darby, J. Merz, G. B. Pasternack, D. Sear, and D. Vericat. 2010. Linking geomorphic changes to salmonid habitat at a scale relevant to fish. River Research and Applications **26**:469-486.

Wheaton, J. M., S. E. Darby, and D. Sear. 2008. The Scope of Uncertainties in River Restoration. Pages 21-39 *in* S. E. Darby and D. Sear, editors. River Restoration: Managing the Uncertainty in Restoring Physical Habitat John Wiley and Sons, Chichester, U.K.

Wipfli, M. S. 1997. Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth and young-growth riparian forests in Southeastern Alaska, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences **54**:1259-1269.

Wissmar, R. C. and P. A. Bisson. 2003. 11. Strategies for Restoring Rivers: Problems and Opportunites. Pages 245-262 *in* R. C. Wissmar, P. A. Bisson, and M. Duke, editors. Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems. American Fisheries Society, Bethesda, Maryland.

Wohl, E., P. L. Angermeier, B. Bledsoe, G. M. Kondolf, L. MacDonnell, D. M. Merritt, M. A. Palmer, N. L. Poff, and D. Tarboton. 2005. River restoration. Water Resources Research **41**.

WSI. 2012. 2012. LiDaR remote sensing: Asotin Watershed, Washington. Prepared for Eco Logical research Inc.. Prepared by Watershed Sciences, Inc., Corvallis, OR.

Zeedyk, B. and V. Clothier. 2009. Let the water do the work: induced meandering, an evolving method for restoring incised channels. The Quivira Coalition, Santa Fe, NM.

APPENDIX A. Asotin IMW CHaMP habitat surveys: 2011.

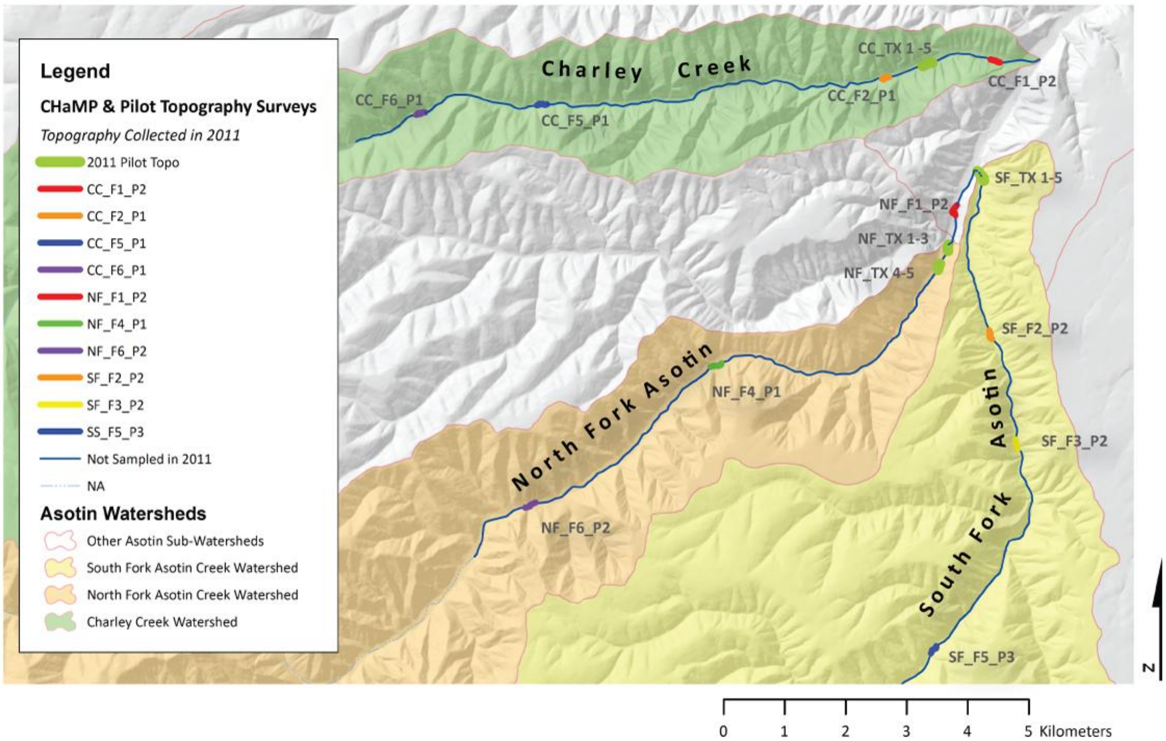

Figure A1 – **Locations of topographic surveys using CHaMP protocol, conducted in 2011. CC, NF and SF are abbreviations for Charley Creek, North Fork Asotin Creek and South Fork Asotin Creek respectively. F# refers to the two kilometer IMW fish sampling reach (six in each creek; see Figure 9), whereas TX refers to the pilot treatment reaches.**

Table A1 – **IMW Habitat Sampling in terms of length of stream (in meters) and number of surveys at discrete reaches.**

	Longitudinal Length of Stream (m) Surveyed by:				**Number of Discrete Surveys**			
	Pilot Structure Topo	CHaMP Topo	Fluvial Audit	IMW Fish Sample Reaches Not Surveyed	Pilot Structure Topo	CHaMP Topo	IMW Fish Sample Reaches Not Surveyed	
Charley Creek	122	690	12,000	11,188	3	4	2	of 6
South Fork Asotin Creek	188	503	12,000	11,310	4	3	3	of 6
North Fork Asotin Creek	212	633	12,000	11,155	2	3	3	of 6
Total	522	1826	36,000	33,653	9	10	8	of 18

CHARLEY CREEK

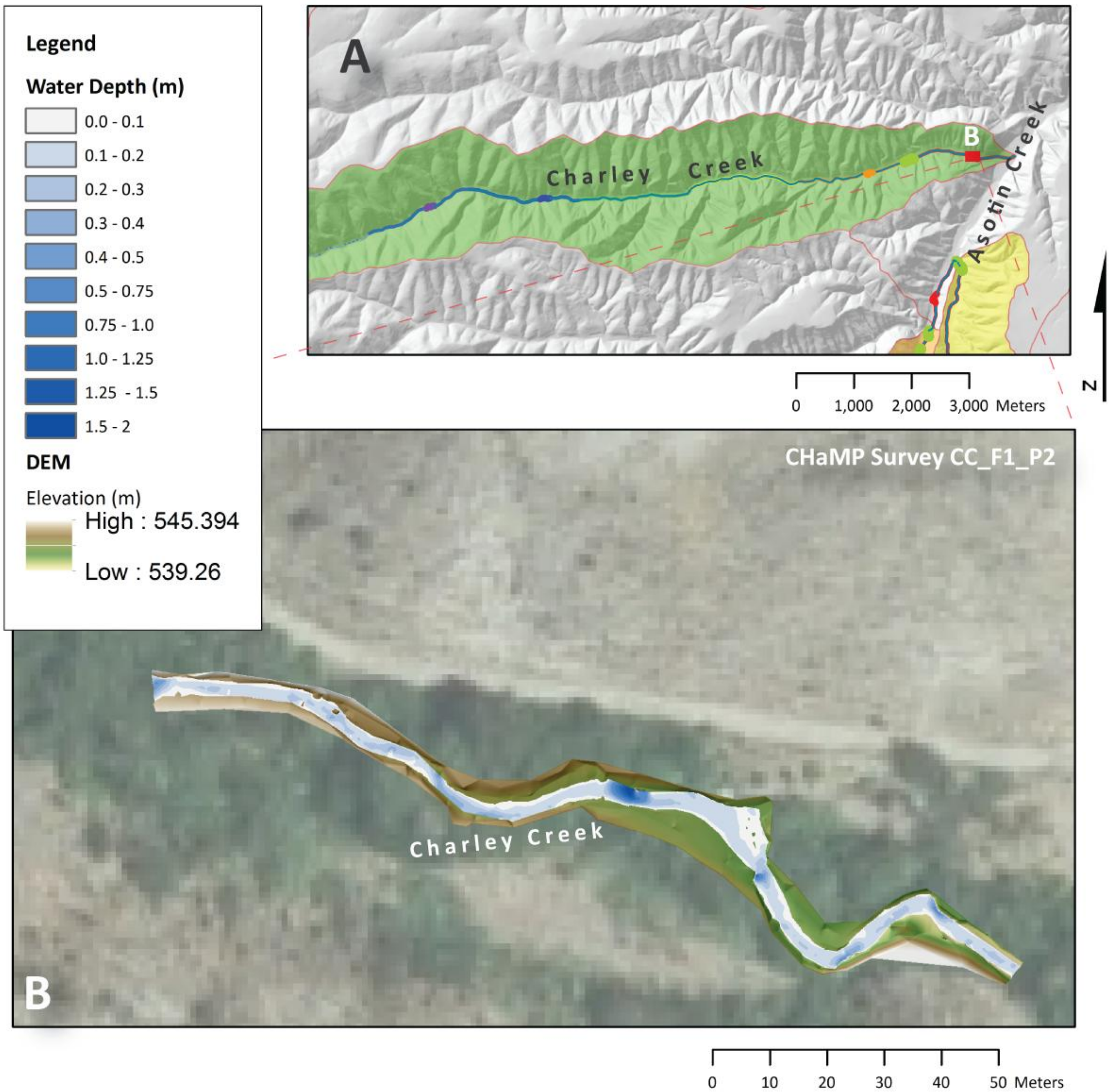

Figure A2 – CHaMP Topographic Survey and water depth map for Site CC_F1_P2.

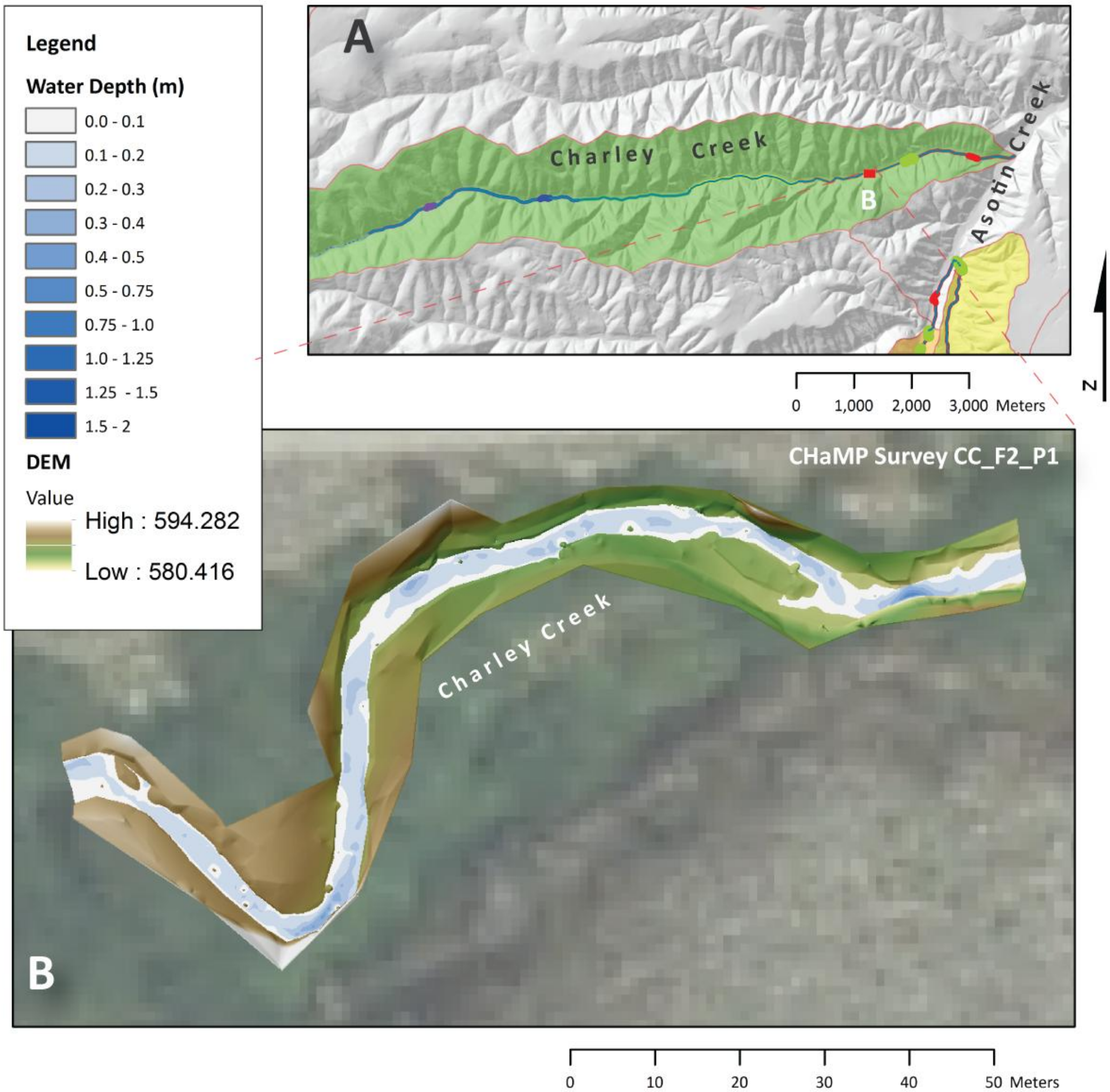

Figure A3 – CHaMP Topographic Survey and water depth map for Site CC_F2_P1.

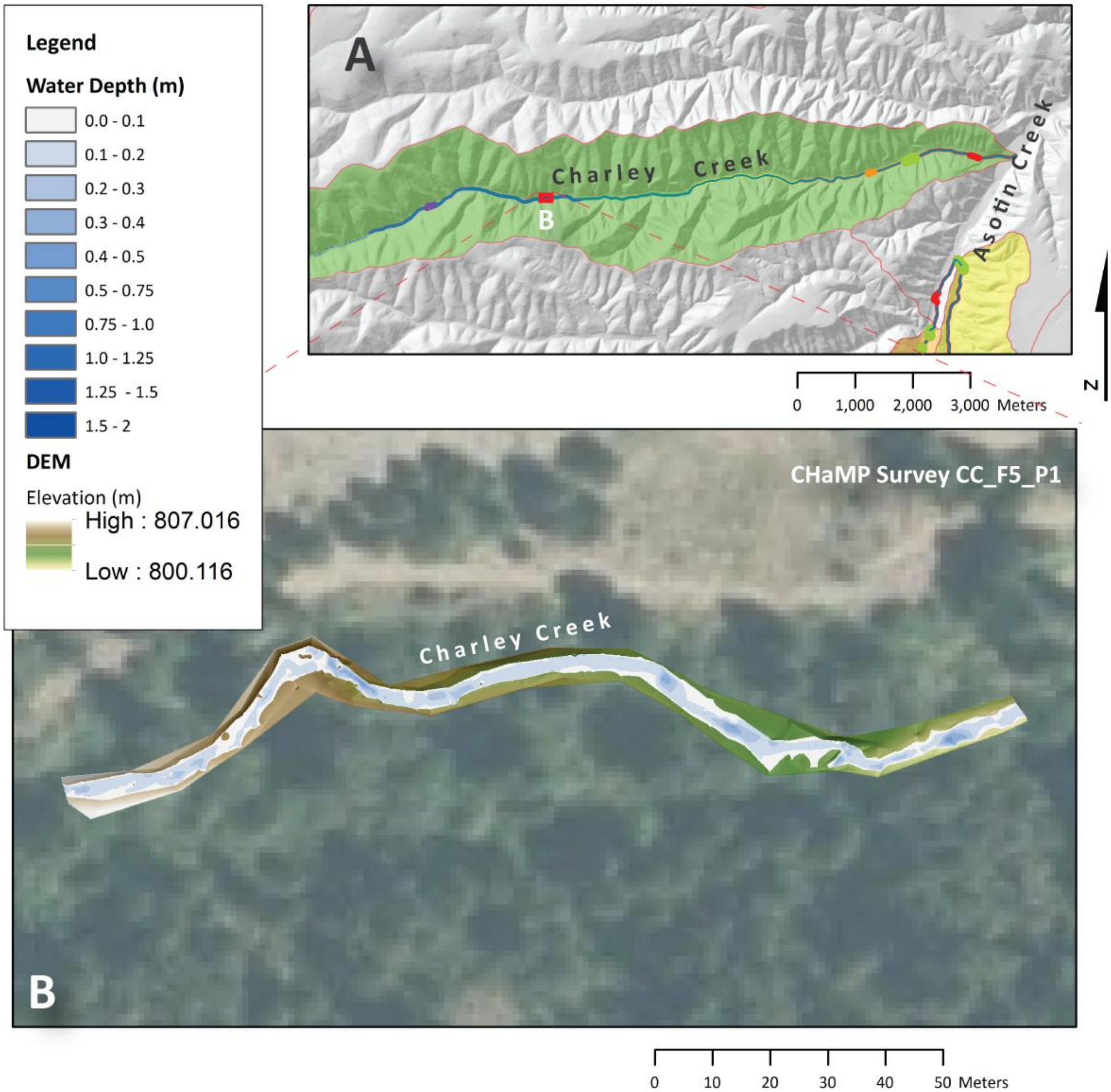

Figure A4 – CHaMP Topographic Survey and water depth map for Site CC_F5_P1.

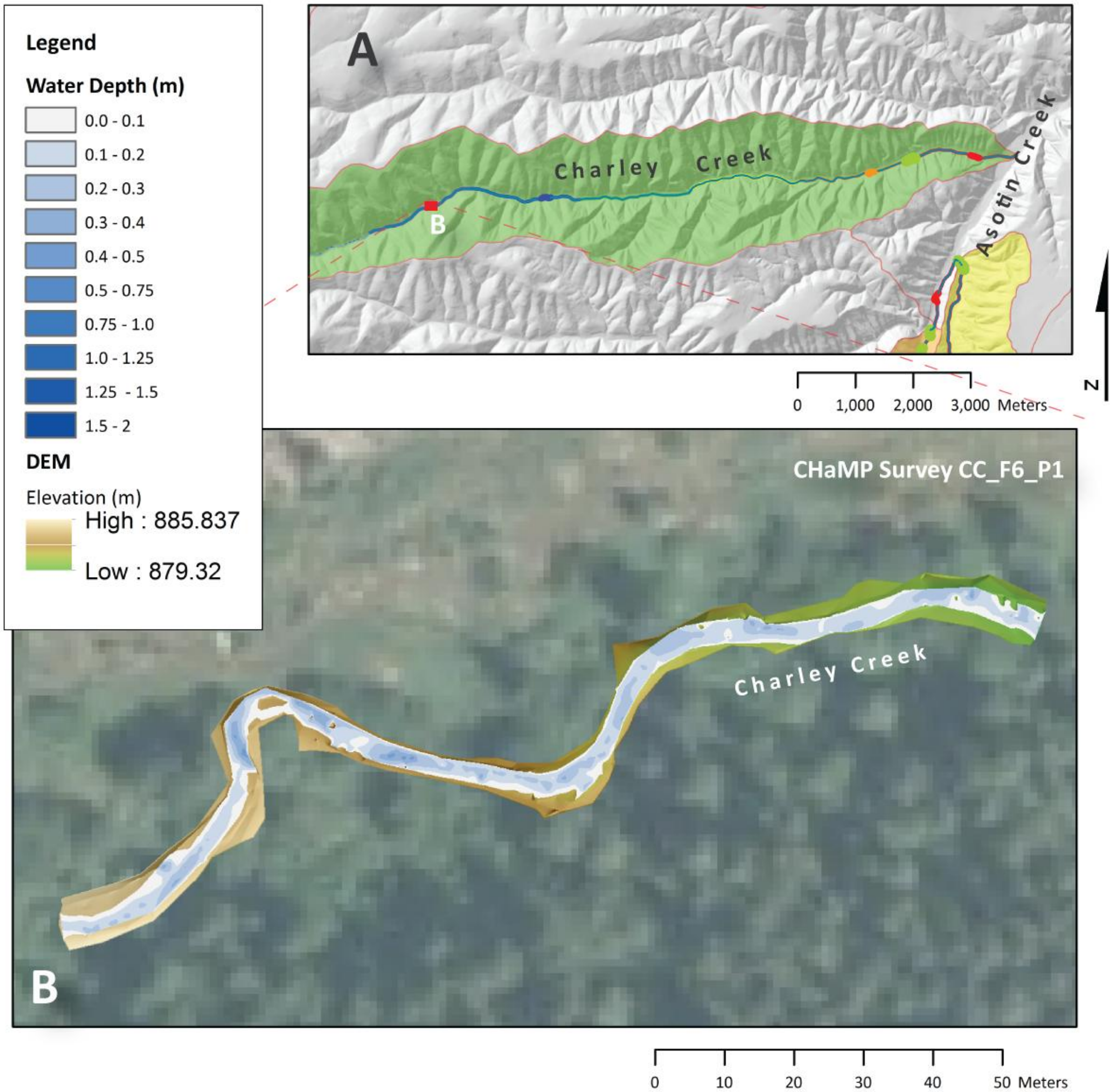

Figure A5 – CHaMP Topographic Survey and water depth map for Site CC_F6_P1.

SOUTH FORK ASOTIN CREEK

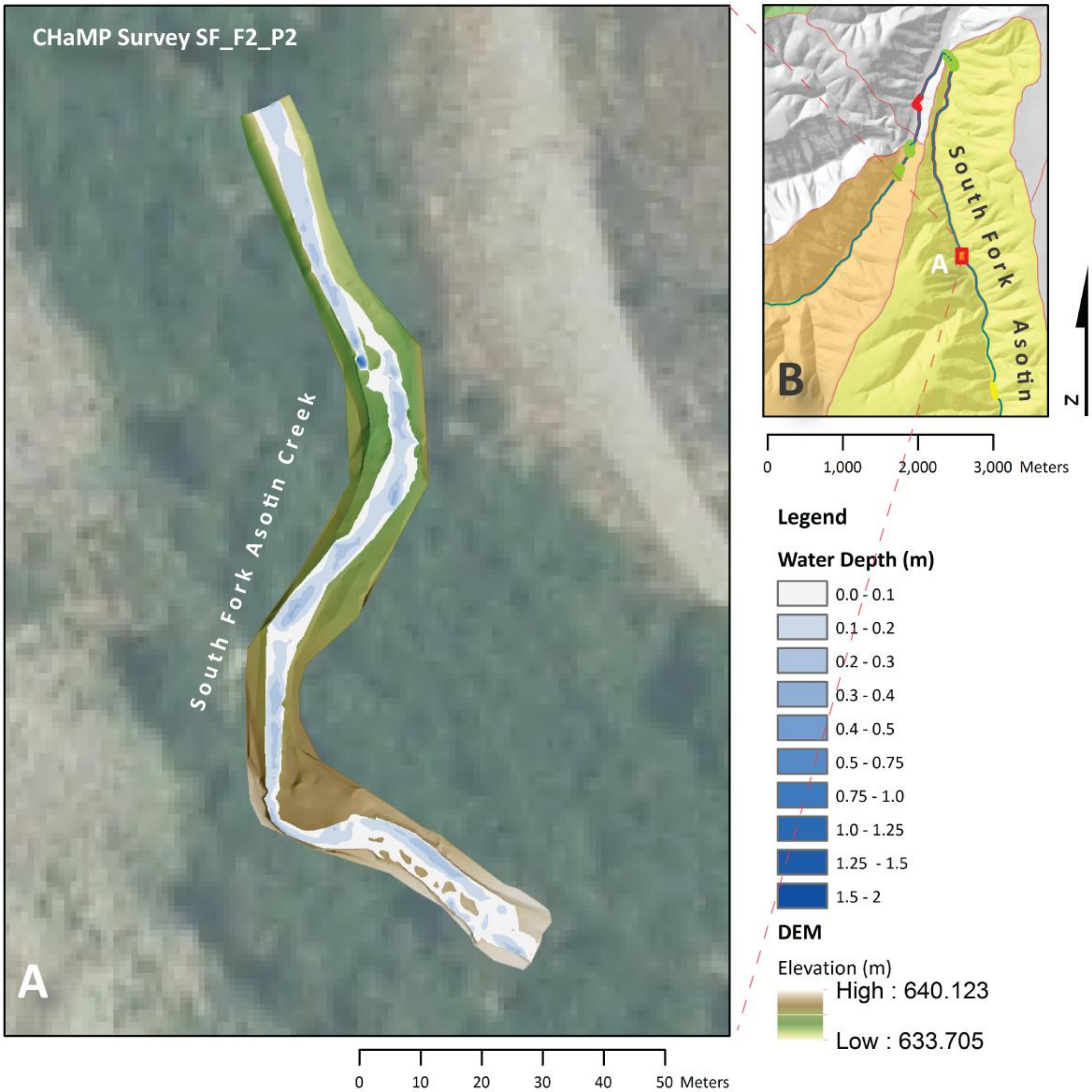

Figure A6 – CHaMP Topographic Survey and water depth map for Site SF_F2_P2.

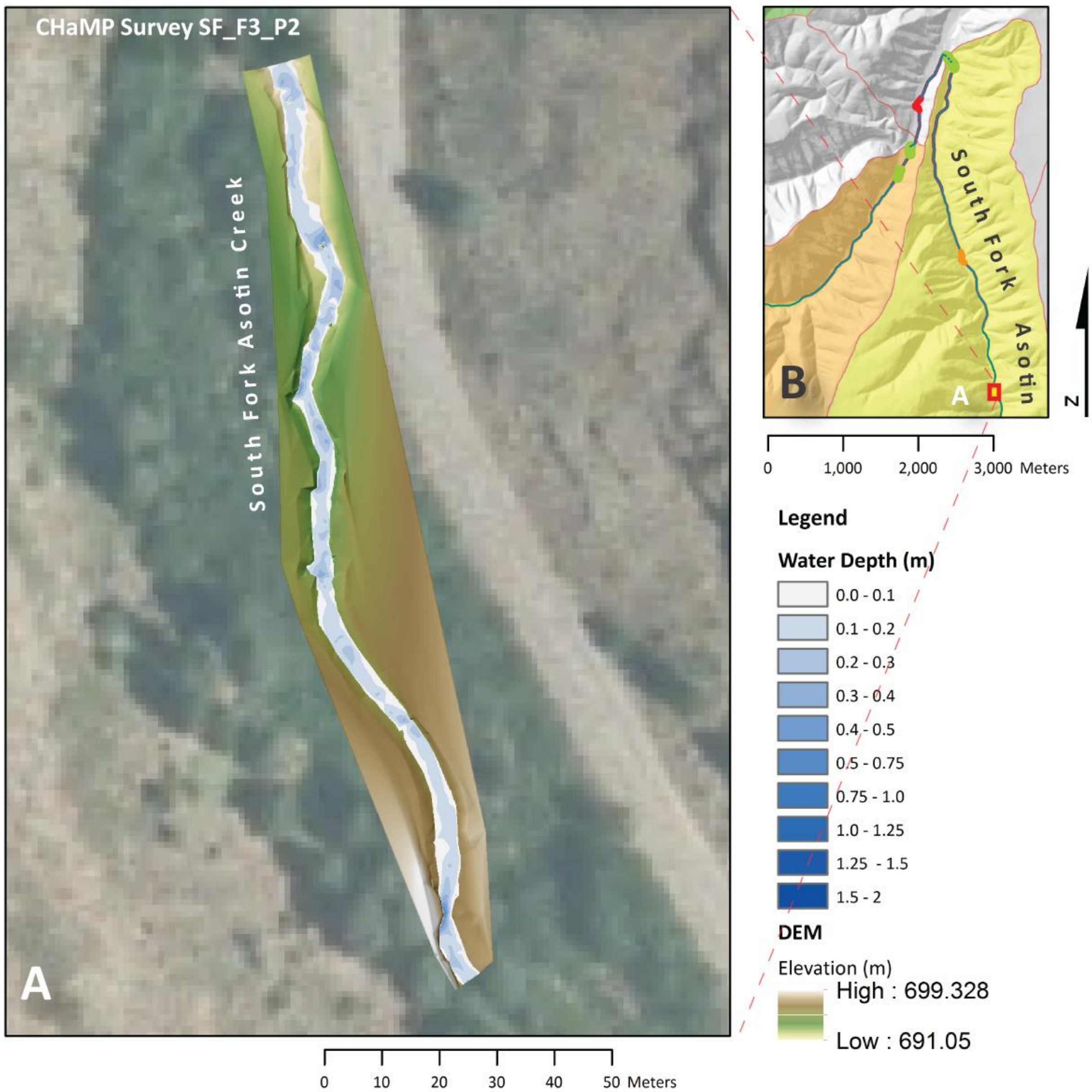

Figure A7 – CHaMP Topographic Survey and water depth map for Site SF_F3_P2.

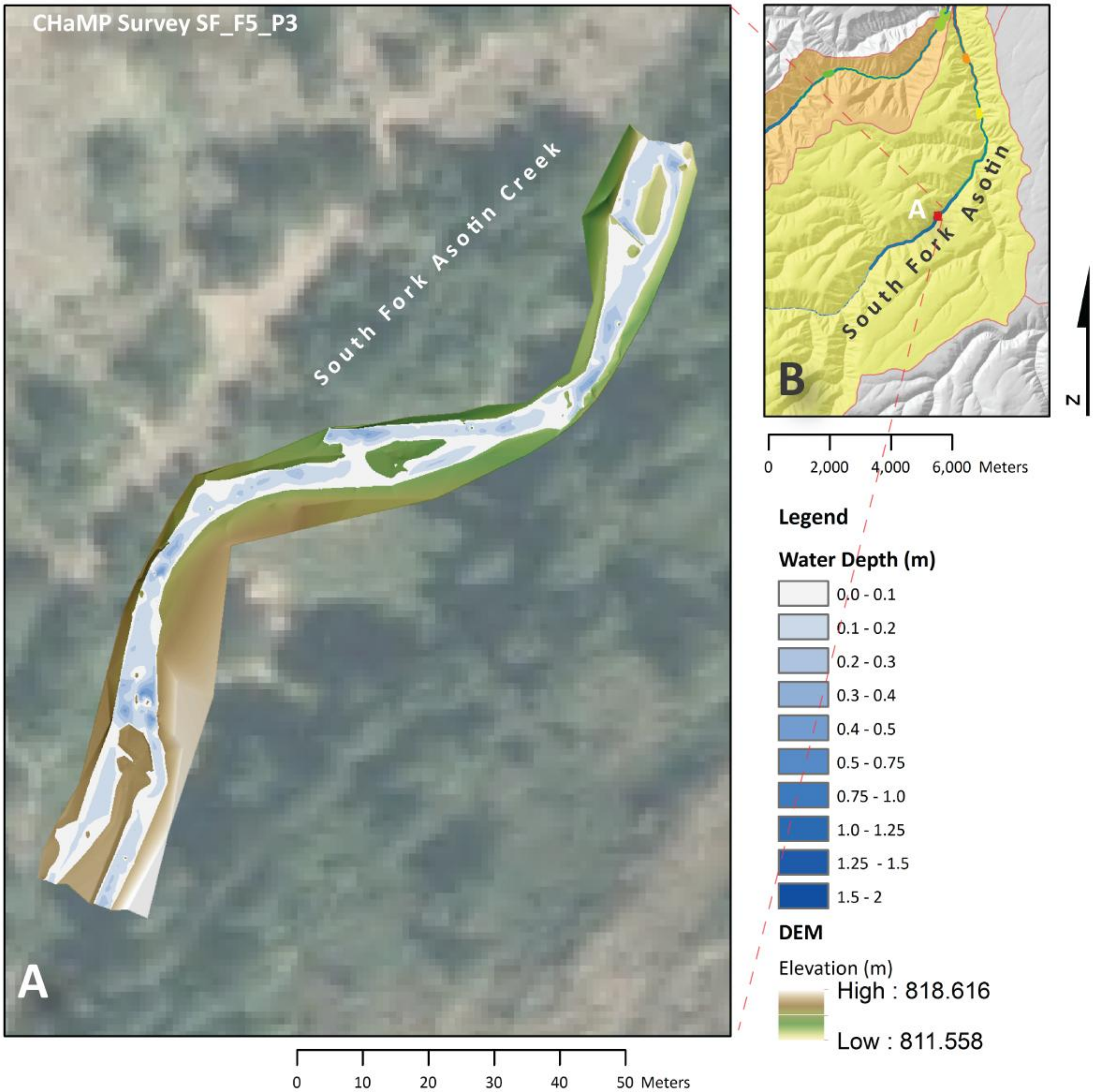

Figure A8 – CHaMP Topographic Survey and water depth map for Site SF_F5_P3.

NORTH FORK ASOTIN CREEK

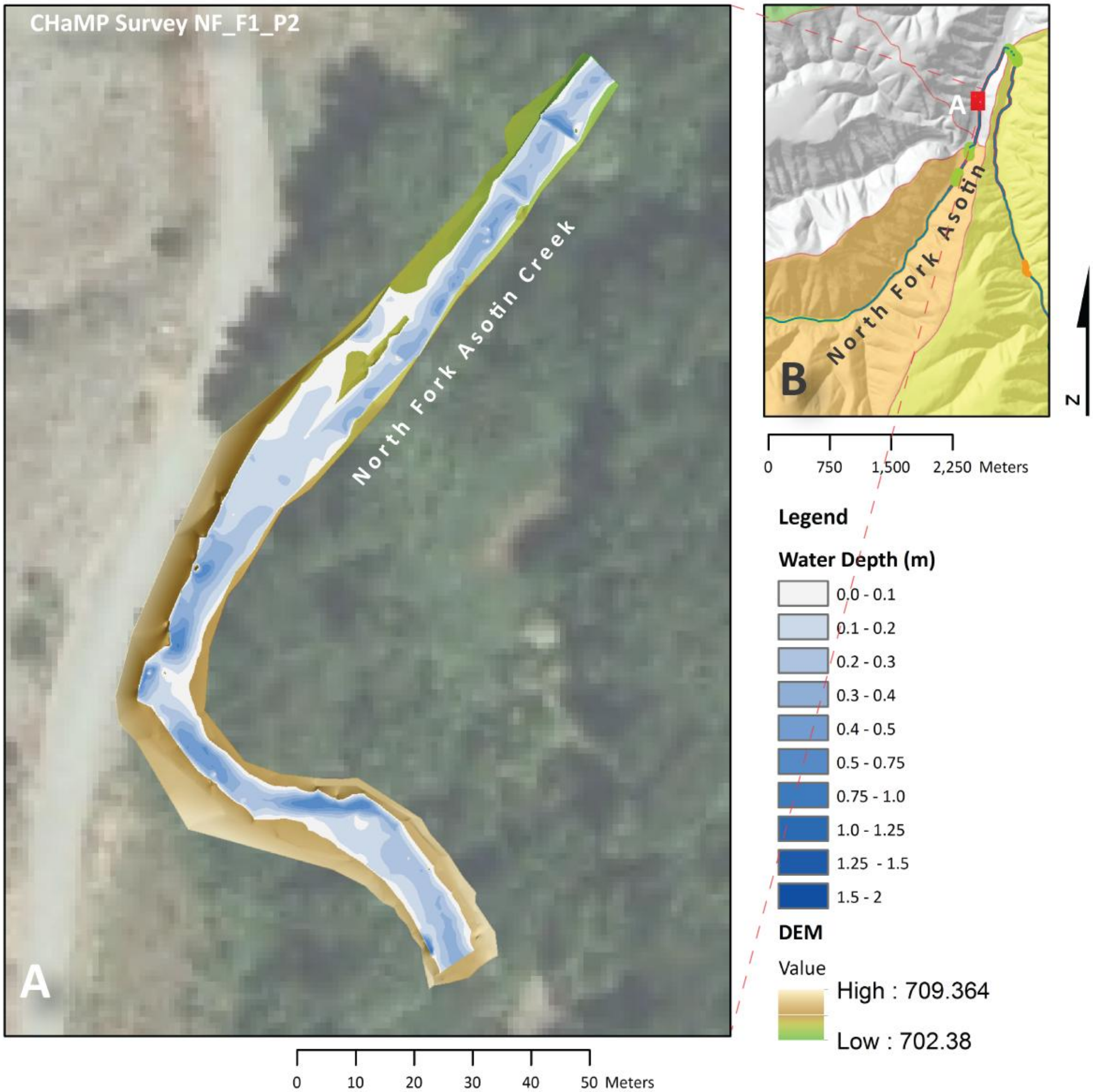

Figure A9 – CHaMP Topographic Survey and water depth map for Site NF_F1_P2.

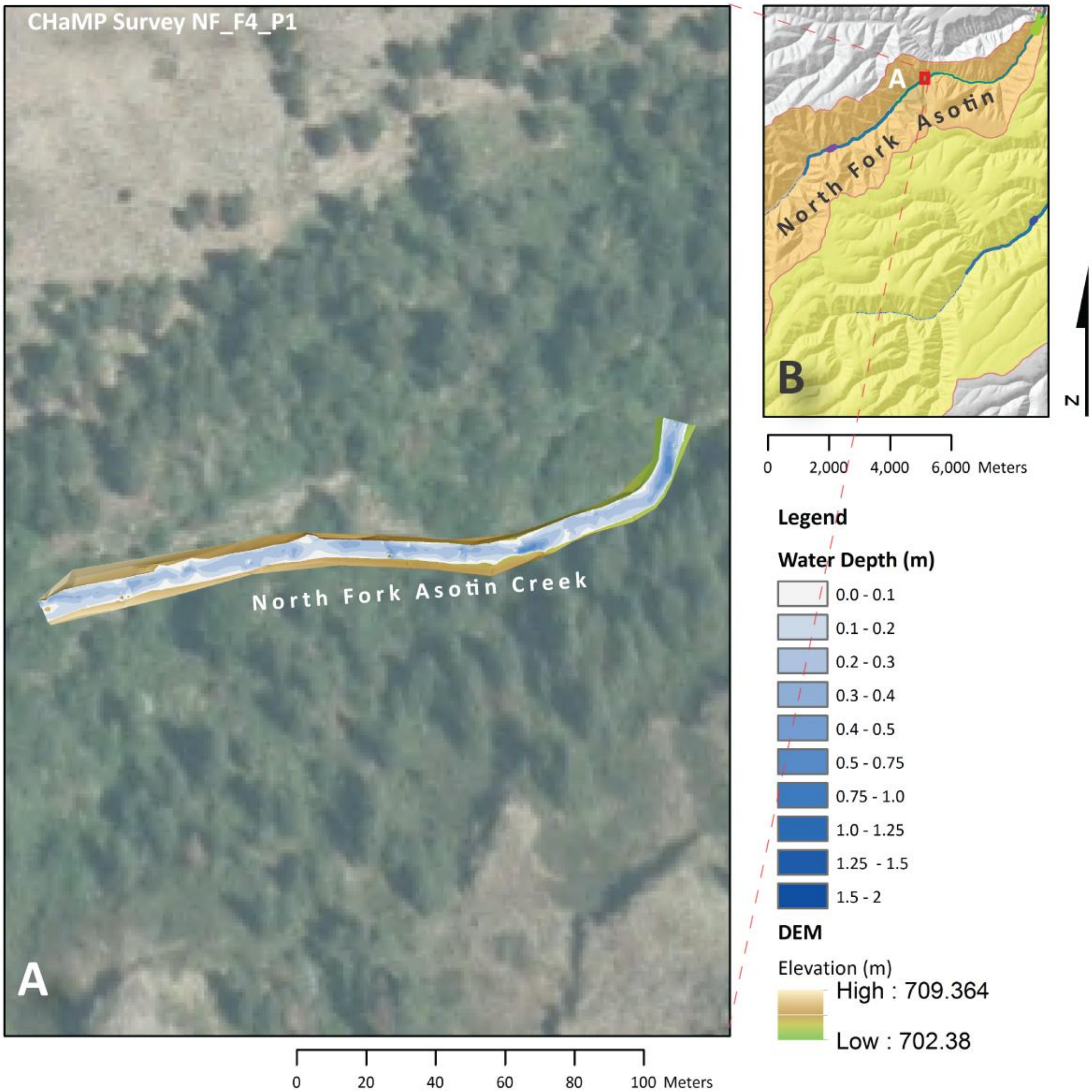

Figure A10 – CHaMP Topographic Survey and water depth map for Site NF_F4_P1.

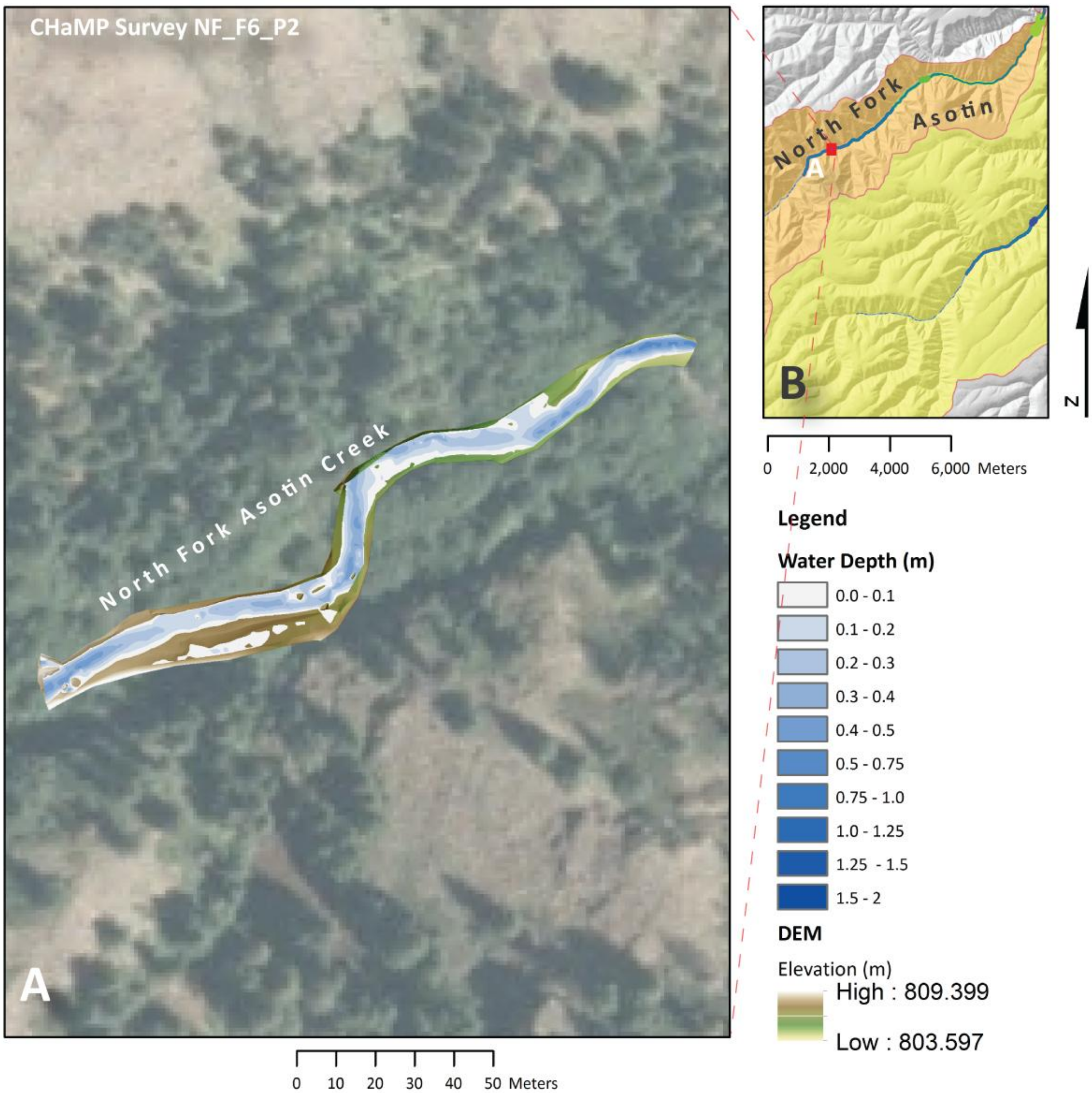

Figure A11 – CHaMP Topographic Survey and water depth map for Site NF_F6_P2.

Appendix B. Examples of trial restoration structures and responses to flooding in Charley Creek, North Fork Creek, and South Fork Creek pre, during, and post flooding in the spring of 2012.

A) Charley Creek trial structure TX1 – view upstream.

July 21, 2011 (looking downstream to TX2 and 1)

March 20, 2012

November 30, 2011

March 31, 2012

March 16, 2012

April 2, 2012

B) Charley Creek trial structure TX2 – view upstream.


August 5, 2011


March 20, 2012


November 30, 2011


March 31, 2012


March 16, 2012


April 2, 2012

C) North Fork trail structure TX1 – view upstream.

 July 21, 2011	 March 20, 2012
 January 17, 2012	 March 31, 2012
 March 16, 2012	 April 2, 2012

D) North Fork trial structure TX2 – view upstream.

August 18, 2011

March 20, 2012

January 17, 2012

March 31, 2012

March 16, 2012

April 2, 2012

E) South Fork trial structure TX1 – view from above structure.


August 5, 2011


March 20, 2012


January 17, 2012


March 31, 2012


March 16, 2012


April 2, 2012

F) South Fork trial structure TX3 – view downstream.


August 5, 2011


March 20, 2012


January 17, 2012


March 31, 2012


March 16, 2012


April 2, 2012

G) Examples of hydraulic and geomorphic responses of dynamic woody structures to large floods in spring of 2012.

 Dam pool upstream of NF-TX3	 Flow width constriction at CC-TX1
 Debris catching and eddy pool at SF-TX4	 Flow width constriction and scour pool NF-TX2
 Gravel bar developing upstream of SF-TX2	 Forced bank erosion at SF-TX2