Southeast Washington Intensively Monitored Watershed Project in Asotin Creek:

Year Two Pretreatment Monitoring Annual Report

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Executive Summary

The Snake River Salmon Recovery Board (SRSRB) is in the process of implementing a salmon and steelhead recovery plan in southeast Washington. As part of the recovery plan the SRSRB has drafted an Intensively Monitored Watershed (IMW) design and work plan. A primary goal of IMW projects is to determine the effectiveness of specific restoration actions on increasing salmonid production. The Asotin Creek Watershed was selected by the SRSRB's Regional Technical Team (RTT) to monitor fish response to habitat restoration activities, focusing on increasing the density of large woody debris and percent pools in the short-term, and restoration of riparian function in the long-term. The IMW project is being conducted using a phased approach and this report summarizes the work completed during Phases 1 and 2. This report also provides a work plan for Phase 3, which supports project management, data collection and analysis, fish and habitat monitoring, equipment costs, development of a restoration plan, and annual reporting for the period March 1, 2010 to September 30, 2010. Phase 3 will complete the proposed three years of pretreatment data collection and Phase 4 funds will be sought to implement the restoration activities in a subsequent request.

A hierarchical staircase experimental and monitoring design has been implemented and refined based on input from the RTT and field trials of the methodologies. Power analysis and statistical modeling indicates that the experiment has sufficient power to detect change in steelhead abundance (i.e., 75% power to detect a 50% change). Preliminary estimates indicate that approximately a 160% increase in pool habitat (e.g., an additional 65 pools/km) is required o increase the abundance of juvenile steelhead by 25%.

Fish abundance estimates and tagging operations have been conducted in the summer and fall to assess seasonal growth, movement, and survival. All tagging operations are integrated with ongoing WDFW assessments in Asotin Creek and to date 13,648 juvenile steelhead have been tagged. More assessments will be conducted to determine the most efficient methods to increase resighting of tagged fish using a variety of mobile antenna techniques. Stream habitat monitoring sites are established at all fish reaches and detailed geomorphic surveys have been completed for most of the proposed treatment sections of Charley Creek. Continued assessment and revision of protocols used to monitor stream habitat are expected to ensure that the metrics being assessed are being monitored with sufficient precision to detect change, and to ensure that the metrics are related to critical habitat requirements of fish. The project has one more year of pre-treatment data proposed for 2010 and restoration treatments are expected to be implemented in 2011. A detailed restoration design needs to be completed prior to treatments being implemented.

Contents

Introduction

Pacific salmon (*Oncorhynchus spp.*) and steelhead (*O. mykiss*) declines have continued despite extensive restoration efforts directed at improving spawning and rearing habitat in tributary streams (Roni et al. 2002, Katz et al. 2007). Implicit in tributary restoration projects is the assumption that improvements to spawning and rearing habitat will lead to increases in freshwater survival that will in turn lead to increases in overall population growth (Budy and Schaller 2007). However, recent reviews of the responses of salmonids to habitat restoration projects have found that either 1) a population response was not detected, or 2) a population response was detected but there was no clear understanding of the mechanistic relationship between the fish response and the habitat restoration (Bayley 2002, Katz et al. 2007, Roni et al. 2008). Many past restoration projects have also lacked proper experimental designs to determine cause and effect mechanisms and have failed to meet objectives because of a poor assessment of factors limiting fish production, a limited understanding of critical watershed scale processes, and either a lack of monitoring, or monitoring at the wrong spatial and temporal scales (Roni et al. 2008).

There is now a growing awareness that restoration actions must aim to restore natural ecosystem processes, be of sufficient size to cause a population response, and be designed in an experimental fashion that will allow for detailed effectiveness monitoring (Roni et al. 2002, Bilby et al. 2004). In the Pacific Northwest watershed scale coordinated restoration efforts with associated effectiveness monitoring programs are being referred to as Intensively Monitored Watershed studies (IMW; Bilby et al. 2004, PNAMP 2005). A network of IMWs is being developed in the Pacific Northwest to evaluate the effectiveness of different restoration actions on fish populations and habitat across a range of watershed types (Bilby et al. 2004).

The Snake River Salmon Recovery Board (SRSRB) received funds in November 2007 to begin an IMW in the southeastern Washington area of the Snake River salmon recovery region. The SRSRB chose to implement an IMW in Asotin Creek after a comprehensive selection process. A detailed IMW experimental design, monitoring plan, and work plan was developed using a phased approach. Phase 1 included the identification of a suitable location for an IMW, development of an experimental and monitoring design, assessment of restoration goals, and initiation of fish and habitat monitoring. Phase 1 was completed January 31, 2009. Phase 2 was initiated on April 15, 2009. The main focus of Phase 2 was the refinement of the IMW experimental design developed in Phase 1, full implementation of baseline monitoring (including ground based LiDAR, aerial photography, bathymetry, fish, riparian, and stream habitat monitoring), installation of automated monitoring infrastructure such as PIT tag antenna arrays, water gauges, and temperature probes, and development of databases programs to store, analyze, and share the monitoring data collected. Phase 2 was completed February 28, 2010.

This report updates the progress of Phase 1 and 2 and proposes a work plan for Phase 3, which will support the third and final year of pretreatment monitoring programs, and the development of a restoration design and implementation plan. During Phase 1 preliminary restoration goals were developed based on a limiting factors analysis that was based mostly on a review existing watershed assessments (NRCS 2001, ACCD 2004) and limited field surveys. This plan did not contain specific design criteria of restoration elements, specific cost estimates, or a detailed implementation strategy. Developing a detailed restoration design and implementation plan will be a major focus of Phase 3.

Study Area

Asotin Creek is a tributary of the Snake River, flowing through the town of Asotin, in southeast Washington. The area is semi-arid, with rainfall ranging from 115 cm at higher elevations (1800 m) to less than 30 cm at lower elevations (240 m). The most common land use is pasture/rangeland (43%), followed by forestland (30%), and cropland (27%; ACCD 2004). Three species of salmonid populations listed as threatened under the Endangered Species Act (ESA) in the Asotin Creek watershed are summer steelhead, spring Chinook salmon (*O. tshawytscha*), and bull trout (*Salvelinus confluentus*; SRSRB 2006). The Snake River Salmon Recovery Plan identifies goals, objectives, strategies, and actions for steelhead and spring Chinook recovery. The ESA-listed Asotin Creek population of summer steelhead in the Snake River Distinct Population Segment was identified as the target of this IMW by the SRSRB's Regional Technical Team (RTT; ELR 2009).

Prior to the initiation of the IMW in Asotin Creek, ecosystem diagnostic and treatment (EDT) analysis was used to initially identify limiting factors for steelhead in the Asotin Creek watershed. The EDT analysis identified sediment, large woody debris (LWD), pool habitat, riparian function, stream confinement, summer water temperatures, bed scour, and flow as limiting factors for steelhead (ACCD 2004; SRSRB 2006). In addition, historic over-grazing, channel modification, flooding, road building, agriculture, and forest harvest activities were identified as key causes of stream degradation. The IMW experimental and monitoring design identified three tributaries of Asotin Creek as candidates for an IMW: Charley Creek, North Fork of Asotin Creek (North Fork), and South Fork of Asotin Creek (South Fork; ELR 2009). All three streams are in the upper Asotin Creek Major Spawning Area (MSA; Figure 1). Charley Creek is the proposed treatment stream, which has a basin area of approximately 58 square km. The North Fork and South Fork are proposed control watersheds with basin areas of approximately 104 square km and 57 square km, respectively.

Development of the Asotin Creek Intensively Monitored Watershed

Phase 1

Watershed Selection Process

In November 2007 funds were made available to the SRSRB to develop an IMW in southeast Washington. The SRSRB contracted Eco Logical Research Inc. (ELR) to coordinate the development of the IMW. Phase 1 of the southeast Washington IMW project had the following goals:

- Develop a process for selecting a location for an IMW in southeast Washington,
- Select a watershed(s) to implement an IMW,
- Determine the limiting factors for steelhead production and suggest restoration options,
- Develop an experimental and monitoring design, and
- Initiate preliminary pretreatment sampling.

The RTT in conjunction with ELR used the following series of activities to develop Phase 1 of the Asotin Creek IMW (each one of these activities is described in detail in ELR 2009):

- Coordinate with agencies engaged in project management and monitoring,
- Define goals of the restoration activities,
- Develop a set of criteria to use in the selection of an IMW,
- Review of past technical evaluations of a potential IMW,
- Refine questions into testable hypotheses,
- Determine the analyses used to identify limiting factors,
- Develop an experimental design,
- Determine the restoration activities for the study,
- Develop an effectiveness monitoring design,

- Develop a data management system,
- Develop and IMW work plan
- Provide peer review of the experimental design and work plan, and
- Collect baseline field data, beginning in July 2008.

A set of ecological and socio-political criteria were used to rank potential locations (watersheds) for the IMW (Table 1). Asotin Creek best met these criteria and therefore was selected as the location for an IMW in southeast Washington. Asotin Creek is desirable as an IMW in this recovery region, in part, for the following reasons:

- Is an area of regional concern with strong agency and land owner support,
- Has a large wild steelhead population (< 13% hatchery fish; Mayer et al. 2008),
- Past restoration reduced many imminent threats (Browne et al. 1995, ACCD 2004, SRSRB 2006),
- Is a single MSA with criteria and benchmarks to assess steelhead recovery,
- WDFW has long-term data on adult escapement and juvenile abundance (1980s – present), and has operated a smolt trap since 2004 and adult weir since 2005, and
- Historic data available for stream habitat (e.g., USFS 1996, NRCS 2001) and water quality (e.g., discharge, water temperature, sediment, nutrients; WSU 2000, Bumgarner et al. 2004).

Limiting Factors

Prior to the initiation of the IMW study in Asotin Creek, EDT analysis was used to identify limiting factors for steelhead in Asotin Creek (SRSRB 2006). Common limiting factors that were identified in the Asotin Creek subbasin were related to riparian function and included increased sedimentation, substrate embeddedness, water temperature, decreased riparian function, floodplain connectivity, habitat diversity, low LWD, and low pool frequency and quality. These limiting factors appear to be caused by over-grazing, channel modification, flooding and flood control efforts, road building, agriculture, housing development and forest harvesting. Restoring riparian function can potentially take many years due to the length of time it takes to establish native vegetation (e.g. fencing, cattle exclusion, planting). The current riparian forests are dominated by young alder and some willow and water birch. This woody vegetation likely provides adequate shading and organic and terrestrial invertebrate inputs tend to be higher in alder dominated systems relative to conifer dominated riparian areas (Wipfli 1997). However, the riparian forests in the study streams seemed to provide little LWD (i.e.> 30 cm diameter) inputs (ELR 2009). Smaller diameter LWD tend to decay faster than large pieces and 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 pools in Asotin Creek than is predicted for similar streams in reference conditions (i.e. natural conditions unaltered by development). This was the finding of preliminary analysis that found both LWD > 30 cm diameter and deep pools were substantially lower than reference conditions (ELR 2009).

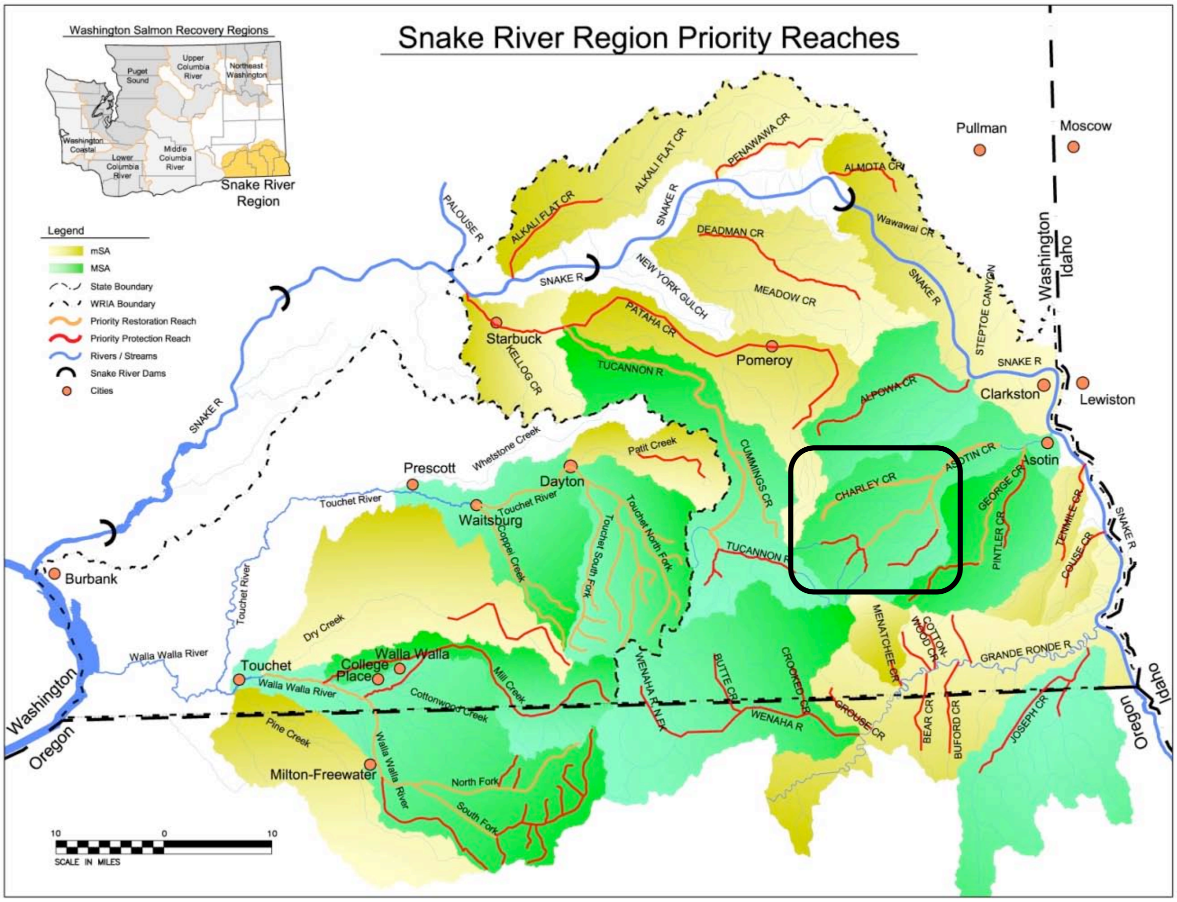

Figure 1. Snake River salmon recovery region showing summer steelhead MSAs, priority restoration/protection reaches (SRSRB 2006). The upper Asotin Creek MSA and the IMW are located within the outlined area west of the towns of Asotin and Clarkston.

Proposed Restoration

Charley Creek was selected as the treatment stream and it is proposed that riparian function be restored via riparian fencing, native plant reestablishment, and LWD additions. The lower 12 km of the stream will be treated. The treatment section is mostly private land owned by two landowners (who support the project). The riparian fencing and planting of native riparian vegetation are proposed to treat the damage caused by current and historic cattle grazing, channelization, flooding, and riparian harvest activities (ACCD 1995; NRCS 2001; ACCD 2004). Riparian fencing should help to increase and protect riparian vegetation. A mature riparian forest will lead to an increase in canopy cover that should result in decreased temperatures providing a thermal environment closer to the energetic optima of steelhead, resulting in an increase in growth rates. In addition, allocthonous inputs will increase primary and secondary production, and increase growth rates of fishes. Perhaps more importantly in Charley Creek, a mature riparian forest will provide a constant source of LWD. The lack of LWD has likely resulted in a high gradient, low complexity system (few pools and high velocity currents).

The addition of LWD has been proposed to simulate natural LWD volumes based on estimates of reference conditions described in the literature (Carlson et al. 1990, Fox and Bolton 2007) and from USFS stream habitat surveys (unpublished data). The addition of LWD is expected to accelerate the formation of pools, creating a step/pool longitudinal profile, to replace the current high gradient plane bed morphology in Charley Creek. Greater habitat complexity from more frequent and deeper pools provides refuge from predation, interference competition, and high velocity current. Decreases in energetic expenditures (e.g., temperature and refuge, increases in energetic inputs (e.g., production), and decreases in mortality (e.g., predation) are expected to increase survival rates, carrying capacity and ultimately production of the early life stages of steelhead in Charley Creek. LWD has also been shown to sort sediments by collecting fine sediments and redirecting currents that recruit gravels. These processes increase spawning habitat through a decrease in embeddedness and increase in spawning gravels resulting in an increase in steelhead production and survival rates.

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

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

Phase 2

Phase 2 of the Asotin IMW was initiated April 15, 2009 and will be completed Feb 28, 2010. The primary goals of Phase 2 were to:

- Refine the existing IMW experimental and monitoring design,
- Install PIT tag arrays, water gauges, and temperature probes,
- Continue pretreatment fish and stream habitat monitoring, and
- Initiate baseline stream channel and floodplain assessments using light detection and ranging (LiDAR), low elevation photography, and detailed bathymetry studies.

Refinement of Experimental and Monitoring Deign

The majority of the original experimental and monitoring design was unchanged after a review during Phase 2. The main changes are summarized below:

1. Fish sampling was changed to sample a summer and fall session. This was a change from spring and summer sampling and was done because of the logistical difficulties of sampling in the spring.
2. Ground based LiDAR was implemented instead of aerial LiDAR. Low elevation photography was conducted with a blimp to supplement the ground based LiDAR and provide continuous sampling of the treatment stream.
3. Three pass mark recapture robust design was conducted in the summer session to increase the recapture rate compared to two pass (50-60% vs. 15-20%) and to allow calculation of capture efficiency.
4. Mobile antenna surveys were implemented to increase resighting of tagged fish. The number of fixed antennas planned in the original design were reduced to the following locations: mouth of Charley Creek, North Fork Creek, South Fork Creek, and the lower mainstem Asotin Creek. All arrays have been have been collecting data since August 2009 and weekly assessments of the read range and antenna performance have been conducted since their installation. See below for a summary of antenna detections.

Revised IMW Experimental and Monitoring Design

The original IMW design was peer reviewed by regional habitat restoration and monitoring professionals and state and federal agencies. The design was approved by the RTT in January 2009, and serves as the template for further monitoring and implementation of habitat improvement treatments (ELR 2009). The first year of three years of pretreatment monitoring was initiated in the summer of 2008 and data collected were used to further assess the experimental and monitoring design. During Phase 2 the design was revised based on the first year of pretreatment monitoring and further discussions with the RTT. The following briefly summarizes the revised design elements.

Experimental Design

To increase the power to detect changes in the physical habitat and steelhead population response, comparisons will be made between treatment and control sites, before and after the implementation of the restoration activities. These before-after-control-impact (BACI) designs have been employed in areas where replication is low (or not possible) to optimize detection of environmental impacts (Roni et al. 2005). Rather than use a traditional BACI design, a hybrid design that allows for an evaluation of spatial and temporal extents was adopted. A nested hierarchy has been implemented to compare restored treatment sections within Charley Creek to control sections in North Fork and South Fork to evaluate the spatial influence of the actions. The nested hierarchy design will delineate three sections of the lower 12 km of Charley Creek (Figure 2). Restoration treatments will be implemented in each section every 2-3 years in a "staircase" design, which will help assess initial period effects. These sites will also provide a time contrast in riparian function trajectories (Walters et al. 1988) and provide a longer pre-treatment time series within the treatment stream. At the watershed scale, Charley Creek will be compared to North Fork and South Fork of Asotin Creek. Because a goal of the IMW approach is to inform the region of the effectiveness of different restoration strategies, the results of the experiment needs to be somewhat transferrable. Because replication of experiments of this size are logistically and financially constrained, an understanding of the mechanism is necessary to extrapolate observed responses (Carpenter et al. 1995) which requires greater detail of monitoring information than standard status and trend monitoring programs.

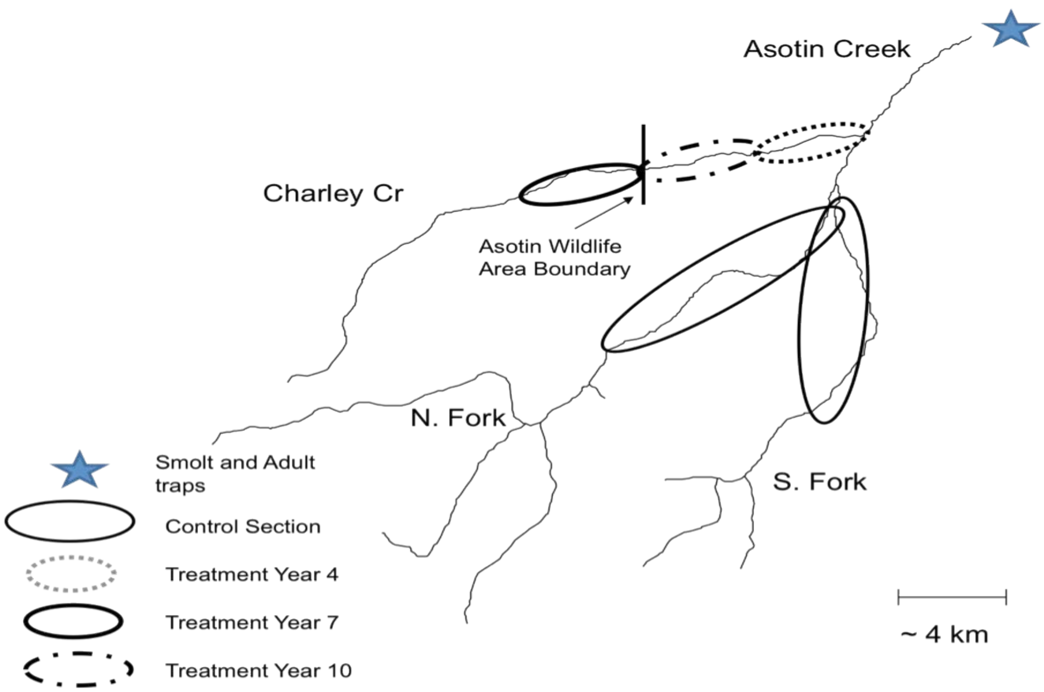

Figure 2. Experimental design of the Asotin IMW in southeast Washington.

Monitoring Design and Sample Methods

The monitoring design is composed of four components: fish, stream habitat, riparian habitat, and stream channel/floodplain monitoring. The specific protocols used to monitor the different components are regionally recognized protocols that will allow efficient and precise data collection, and data sharing between various agencies. Most monitoring activities are focused on Charley Creek, North Fork, and South Fork Creeks (Figure 3). PIT tag antennas were installed at the mouth of Charley, North Fork, South Fork Creeks, and in the mainstem of Asotin Creek. All monitoring activities will be integrated with ongoing WDFW's Asotin Creek Assessment Project (Mayer et al. 2008).

An important goal of IMW projects is to test and develop the most effective monitoring tools for change detection. Although the Asotin IMW is using the most accepted protocols for stream habitat monitoring, recent reviews of a variety of stream protocols have demonstrated that several attributes are not measured consistently between observers or with enough precision to detect moderate changes (Olsen et al. 2005, Whitacre et al. 2007, Bunte and Abt 2009, Roper et al. *in press*). It is also important to note that it is not always clear how the specific metrics used to monitor stream habitat are related to the habitat requirements of fish, which is an often unstated assumption of the monitoring program. For example, the size distribution of substrate is often measured with pebble counts because research has shown that increased fine sediments can negatively impact salmonids redds (Quinn 2005). However, fines sediments are often underestimated in pebble counts or the location of pebble counts are not stratified by habitat type so the percent fines represents an average across several habitat types (Bunte and Abt 2009). Due the difficulty in measuring stream habitat, the IMW will continually review the monitoring protocols that are used in an effort to use those protocols that focus metrics that are precisely measured, strongly correlated with the truth, and are related to fish production.

Fish

The IMW design calls for monitoring steelhead migration, spawning, juvenile abundance, and juvenile survival. Adult and juvenile migration and spawning activities are monitored by existing WDFW operation of an adult weir and smolt trap on the mainstem Asotin Creek and redd counts throughout the study streams (Mayer et al. 2008, Mayer et al. 2009). These data will be used as part of the IMW monitoring program. For example, adult fish captured at the WDFW weir will be PIT tagged to allow detection of returning adults to the tributary streams.

To determine juvenile abundance in the treatment and control streams the IMW design calls for mark-recapture sampling in six fish reaches in Charley Creek, and three reaches in both North Fork and South Fork Creeks (Figure 3). Each reach is approximately 400-500 m long. Fish are captured using electro-herding with low voltage electroshocking to scare fish downstream into seine or dip nets. Seine nets have a modified fyke net to increase capture efficiency. All juvenile steelhead and bull trout over 70 mm are tagged with 12 mm PIT tags, measured (total length), weighed, and released. The reach is resampled on the following 1-2 days in the same manner and abundance is calculated using Petersen method (two pass; Seber 1992) or the Schnabel method (three pass; Schnabel 1938). More advanced population estimates and survival estimates (e.g., the Barker model) will be employed with the use of the program MARK (Cooch and White 2006) using multiple resighting of marked fish from abundance estimates, fixed PIT tag arrays, and Columbia River arrays during outmigration.

Juvenile abundance at each reach is monitored during two seasons each year: spring/summer and fall. Sampling within these two seasons will allow calculation of growth and survival parameters for juvenile fish for the summer and winter/spring seasons with the use of mark recapture techniques in conjunction with PIT tag antennas. Approximately 1500 juvenile steelhead will be tagged each sample session.

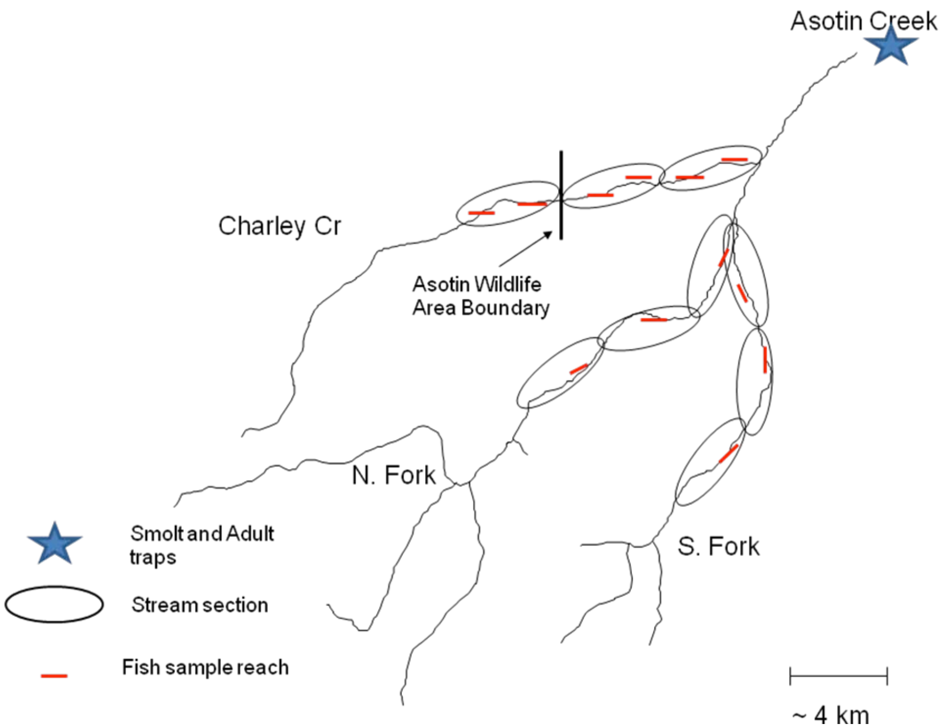

Figure 3. Fish abundance and tagging reach locations in Asotin Creek. Three stream habitat reaches are located within each fish reach. Fish reaches are approximately 400-500 m long and stream habitat reaches are approximately 160-200 m long.

Habitat

Stream habitat characteristics will be measured using protocols described by the PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program stream habitat protocols (Heitke et al. 2008). The surveys will be used to quantify key characteristics including pool frequency, LWD abundance, width to depth ratio, and substrate size. Stream habitat will be measured at 12 permanent sites and 12 alternate sites each year (24 sites total). Riparian habitat will be sampled along 20 m transects perpendicular to the stream within each PIBO stream survey reach also using PIBO protocols. Plant cover, tree age and diameter and the extent of the riparian zone will be measured.

Stream channel and floodplain characteristics will be measured using ground based LiDAR technologies (Jones et al. 2007), low elevation aerial photography, and detailed mapping of the streambed with total station and GPS technologies. These tools will allow measurement and change detection of the extent of riparian vegetation, canopy cover, stream geomorphology, including cross-section geometry, planform sinuosity, longitudinal gradient profile and habitat unit identification (Jones et al. 2007; McKean et al. 2008, Vericat et al. 2008). The IMW is actively testing how these technologies compare to standard stream habitat protocols such as PIBO and which approaches are the most cost effective at providing detailed assessments of habitat change. An area of focus is to measuring habitat metrics in a spatially explicit manner that will allow not only the estimation of the mean response of habitat to restoration, but the detection and understanding of the mechanisms by which change has occurred and its direct and indirect impact on fish production.

Hypotheses, Response Variables, and Expected Outcomes

The specific hypotheses of the IMW are:

- Additions of LWD that simulate natural LWD inputs will lead to a doubling of pool abundance (i.e. mean of 4.2 pools/100 m to 8.4 pools/100 m) in the lower 12 km of Charley Creek within 1-3 years after addition of LWD relative to change in pool abundance in control watersheds.
- A doubling of pool abundance as a result of the LWD inputs will lead to at least a 50% increase in juvenile steelhead density and abundance within the treatment sections 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.
- A doubling of pool abundance as a result of the LWD inputs will lead to a 50% increase in juvenile steelhead production (as measured by the number of smolts/spawner) within the treatment sections 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.

To evaluate whether fish are responding to changes in habitat as expected it was recommended that the following list of response variables be assessed. Some of these variables may be difficult to measure with sufficient precision to be useful in modeling fish response to treatments; however, all of these response variables will be assessed to determine which variables will provide the most robust assessment of treatment effects.

Possible response variables for steelhead include:

- Smolts/spawner, smolt-to-adult ratio (SAR), recruiting adults (R/S),
- Population abundance and spatial distribution,
- Seasonal and parr-to-smolt survival, and
- Migratory timing, size, and growth rates.

Statistical Modeling and Power Analysis

One of the main purposes of a monitoring program is to detect changes in a particular variable of interest over time. Serious concerns have been raised about the ability of many fish and stream habitat monitoring programs to detect biologically meaningful changes due to confounding factors such as high natural variability in many ecological variables, poorly designed monitoring programs, inconsistent monitoring protocols, and low statistical power (Larsen et al. 2004, Roni et al. 2008). Power curves for the Asotin IMW were developed based on the experimental design and measures of variability that were calculated from preliminary sampling and that are available in the literature (Gibbs et al. 1998, Roper et al. in press; Figure 4). The power curves provide an estimate of the range of statistical power we can expect based on different levels of variability and the mean effect size we wish to detect. These results indicate that to achieve 80% power after one treatment a mean difference of approximately 25 fish /100 m^2 is required (i.e., a doubling of the density based on a mean of 26 fish /100m^2 based on 2008 sampling results).

However, once all three treatments have been applied, a 50-60% increase in the population should be able to be detected with the same level of power. These power curves are worst case scenarios and do not take into account increases in capture efficiency that are possible with our mark recapture technique (i.e. increase recaptures by more intensive recapture effort and improvement of capture methods).

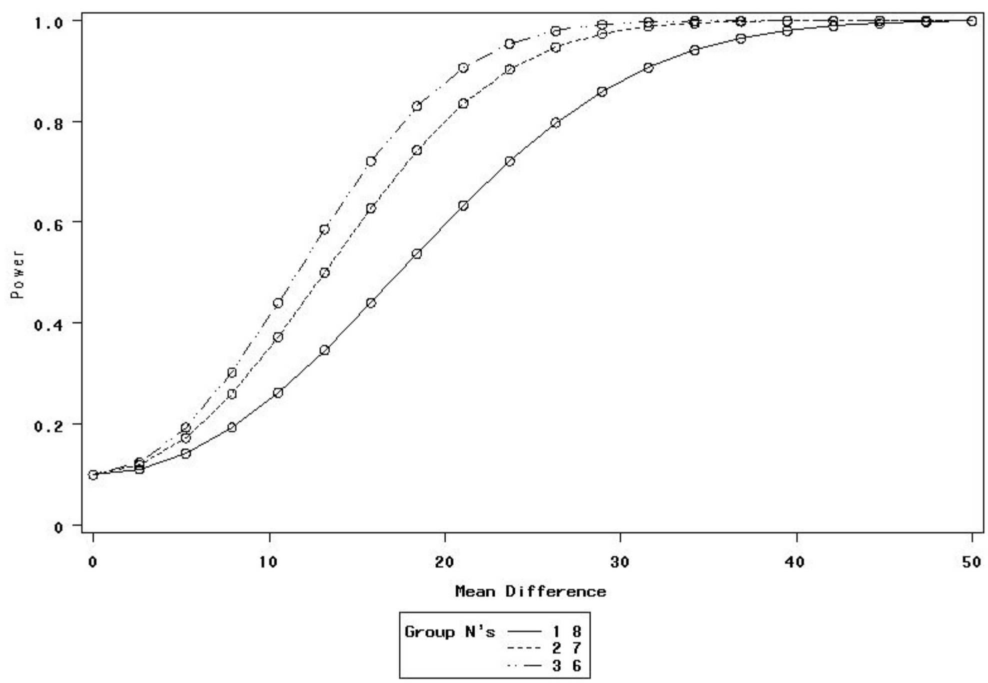

Figure 4. Power curves for two-sample t-test of the mean difference between treatment and control means for a variety of treatment options. Groups refer to the number of treatments (first number) and the number of controls (second number). Power curves for three scenarios that relate to the years each treatment (i.e. replicate) is applied to Charley Creek. To achieve 80% power after one treatment a mean difference of approximately 25 fish /100 m^2 is required (i.e. a doubling of the density based on a mean of 26 fish /100m^2 based on 2008 sampling results). Power curves based on a SD = 9 and $\alpha = 0.1$.

Further power analysis is being conducted using statistical modeling of the experimental design and simulation with preliminary data. The main goal of these efforts it to further test the power of the experimental design and develop a model that will be able to separate the natural variance inherent in the system (yearly variances, variances between streams, variances between reaches, etc.) from the possible response. To date these simulations indicate that the IMW staircase experimental design is robust to the know variance sources and has slightly more power to detect changes in fish response compared to a traditional BACI design (~ 75% to detect a 50% increase after one treatment). The parameters that will be used in the staircase model are provided in table 2.

Table 2. Hierarchical/Staircase model parameters to be used in modeling fish response to restoration treatments in the Asotin IMW project. YAR denotes the "years."

Source	DF	Fixed or Random	Symbol	Subscript
Year	11	Random	y	h
Season	1	Fixed	α	i
Year*Season	11	Random	(yα)	hi
Creek	2	Fixed	β	j
Year*Creek	22	Random	(yβ)	hj
Season*Creek	2	Fixed	(αβ)	ij
Year*Season*Creek	22	Random	(yαβ)	hij
YAR*Creek	9	Fixed	(βτ)	jk
Section(Creek)	6	Random	s	jl
Year*YAR*Section(Creek)	57	Random	(yτs)	hjkl
YAR*Season*Creek	9	Fixed	(αβτ)	ijk
Year*YAR*Season*Section(Creek)	63	Random	(yατs)	hijkl
Reach(Section*Creek)	3	Random	r	jlm
Year*YAR*Reach(Section*Creek)	33	Random	(yτr)	hkjlm
Residual Error	36	Random	e	hijklm

How Much Restoration is Enough?

Roni et al. (2009) recently demonstrated that "how much restoration is enough" can be estimated from known responses of steelhead and coho (*O. kisutch*) abundance to common instream LWD restoration treatments. These estimates are based on research that has been conducted on the west side of the Cascade mountain range (e.g., Cederholm et al. 1997, Solazzi et al. 2000). There are no published studies that demonstrate steelhead responses to restoration on the east side of the Cascades. However, there is one long-term unpublished WDFW study that tested the effectiveness of LWD treatments to increase abundance of fishes in Asotin Creek and Tucannon River, both east side streams (Viola et al. 1989). The goal of the WDFW study was to use LWD and boulder structures to increase pool habitat and fish abundance (particularly age $\geq$ 1+).

The Viola et al. (1989) study used treatment and control reaches and measured fish abundance pre-treatment and post treatment (1 and 5 years post treatment). The mean response of juvenile steelhead (age > 1+) from this well designed study was 15.1 fish/100 m^2. This estimate of steelhead response was used to determine how many pools would need to be created in Charley Creek to increase the overall abundance of steelhead by 25% in the lower 12 km (i.e., the treatment section). It was assumed that each treatment (i.e., LWD addition) in Charley Creek would create an average sized pool (24.5 m^2 based on 2008 and 2009 PIBO surveys). Based on the Viola et al. (1989) study the addition of a pool in Charley Creek should result in an increase of 3.7 fish/pool (i.e., 15.1 fish /100 m^2 * 24.5 m^2). To estimate "how much restoration is enough" in Charley Creek, the percent increase in the population of steelhead was calculated for each additional pool added to the 12 km treatment reach (Figure 5). The current number of pools in treatment reach is approximately 500 pools and the current steelhead population is 11,520 fish based on two years of pretreatment sampling. These were used as the starting points for this simulation. To increase the overall steelhead population by 25% (i.e., an additional 2,880 fish), there would need to be an additional 780 pools (i.e., 160% increase in the number of pools; Figure 5).

These calculations should be treated with caution as they are based on one treatment study and do not take into account the natural variability in fish populations within and between years at the reach, stream, and watershed scales. Also, the original response estimate from Viola et al. (1989) assumes that the increases measured are a result of increased production. Studies have found that fish measured at treatment sites have moved there from somewhere else and are not necessarily a product of increased production (Gowan and Fausch 1996). Also, preliminary results suggest that growth may be poor and habitat restoration may result in better growth and ultimately survival and not overall increases in abundance (see Fish Growth Section below). The proposed experimental and monitoring design using multiple scales of data and measuring true freshwater production via smolt/spawner is the best way to measure whether there is a true population response to the proposed treatments.

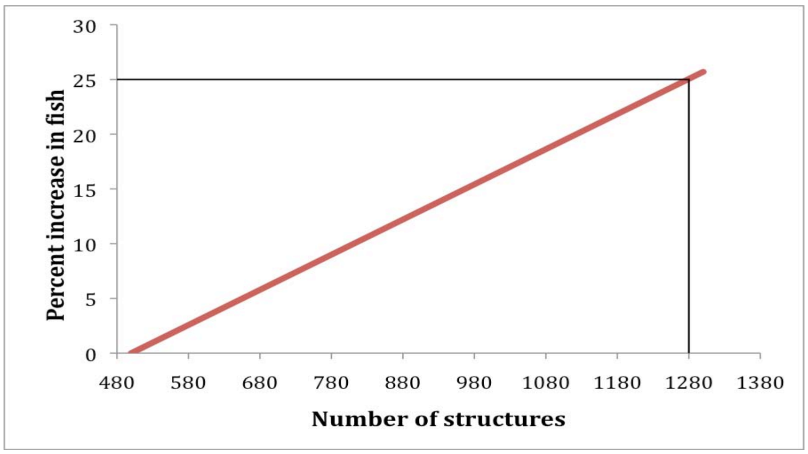

Figure 5. The amount of restoration (LWD structures) that may be required to increase the overall population of age $\geq$ 1+ juvenile steelhead in the lower 12 km of Charley Creek by 25% (i.e., 2,880 fish) using LWD treatments to create pools. Estimates of mean fish response to LWD = 15.1/100 m^2 based on Viola et al. (1989).

Assumptions and Contingencies

The primary response variable of interest is smolts/spawner which is a direct measure of freshwater production. The main assumptions in the development of this IMW design are that:

- Lack of pool habitat historically created by LWD is a major limiting factor in Asotin Creek;
- Proposed treatments will be of sufficient size to cause a measurable effect;
- Proposed sampling design has sufficient power, specifically:
    - That enough fish can be captured, marked, and recaptured to provide relatively precise estimates of abundance and survival;
- Changes detected will be attributable to the treatments (i.e. causal relationship); and

If some of these assumptions are invalid possible contingencies include:

- Increasing the size of the treatment (density, extent, or both) if treatment of the first 4 km does not cause the expected change in pool frequency and juvenile abundance (an advantage of the staircase design).
- Increasing capture techniques by using higher voltage electroshocking, the frequency of sampling (e.g. sample for three or four consecutive days instead of two), and/or resighting rates by using mobile antenna surveys (Roussel et al. 2000).

Causal mechanisms should be revealed due to the hierarchical structure of the design, the multiple controls within and between streams, and the multiple monitoring programs.

Data Management System

The IMW will work with the Integrated Status and Effectiveness Monitoring Program (ISEMP 2008) to develop normalized database tools. ISEMP has created data management tools, called automated template modules (ATMs) that are MS Access based databases residing on agency computers, providing users with database structures that ensure that newly collected data and historic data are structured with consistent formats. These databases also ensure metadata is directly linked to raw data, and that a minimum level of data quality is assured at the time of data entry. For example, through the use of these templates, ISEMP has compiled, cleaned, and summarized approximately 4 million temperature records from nearly 3000 spreadsheets into a single, consistent database.

Pre-treatment Monitoring Results

Two years of pre-treatment monitoring of the fish populations and stream habitat have been competed in Asotin Creek (2008 and 2009). The following section summarizes the pretreatment data (both years combined) for the major attributes of interest in the IMW study. All the fish tagging and resighting data and stream habitat data are stored in temporary Access or Excel databases (see Appendices). These databases are currently being used to store the data, run QA/QC queries on the data, and provided general summaries of the data. These databases will be integrated with ISEMP databases as those databases are completed. Where appropriate data will also be available using an Asotin IMW website.

Juvenile Abundance and Tagging

Mark-recapture procedures have been used to estimate steelhead juvenile abundance in the summer and fall seasons in Charley Creek, North Fork and South Fork Creek. Nine reaches were sampled in the summer of 2008, 12 reaches in the summer of 2009, and 12 reaches in the fall of 2009. All juvenile steelhead captured (> 70 mm) were tagged with 12 mm PIT tags. Since 2005 13,648 PIT tags that have been implanted in juvenile steelhead by the Asotin Creek Assessment project (WDFW) and the two phases of the IMW pretreatment monitoring (Appendix 1; Table 3).

Table 3. Summary of the number of juvenile steelhead (> 70 mm) PIT tagged in Asotin Creek from 2005-2009.

			YEAR			
Stream	**2005**	**2006**	**2007**	**2008**	**2009**	**Total**
Asotin Creek*	2,462	1,552	1,895	1,862	869	8,640
Charley Creek	-	-	-	454	1,925	2,379
North Fork	-	-	-	410	578	988
South Fork	-	-	-	615	1,026	1,641
Total	2,462	1,552	1,895	3,341	4,398	**13,648**

* Fish PIT tagged in Asotin Creek were captured at the WDFW smolt trap on the mainstem. All other fish were captured in tributaries during IMW mark recapture surveys.

A minimum of two pass mark-recapture estimates were conducted at each reach during 2008 and 2009. In the summer of 2009 three pass mark-recapture estimates were used to test assess if precision in estimates would be significantly increased. The mean summer abundance of steelhead was highest in South Fork and Charley Creek (25 fish/100m2; Figure 6). These mark-recapture estimates are very similar to estimates of juvenile steelhead based on smolt trap surveys (26.3 fish/100m2; Mayer et al. 2008). Confidence intervals for the two pass mark-recapture surveys were relatively high (+ 30-40%) and overlapped between streams. The mean recapture rate for all study streams based on two pass mark recapture was 20.3%.

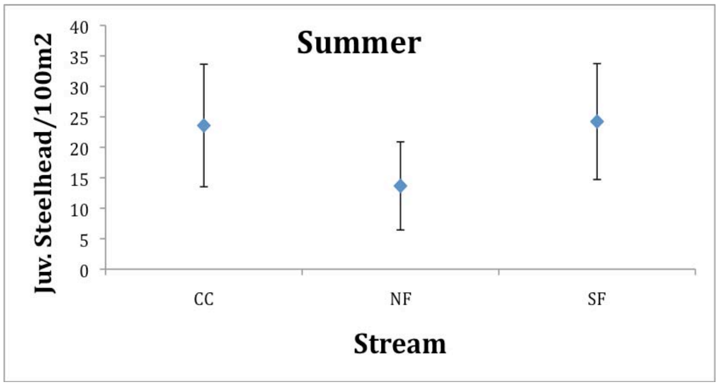

Figure 6. Mean summer abundance of juvenile steelhead (> 70 mm) in Asotin IMW study streams (CC - Charley Creek, NF - North Fork Creek, and SF - South Fork Creek). Error bars represent 95% confidence intervals based on 2 pass mark-recapture estimates.

The mean fall abundance estimates were uniformly lower and the number appeared to be lowest in South Fork Creek (Figure 7). This may suggest that fish are moving out of South Fork Creek in the late summer, possibly due to high temperatures noted in South Fork Creek and cooler summer temperatures in Charley Creek (see temperature results below). Confidence intervals were narrower due to the greater recapture rates. The mean recapture rate in the fall was 30.1%.

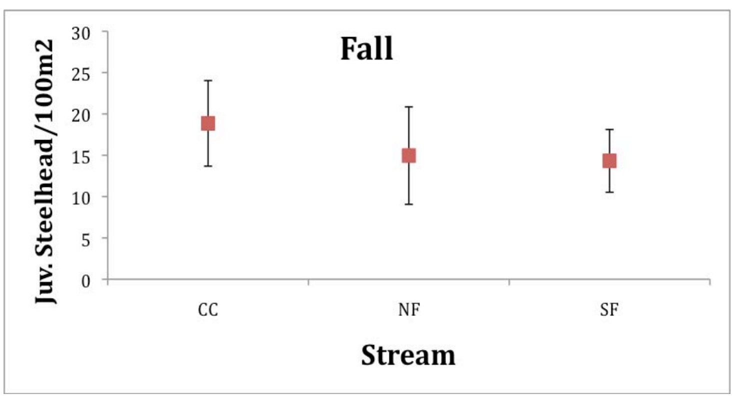

Figure 7. Mean fall abundance of juvenile steelhead (> 70 mm) in Asotin IMW study streams (CC - Charley Creek, NF - North Fork Creek, and SF - South Fork Creek). Error bars represent 95% confidence intervals based on 2 pass mark-recapture estimates.

Use of three pass mark-recapture estimates increased the precision of population estimates in Charley Creek and South Fork Creek (estimates of abundance in North Fork Creek were not possible in the summer session due to high stream flow; Figure 8). Fish movement between reaches appeared to be very low as 95% of all fish tagged in a reach were recaptured in the same reach during abundance surveys within the same season, between seasons, and between years. This partly explains why two pass sampling in the fall of 2009 provided relatively precise population estimates compared to three pass estimates during the summer of 2008. A large percentage of the population was marked in the summer session which helped increase the recapture rate of marked fish in the fall. A test of the model assumptions of the mark-recapture technique also suggested that fish are not moving out of the sample reaches during the mark-recapture surveys and that the assumptions of the technique (no immigration, emigration, births, or deaths during the survey) are not being violated (Figure 9; Schnabel 1938).

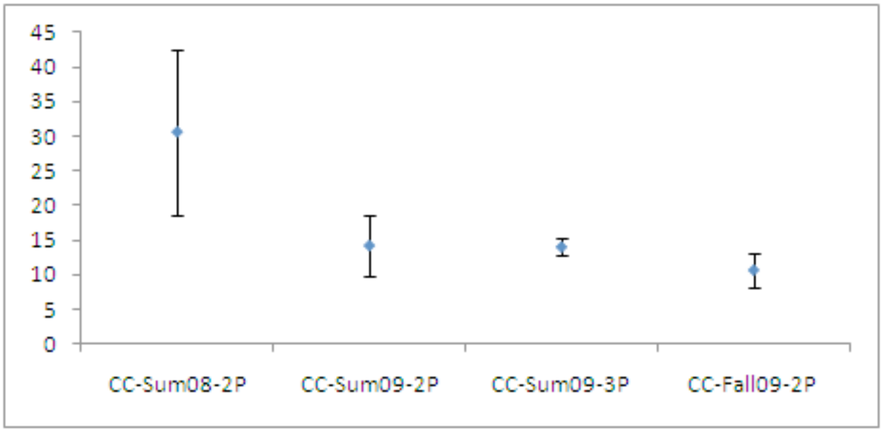

Figure 8. The population estimates for reach 3 of Charley Creek based on two pass sampling in the summer of 2008 (CC-Sum08-2p), two pass sampling in the summer of 2009 (CC-Sum09-2P), three pass sampling in the summer of 2009 (CC-Sum09-2P), and two pass sampling in the fall of 2009 (CC-Fall09-2P). Error bars equal 95% confidence intervals.

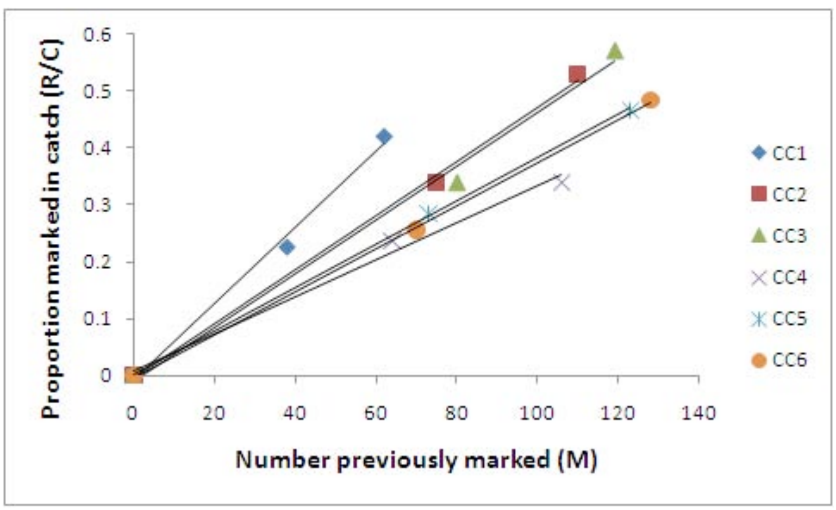

Figure 9. Test of the mark-recapture model assumptions using three pass mark-recapture estimates for Charley Creek (reaches 1-6) from the summer of 2009. The relationship should be linear between the number previously marked and the ration of recaptures/captures if the assumption s of the model are met (r^2 for all regressions >0.98).

Fish Growth and Potential Response to Restoration

The Fish Bioenergetics 3.0 model (Hanson et al. 1997) was used to conduct a preliminary investigation into the potential benefits of the planned restoration treatment of creating more pools in Asotin Creek using LWD structures. Mark recapture data collected from June to October 2009 was used to calculate the average growth of individual age classes. These data plus water temperature data collected at each fish reach was used to model consumption under a variety of water velocity scenarios (i.e., slow velocity = pool habitat and high velocity = riffle habitat). The results of the growth analysis suggest that current growth is relatively poor over summer and early fall period especially for age class 2 and 3 (Table 4). When moderate decreases in water velocity were simulated (i.e., adding LWD to create pools) positive fish growth was observed for all fish ages. These analyses are preliminary but they suggest that poor juvenile growth in Asotin Creek could be compensated by increased pool habitat (i.e., decreases water velocities). Increased juvenile growth could in turn lead to increased survival within the stream and/or during migration, resulting in increased adult returns.

Table 4. Average weight change (grams) by age class and stream from June to Oct 2009.

	Age*		
Stream	1	2	3
Charley Creek	3.39	-0.64	-5.32
North Fork	1.61	1.16	-4.80
South Fork	4.36	0.70	-5.00
Total	3.48	0.06	-5.14

* Age 1 < 115 mm, Age 2 < 160 mm, Age 3 >= 160 mm

PIT Tag Detections

Fixed antenna detections

Three PIT tag arrays were installed in July 2009. An antenna array was installed at the Cloverland Bridge approximately 20 km from the mouth of Asotin Creek, at the mouth of Charley Creek, and an array was installed at the confluence of North Fork and South Fork Creek (i.e., the Forks; Figure 10). The antenna array at the Forks have antennas that cross the mouth of South Fork Creek, North Fork just upstream of the junction with the South Fork, and the mainstem Asotin just downstream of the confluence of North Fork and South Fork (Figure 10). These three arrays allow detection of tagged fish entering or leaving the Charley, North Fork, and South Fork Creeks and fish entering or leaving Asotin Creek (i.e., passing downstream of Cloverland Bridge).

All the fish tagged at the smolt trap in the lower reach of Asotin Creek were only detected at the Cloverland array which is downstream of the smolt trap on the mainstem of Asotin Creek (Table 5). Only 24 steelhead that were captured in the tributaries during the summer and fall of 2008 and 2009 moved downstream and were detected passing the Cloverland array. However, 83 fish moved out of the tributaries including 3 fish that moved upstream form Charley Creek where they were tagged to the array on the mainstem at the Forks. Also, one fish from tagged in the South Fork moved downstream to Charley Creek and entered Charley Creek (Table 5). This demonstrates there is fish movement between tributaries. Movement patterns and timing of migration will be further assessed.

Each antenna and data recorder is checked every 1-2 weeks depending on flows and fish migration patterns. All the data are downloaded and backed up upon each antenna inspection. A test tag is used to measure the detection range of each antenna and the data logger provides information that power output and background noise of each antenna. To date the average read range and power output at each antenna has been good (> 40 cm at Cloverland and Asotin Forks sites using a MUX reader and > 20 cm at Charley Creek using a single antenna reader). Detection probabilities of each antenna array will be calculated from the Barker model using data from fish that pass multiple antennas. For example, fish tagged in the tributaries may pass an antenna at the mouth of a tributary undetected but detected downstream at Cloverland Bridge. These data will be used to estimate detection efficiencies.

Table 5. The number of juvenile steelhead detected at PIT tag antenna arrays in Asotin Creek between Aug 1, 2009 to January 21, 2010. Detection location refers to the location of the PIT tag antenna arrays and the tag location refers to the location where the fish were tagged.

Detection Location	Tag Location			
Array Name	Trap*	Charley	N Fork	S Fork
Cloverland	275	5	9	10
Asotin Forks		3	28	52
Charley Mouth		91		1
NF Mouth		3	22	26
SF Mouth			4	58

* Trap refers to the smolt trap operated by the WDFW on the mainstem Asotin Creek.

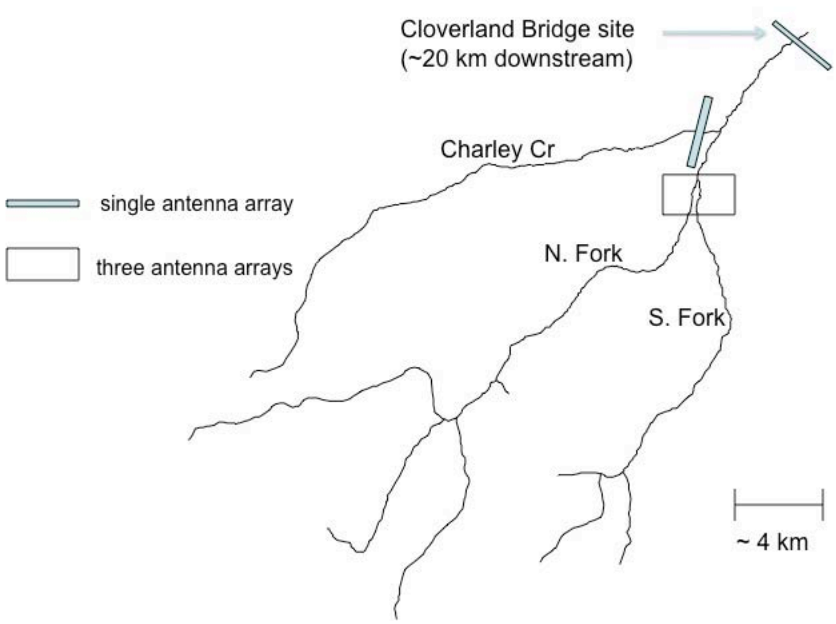

Figure 10. Antenna array locations within the Asotin Creek IMW study. The arrays at the junction of North Fork and South Fork span the mouth of the North Fork, South Fork, and mainstem Asotin Creeks (i.e., Asotin Forks).

Mobile antenna detections

We conducted trial mobile antenna surveys between the summer and fall sampling sessions in 2009. A FS2001F-ISO Reader and wand was fixed to a pole and used to scan the stream for tagged fish. Two trial reaches were surveyed with the mobile antenna (Charley Creek reach 4 and South Fork reach 3) during the day and night and surveys extended 100-300 m upstream and downstream of each reach. Night surveys were more effective at resighting tagged fish: approximately 30% resighting at night of fish tagged the previous session versus 17% resighted during the day. These trials will be used to develop a mobile sampling protocol to increase resighting of tagged fish to improve survival estimates and estimation of other population parameters.

Habitat Sampling

A total of nine stream habitat surveys were conducted in 2008 and 24 surveys were conducted in 2009 using PIBO protocols (Appendix 2). All the sites surveyed in 2008 were resurveyed in 2009 as per the monitoring design (i.e., permanent and alternate sites). The stream habitat sites overlap the fish survey sites so that direct comparisons can be made between fish abundance and habitat conditions (Figure 3). Below we summarize key habitat attributes that the IMW will focus on, and compare treatment and control sites to each other and to estimates of reference conditions.

Large Woody Debris

During the first year of pretreatment monitoring in 2008, the abundance of large woody debris was found to be significantly lower in all study streams compared to mean abundance of LWD in reference conditions from published and unpublished reports from similar sites in eastern Washington (Carlson et al. 1997, Fox and Bolton 2007, PIBO 2008). The combined results from both years of pretreatment monitoring showed the same significant difference between the abundance of LWD in each treatment stream and reference conditions ($p < 0.001$; Figure 11). On average the Asotin study streams had < 20 pieces of LWD/100 m compared to over 40 pieces/100 m at the reference sites. The Tukey multiple comparison test showed that all the Asotin study streams and UNF managed streams did not have a significantly different mean number of LWD/100 m ($p > 0.2$)

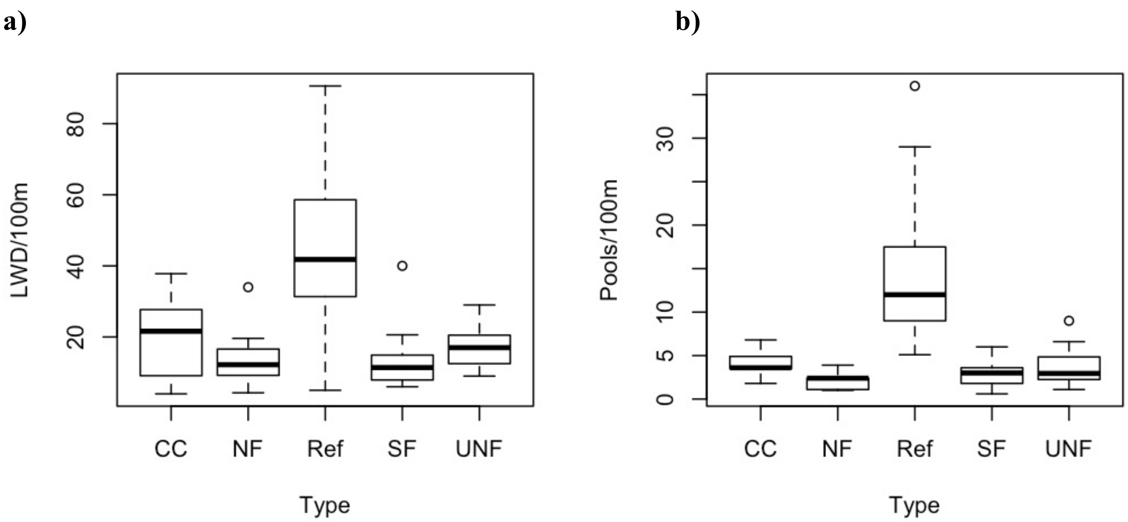

Figure 11. Distribution of a) large woody debris (> 10 cm diameter and 1 m long within the bankfull width) and b) pools (residual pool depth > 1.5, > 90% of channel width, and length > width) per 100 m stream length in Charley (CC), North Fork (NF), South Fork (SF) Creeks, reference conditions (see text for source), and Umatilla National Forest Managed sites (UNF): 2008 and 2009 combined. Box plot edges represent 25th and 75th percentiles, the horizontal line is the median, and error bars are 5th and 95th percentiles. LWD sample sizes = CC (17), NF (9), SF (9), Ref (20), UNF (16). Pool sample sizes are CC (17), NF (9), SF (9), Ref (12), UNF (16).

Pools

A similar trend was observed for pools/100 m in the Asotin study streams compared to reference conditions and UNF managed sites (Figure 11). The mean number of pools/100 m was significantly lower at ≤ 4.1 pools/100 m in the Asotin study streams and the UNF managed sites compared to 14.8/100 m in the reference conditions ($P < 0.001$). Multiple comparisons using the Tukey multiple comparison test showed that all the Asotin study streams and UNF managed did not have significantly different mean number of pools/100 m ($p < 0.001$).

Temperature and Water Quality

Temperature loggers are located in each fish reach and strategically throughout the watershed to assess water temperatures fluctuations and spot water quality sampling was conducted at each fish reach during low flow conditions in 2009 (Appendix 3; Figure 12). Stream temperatures continue to exceed the 7-day maximum temperatures limits set by the WDOE for salmonid spawning, rearing, and migration (17.5 ˚C) and the adult migration criteria of 20.1 ˚C recommended by Hicks (2002) and USEPA (2003). The mainstem of Asotin Creek was the warmest and the North Fork and Charley Creek were the coolest. However, the all streams exceeded the criteria for less time than those temperatures recorded by Bumgarner et al. (2004). High stream flows in 2009 were likely responsible for the lower summer temperatures observed. All current and historic temperature data will be migrated into a single database for storage.

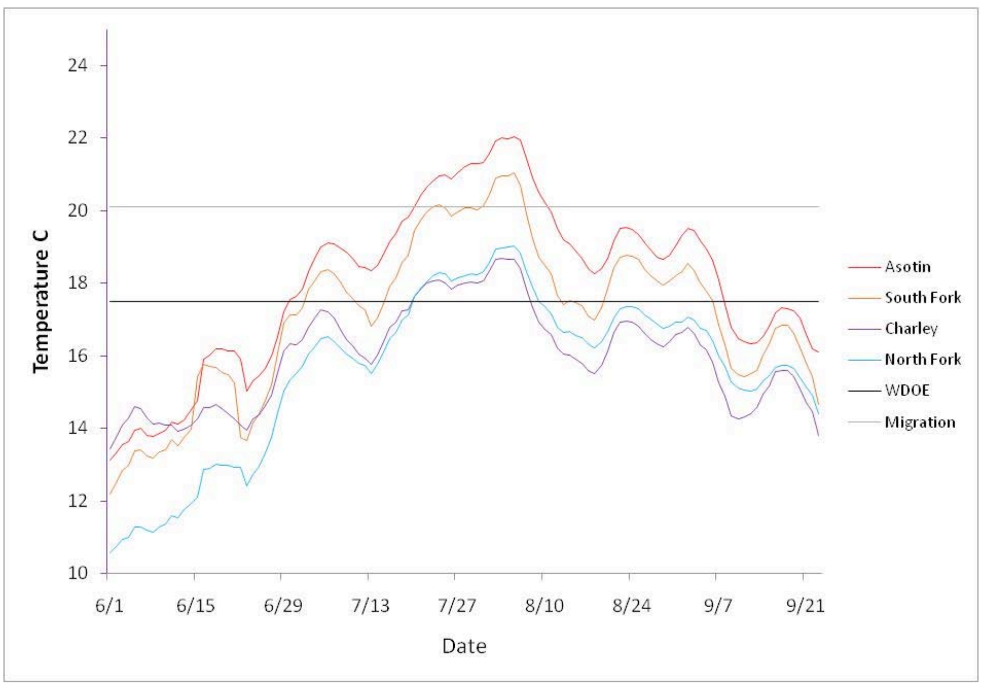

Figure 12. Mean 7-day maximum temperatures at the lower reaches of Asotin, South Fork, Charley and North Fork Creeks from June 1 to September 29, 2009. WDOE represents the maximum temperature limit for adult migration and WDOE is the maximum temperature limit for juvenile rearing.

Water quality parameters were similar to those reported in the late 1990's (Table 6; WSU 2000). Turbidity and nutrient levels do not seem to be an problem but dissolved oxygen levels are low, likely due to the relatively high water temperatures during the summer. We did not monitor fecal coliform levels but suspect that they could be high during spring and early summer in Charley Creek when cattle and horses were observed having open access to the creek.

Table 6. Water quality results from single visits during the summer of 2009 to fish sample reaches in Charley Creek (CC), North Fork Creek (NF), and South Fork Creek (SF).

Site	Turbidity (JTU)	Phosphate (ppm)	D.O. (ppm)	Alkalinity (ppm)	Nitrogen (ppm)	pH	Temp (°C)
CC-01	0	0	8.8	72	0	7	14
CC-02	0	0	8.4	71	0	7	14.5
CC-03	5	0.2	8.2	72	0	7	15
CC-04	0	0	9.6	62	0	7	12
CC-05	0	0	9.2	59	0	7	11.5
CC-06	-	-	-	-	-	-	-
SF-F2	5	0	8.2	48	0	7	15.5
SF-F3	5	0	7.8	60	0	7	14.5
SF-F5	0	0	8.6	52	0	7	13
NF-F1	0	0	8.2	55	0	7	19
NF-F4	0	0	7.8	42	0	7	17.5
NF-F6	0	0	8.2	42	0	7	15.5

Riparian Habitat

Riparian surveys were conducted using the PIBO protocol at each stream habitat site in 2009 (24 sites total; Appendix 4). Surveys included forb, shrub, and tree cover plots. Tree ages were also calculated from tree core analysis of a representative sample of each major tree species identified. The width of the riparian area was narrow at all sites 4-5 m and cover was highly variable. Alder trees were the most common tree species at all sites and averaged 70% of all the tree species counted within a riparian plot. Black cottonwood, Grand fir, Douglas fir, and ponderosa pine were the next most common tree species. The average diameter of all trees species across all sites was 17.5 cm and no site had an average tree diameter > 28 cm dbh.

Geomorphic Assessments

Field surveys were conducted from October 29 through November 9th, 2009 to collect baseline high-resolution topographic and photographic data of pre-treatment conditions in Charley Creek. Ground based LiDAR and stream bathymetry was collected at the lower five fish reaches in Charley Creek, and 12 km of Charley Creek was surveyed using low elevation from the mouth of Charley Creek upstream covering the entire proposed treatment area. These data were collected to be used as baseline data from which future change detection monitoring can be based. A secondary objective of the research was to test the practical utility of some monitoring techniques in a system like Asotin Creek. All geomorphic data is provided on a hard drive due the amount of data collected (Appendix 5). A summary of the data collected and the resolution on these data is provided in a separate report (Appendix 6).

A comparison was conducted to test the accuracy and precision of different methods for georectify aerial photography (Appendix 7). The time invested in georectification and the resulting accuracy of images were investigated and a series of blimp photos were georectified using five different methods to form mosaic images of Charley Creek reach 2 and its riparian area. The five methods were compared and contrasted to identify strengths and weaknesses of each method. The methods that used established control points and the method that used established control points and strategically cropped photos appeared to be the best methods for building a composite photo of the stream reach with the possibility of detecting change in stream channel morphology greater than 1 - 2 m (Appendix 7). These methods will be further tested and refined in future phases of the project.

Ground based LiDAR and bathymetry data were collected for five of the six fish reaches in Charley Creek and low elevation aerial photography was collected for the lower 12 km of Charley Creek. These data will provide a variety of products including bare earth spatial data for assessing channel and floodplain change (e.g., Figure 13), vegetation heights and extent, and valley context for planning and restoration design (Vericat et al. 2008). These surveys will be repeated post-treatment. More details of the resolution of the data, summary statistics, and methods for change detection are provided in the (Appendix 6).

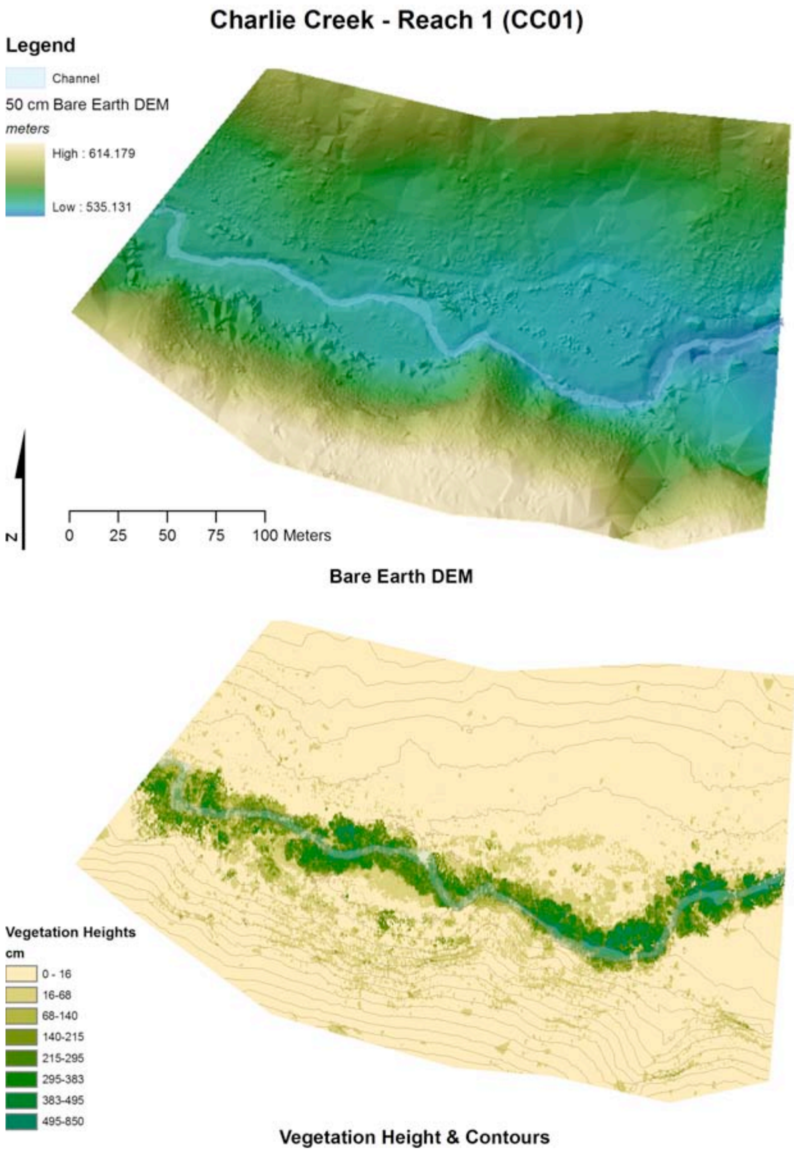

Figure 13. An example of bare earth and vegetation elevation models derived from terrestrial laser scanning surveys in Charley Creek reach 1, November 2009.

Asotin IMW Funding Sources

The Asotin IMW is a collaborative multi-agency initiative sponsored by the Snake River Salmon

Recovery Board with agency support from the Regional Technical Committee (RTT), WDFW, USFS, Asotin County Conservation District and the Confederated Tribes of the Umatilla Indian Reservation. Funding for the primary research components of the IMW are from NOAA's PCSRF account. Those funds were used to fund the experimental design and initial habitat and fish data collection and analysis. Supplementary funding from the BPA for fish in-fish out monitoring compliments the NOAA funding (Mayer et al. 2009). In 2010 and anticipated for future years, BPA has committed to continue funding the fish in-fish out monitoring (adult weir and smolt trap). Funding for the restoration and protection actions will come from myriad sources including, but not limited to, PCSRF through the State of Washington's Salmon Recovery Funding Board, BPA, Conservation Commission, USFS, and WDFW. Further, opportunities have been identified to support implementation actions including the Oregon Department of Transportation's I-5/Columbia River Crossing mitigation requirement, American Recovery and Reinvestment Act, National Fish and Wildlife Foundation's Community Salmon Fund, USDA's CREP (conservation reserve and enhancement) program, USDA's EQIP (environmental quality incentive) program and others.

Assuming adequate funding levels and commitment from NOAA, it is estimated that the following tasks will be funded by the sources identified at the amounts estimated:

- NOAA ($300,00 per year for 10 years) - Experimental Design, Effectiveness Monitoring and Analysis plus IMW reports
- BPA ($200,000 per year for 10 years) Status and Trends Monitoring
- PCSRF/BPA/USDA/etc ($500,000 for 4 year) - Restoration and Protection Treatments

This partnership is durable and meaningful only if NOAA funding for the first set of tasks is funded. The status and trend actions and the treatment actions are highly likely to be funded, but these actions will not take place without sources of funding being available to conduct the monitoring necessary to determine the effectiveness of treatments as per the goals of the IMW.

The Asotin Creek IMW study area includes land that is owned by two private individuals and two government agencies (WDFW and USFW). Landowner commitment and support for the Asotin Creek IMW has been obtained. All of these committees and institutions will support and participate in this effort.

Asotin Creek IMW implementation timeline

The Asotin Creek IMW design, monitoring, and restoration activities are scheduled to continue through to 2018 (Table 7). Three treatments will be implemented in 2011, 2013, and 2015 with subsequent post treatment monitoring through 2018.

Table 7. Draft timeline of Asotin Creek IMW implementation and monitoring programs.

Start Year	Phase	Activity	Description
2007	1	Design and project initiation	Select watershed to conduct IMW, develop experimental and monitoring design
	1	Monitoring	Implement pre-treatment monitoring of fish and habitat
	1	Equipment	Install temperature probes throughout watershed
2009	2	Monitoring	Continue pre-treatment monitoring of fish and habitat
	2	Equipment	Install PIT tag antennas and water gauges
	2	Geomorphic Surveys	Conduct pre-treatment LiDAR, aerial photography, and total station survey of in-stream and floodplain areas
2010	3	Monitoring	Continue pre-treatment monitoring of fish and habitat
	3	Restoration	Develop a detailed restoration plan
	3	Restoration	Remove barrier to juv. migration at Headgate Dam on Asotin Ck
2011	4	Restoration	Implement restoration action - add LWD to 4 km treatment section in Charley Creek
	4	Restoration	Fence and plant the treatment portion of Charley Creek
	4	Monitoring	Implement post-treatment monitoring of fish and habitat in treatment and control sections
2012	4	Monitoring	Continue post-treatment monitoring of fish and habitat in treatment and control sections
	4	Monitoring	Conduct post-treatment implementation assessment
	4	Remote Sensing	Conduct post-treatment LiDAR, aerial photography, and total station survey of in-stream and floodplain
2013	5	Restoration	Implement restoration action - add LWD to second 4 km treatment section in Charley Creek
	5	Monitoring	Continue post-treatment monitoring of fish and habitat in treatment and control sections
2014	5	Monitoring	Continue post-treatment monitoring of fish and habitat in treatment and control sections
2015	6	Restoration	Implement restoration action - add LWD to third (and final) 4 km treatment section in Charley Creek
		Monitoring	Continue post-treatment monitoring of fish and habitat
	6	Remote Sensing	Conduct post-treatment LiDAR, aerial photography, and total station survey of in-stream and floodplain areas
2016	6	Monitoring	Continue post-treatment monitoring of fish and habitat
2017	6	Monitoring	Continue post-treatment monitoring of fish and habitat

Summary: Pre-treatment Year Two

Two years of pre-treatment sampling has been completed for the Asotin IMW project. The experimental and monitoring design has been implemented and refined based on input from the RTT and field trials of the methodologies. Fish abundance estimates and tagging operations are working well and are integrated with ongoing WDFW assessments in Asotin Creek. More assessments will be conducted to determine the most efficient methods to increase resighting of tagged fish using a variety of mobile antenna techniques. Stream habitat monitoring sites are established at all fish reaches and detailed geomorphic surveys have been completed for most of the proposed treatment sections of Charley Creek. Continued assessment and revision of protocols used to monitor stream habitat are expected to ensure that the metrics being assessed are being monitored with sufficient precision to detect change, and to ensure that the metrics are related to critical habitat requirements of fish. The project has one more year of pre-treatment data proposed for 2010 and restoration treatments are expected to be implemented in 2011. A detailed restoration design needs to be completed prior to treatments being implemented.

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Appendix 1. Access database of all capture and resight PIT tag data for Asotin Creek IMW. Data includes PIT tags from WDFW smolt trap as well as all IMW mark recapture tagging. Provided on external hard drive. PATH: HardDrive:\Asotin_FieldSurveys\Fish\Asotin_Fish.accdb

Appendix 2. Access database for all stream habitat surveys (PIBO) for the Asotin Creek IMW. Provided on external hard drive.

PATH: HardDrive:\Asotin_FieldSurveys\StreamHabitat\Asotin_PIBOHabitat.accdb

Appendix 3. Access database for all water temperature data for the Asotin Creek IMW. Only current data is included, historic data will be added at a later date. Provided on external hard drive.

PATH: HardDrive:\Asotin_FieldSurveys\WaterTemperature\Asotin_Temperature.accdb

Appendix 4. Excel database of riparian habitat data collected during the summer of 2009. Provided on external hard drive.

PATH: HardDrive:\Asotin_FieldSurveys\RiparianHabitat\

Asotin_Riparian.xlsx
Asotin_TreeAge.xls

Appendix 5. Geomorphic data collected during LIDAR, aerial photography, and bathymetric surveys in the fall of 2009. Provided on external hard drive.

Data provided on the hard drive is arranged in the following manner. See Appendix 6 for more detail on the data collected and its resolution.

Path (Hard Drive:\Asotin_LiDAR_Photos\CC\2009\)	***File(s) or Extensions***	***Description***
Data\AP\Blimp	**.jpg*	*Raw blimp photos (require georeferencing)*
Data\TLS	**.imp*	*Processed TLS data (point clouds); can be viewed in free Cyclone viewer available from: http://hds.leica-geosystems.com/en/Leica-Cyclone_6515.htm*
Data\TLS	**.pts*	*Exported point cloud data in an ascii format*
Data\TLS\DecimationFilter	**.csv & *.txt*	*These are decimated TLS point clouds and statistical filters for building bare-earth, vegetation, roughness, point density and summary surfaces in GIS (e.g. ArcGIS); Data in comma delimitated ascii format and decimated to 50 cm and 3 m resolutions*
Data\LGO	*CC**_All.csv*	*Ascii text file of all GPS and Total Station data*

Data\LGO	*CC**_AP.csv*	*Asciii text file of all blimp ground control target locations (required for georeferencing blimp photography)*
Data\LGO	*CC**_Control.csv*	*Ascii text file of control points*
Data\LGO	*CC**_Topo.csv*	*Ascii text file of bathymetry data*
Cyclone	**.exe*	*Installation file for Leica Cyclone Viewer software for visualizing TLS point cloud data*

Appendix 6. Topographic and aerial photography survey report summarizing data collected during LIDAR, aerial photography, and bathymetric surveys in the fall of 2009.

Asotin IMW Topographic and Aerial photography surveys: 2009 Deliverables

Report to Eco Logical Research, Inc.

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Introduction & STUDY SITE

A field campaign was conducted from October 29 through November 9th, 2009. The goal of the field campaign was to provide high-resolution spatial documentation (via topographic and photographic data) of pre-treatment conditions in Charley Creek. The data collected is intended to serve as baseline data from which future change detection monitoring can be based. A secondary objective of the research was to test the practical utility of some cutting edge research monitoring techniques in a system like the Asotin. The Asotin Creek Watershed is a 755 km^2 watershed located in southeast Washington (Figure 1), which is the last significant tributary to the Snake River before its confluence with the Clearwater River at Lewiston. Charley Creek Watershed is a 58 km^2 left-bank tributary to Asotin Creek (Figure 2).

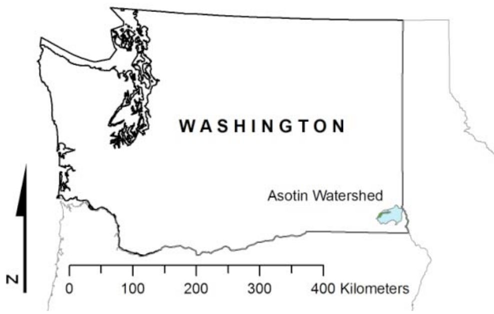

Figure 1. Location Map of Asotin Creek Watershed in Southeast Washington.

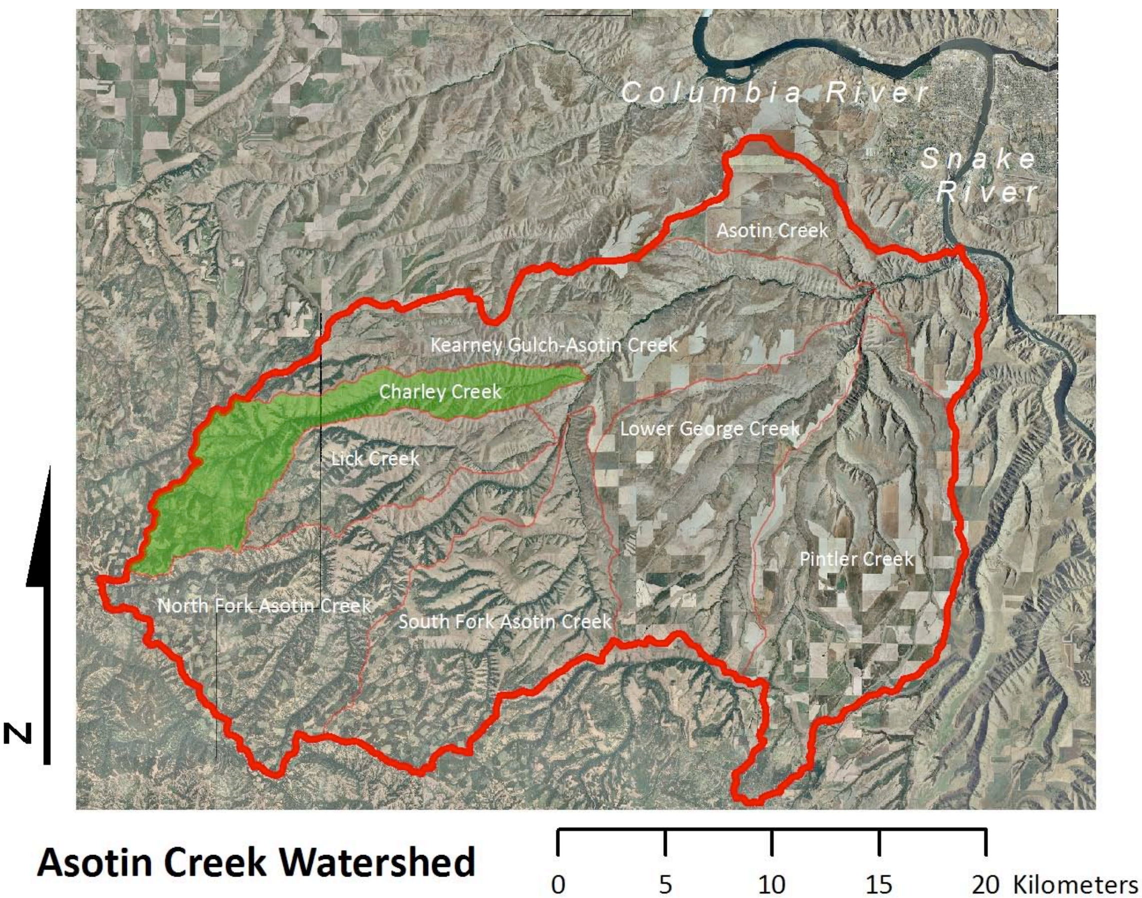

Figure 2. Location of Charley Creek within Asotin Creek Watershed.

Six monitoring reaches have been established in Charley Creek by Eco Logical Research (Figure 3). The reaches are named CC1 through CC6, with CC1 being the downstream most reach and CC6 being the upstream most. In November, CC1 through CC5 were surveyed as well as two former dams were included in the survey.

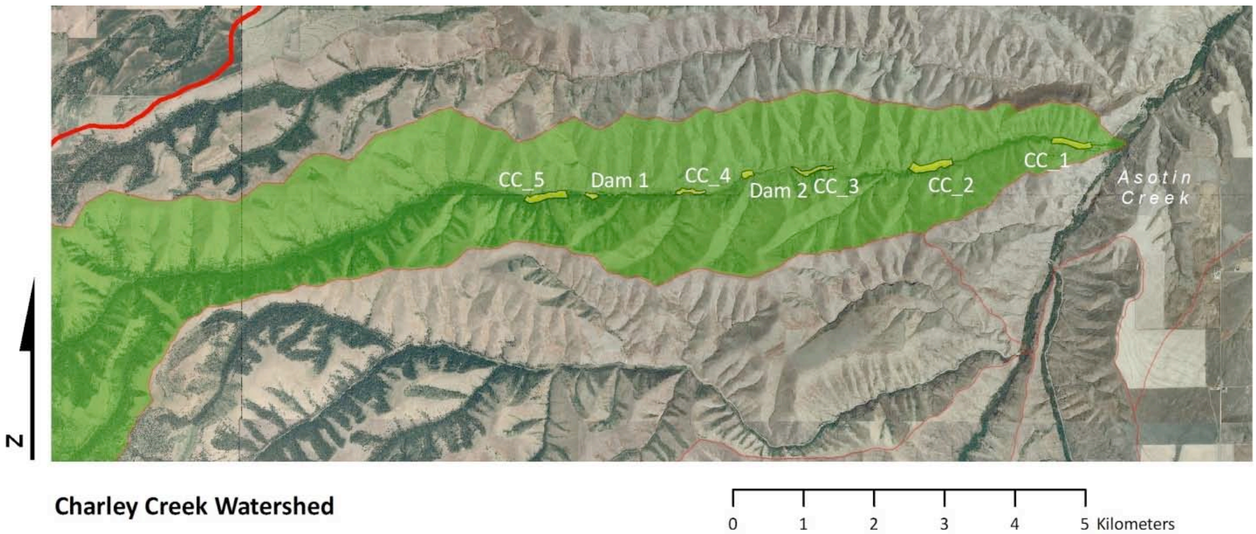

Figure 3. Location of five study reaches (CC _1 through CC_5), surveyed as part of the November field campaign. For an interactive map, visit: http://www.joewheaton.org/Home/research/unlisted-study-sites/asotin-creek/charley-creek-study-reaches.

Deliverables

The deliverables from this phase of work include the post-processed raw data and some examples of the analysis, which can be conducted from these types of snap-shot surveys. See the 'Example Analyses' sub-section of the methods for products that can be readily derived from this data. Bathymetric surveys (with GPS and/or total station), TLS (terrestrial laser scan; i.e. ground-based LiDaR) surveys and blimp surveys were performed at five of the six study reaches on Charley Creek as well as two failed dam sites. The table below summarizes the number of x,y,z survey points surveyed at each reach, average point densities and number of set-ups.

	Reach:	CC_01	CC_02	CC_03	CC_04	CC_05	Lower Dam	Upper Dam	Total	Average (of 5 sites)
Bathymetry	Number of Points	945	539	992	1227	236	NA	NA	**3939**	**788**
	Avg. Point Density (pts/m^2)	0.56	0.21	0.31	0.38	0.15	NA	NA	**NA**	**0.32**
	Area Surveyed (m^2)	1696	2560	3155	3213	1606	NA	NA	**12230**	**2,446**
	Number of Setups	9	9	9	6	12	NA	NA	**45**	**9**
TLS	Number of points scanned (after cleaning)	46,636,150	11,730,810	9,858,971	24,567,815	16,106,305	2,408,403	1,830,364	**113,138,818**	**21,780,010**
	Avg. Point Density (pts/m^2)	404	128	77	296	192	69	27	**1192.32394**	**219**
	Number of points after 50 cm decimation	105,692	139,789	110,742	122,426	113,201	84,703	52,407	**728,960**	**118,370**
	Number of points after 3 m decimation	7,635	8,712	9,767	7,906	7,542	6,144	3,511	**51,217**	**8,312**
	Number of Setups	9	9	9	6	11	3	2	**49**	**9**
	Area Surveyed (m^2)	115,398	91,714	128,297	82,906	83,927	35,146	68,625	606,013	100,448
	Number of control points set	19	14	19	15	16	4	3	90	16.6

For traditional ground-based GPS and total station surveys of wadeable streams and rivers, point densities of 0.2 to 0.4 points per square meter are considered adequate resolution to represent most morphological and habitat features, whereas point densities in excess of 1 point per square meter are considered high resolution (Wheaton, 2008). The raw data deliverables are available in a digital format on the external hard drive provided (Appendix and organized as follows (each group is organized into subfolders by reach):

Path (Hard Drive\Asotin_LiDAR_Photos\CC \2009\)	*File(s) or Extensions*	*Description*
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Data\LGO	*CC**_AP.csv*	*Asciii text file of all blimp ground control target locations (required for georeferencing blimp photography)*
Data\LGO	*CC**_Control.csv*	*Ascii text file of control points*

Data\LGO	*CC**_Topo.csv*	*Ascii text file of bathymetry data*
Cyclone	**.exe*	*Installation file for Leica Cyclone Viewer software for visualizing TLS point cloud data*

Methods

Field Methods

Three crews worked simultaneously to establish survey ground control, acquire bathymetric data of the channel, acquire topographic data of the riparian corridor and valley context, and acquire aerial imagery. One crew operated an RTK GPS and Total Station to set survey ground control, and where possible collect bathymetry. A second crew operated a tethered-blimp (Heli-Kite) to acquire aerial photography. A third crew operated a terrestrial laser scanner (TLS; a.k.a. ground-based LiDaR). The methods associated with each type of data collection are summarized in the next four sub-sections. A mix of surveying methods ranging from the 'standard of practice' in geomatics (e.g. Total Station and GPS) to 'state of the art' experimental research methods still under development (e.g. TLS & Blimp) were employed.

Capturing high-resolution spatial data in heavily vegetated riparian settings like Charley Creek is extremely challenging. High-resolution spatial data is sought because it will enable derivation of a rich range of habitat and geomorphic metrics, as well as providing data precise enough to support change detection through repeat monitoring. Unfortunately, no single method is able to provide all the desired spatial data and as such a hybrid of the above approaches was employed to build a complete spatial dataset of each reach.

SURVEY Control

A ground survey control network was established at each reach to position all survey data appropriately in geographic space. This was important for two reasons: 1) to allow all data sets to overlay reasonably accurately in a GIS, and 2) to facilitate future change detection analyses from repeat monitoring surveys. All spatial data has been projected into the UTM Zone 11N, NAD 1983 projection to facilitate overlay of different layers in GIS.

At each surveyed reach, a primary benchmark (3/4" rebar and stamped red plastic cap) was set in a stable position on the Northern edge of the valley. The benchmark was positioned to maximize good satellite geometry for GPS. In addition, between seven to fourteen additional control points (also 3/4" rebar and stamped red plastic cap) were installed at each reach. Control point locations were positioned to provide good lines of sight for total station and TLS setups and inter-visibility to at least two other control points to accommodate traversing. Between 40 – 100 temporary aerial ground control targets were laid out at locations where they would be visible from the blimp camera to enable georeferencing of blimp photography. These targets were distributed to provide a balanced coverage of the reach and provide a minimum of 5-6 control points per aerial photograph.

A Leica 1200 GPS base station with Pacific Crest radio (for transmitting real-time kinematic (RTK) differential corrections to the rover) was established over the primary benchmark (one at each reach). A simple 'here' fix in WGS84 was used initially1 to define the location of the base station. The base station was set to log observations for the entire duration of each survey. A Leica 1200 GPS rover operating in RTK mode was then used to pull in as many blimp targets and other control points as possible2. To collect the remaining aerial targets and/or control points a Leica 1203+ Total Station was used to traverse from known points (acquired with GPS), to the unknown points.

Bathymetry

As with the control, bathymetry (topography beneath the water's surface) was collected using a Leica 1200 GPS Rover where possible, and an auto-tracking Leica 1203+ Total Station everywhere else. In most reaches of Charley Creek, the GPS was unusable for the bathymetry surveys because of inadequate satellite coverage and geometry. The bathymetric surveys were conducted to capture the major grade brakes and geomorphic units (e.g. pools, bars, etc.) within the channel. Point spacing was semi-regular (1 point every 1-2 meters) feature-based morphologically stratified sampling scheme (Wheaton, 2008). Point densities varied spatially with higher point densities (e.g. 2-3 points/m2) in topographically complex areas and lower point densities in topographically simple areas. An average point density3 of 0.32 points/m2 was achieved across all the reaches.

Given the time constraints of the field campaign, only about 1 day was available per reach. This was a little rushed for producing a high quality bathymetric data set and accordingly only moderate resolution was achieved and in some cases there were some 'holes' in the data due to line of sight limitations. The thick riparian vegetation in most of the Charley Creek reaches posed major challenges to all survey technologies. Given that the GPS was unusable in most of the thickly vegetated areas, a line of sight was necessary between the total station instrument setup (i.e. the control points) and the location being surveyed (whether a reflectorless shot, or a reflector shot to a prism on a rod). In some portions of the reaches line-of-sight distance was limited to 5-10 meters (without excessive trimming of limbs and vegetation). This means that to get a complete coverage of the reach requires many total station set-ups and control points, which adds significant time. The crews did the best they could in the limited time they had to work wtih. The surveys were conducted in the late Fall after the deciduous vegetation had dropped its leaves, to maximize line of sight opportunities. Reasonably complete coverages were attained for reaches CC1-CC4. CC5 had such excessive riparian vegetation cover that only minimal bathymetry was practical to acquire in the time allotted.

Topography

A Leica ScanStation2 terrestrial laser scanner (TLS) was used to acquire topographic data of everything above the water surface in the vicinity of the reaches and provide some valley context topography. A TLS was used instead of a GPS or total station for a variety of reasons. First, the TLS has a point acquisition rate of between 1000 and 50,000 points per second (a fast surveyor can acquire 1 point every 3-5 seconds with a GPS or Total Station). Thus, with the same level of effort, 2-3 orders of magnitude more data can be acquired. Secondly, TLS is an emerging technology in the fluvial sciences and presents new opportunities for characterizing complex landforms, habitats and vegetation at sub-centimeter resolutions over entire reaches. The methods for analyzing these volumes of data and point clouds are an area of active research and are likely to mature over the next five years. Thirdly, given the high accuracy and precision of the point cloud data, they can facilitate exceptionally low minimum levels of detection in change detection analyses. Finally, riparian vegetation, large woody debris and debris jams are extremely

[1] See post-processing section.

[2] Due to the narrow and steep-walled valley setting of Charley Creek and dense riparian canopy, suitable GPS satellite geometry and coverage was not possible at all locations in Charley Creek.

[3] Ground-based surveys in most wadeable rivers and streams adequately represent the topography when average point densities are in the 0.2 to 0.5 points/m^2 range. High point densities for such surveys are typically those in excess of 1 points/m^2.

difficult to measure and characterize with traditional ground-based survey techniques like GPS and TS and cannot typically be resolved from remotely sensed airborne or satellite data. As such, TLS provides a unique opportunity to directly record and measure the physical state of precisely the features that are planned to be used in the restoration experiments.

TLS suffers from the same line-of-sight problems that total station surveys do. Thus, in areas of thick vegetation it can only capture data for what it can see. 'Shadows' or blank areas of data are frequently encountered due to line of sight limitations, and we attempt to fill be in by scanning from different set up positions that provide different perspectives of a common survey area. The Leica ScanStaion2 is a time-of-flight instrument and only provides an X,Y,Z point measurement for the first return from the laser (unlike airborne instruments, which collect a full waveform). Although this simplifies the post-processing of data and provides very reliable measurements, one drawback is that the TLS does not penetrate the water surface. It can provide returns off the water surface, but cannot survey bathymetry (hence the GPS and total station surveys of bathymetry).

At each reach, between six and twelve TLS instrument set-ups were undertaken to provide a complete coverage of the reach. Each instrument setup was over a known control point (the same control points described above and used in the total station survey). The instrument was run in a traverse mode, which allowed the automatic co-registration of the scans from each setup together into a common point cloud, which was georeferenced according to the control network. Point densities over the surveyed regions varied from 0 to 20,000 points/m2 with an average point density of 219 points/m2 (see table 1). Between 9.8 million and 46.6 million points were surveyed at each reach with an average of 21 million points surveyed at each reach. Including the two dam sites, over 113 million points were surveyed.

Aerial Photography

Aerial photography was collected with a 2.0 m3 Alsop helikite blimp and a Richo CX-3 digital camera (10.2 megapixels) using methods described in Vericat et al. (2008). Briefly, the process entails using a regular digital camera with an intervelomter to acquire aerial images from a tethered blimp platform. The camera is affixed to the bottom of the blimp and pointed downward, and the blimp is filled with helium and raised into the air via a heavy-duty kite reel. As the payload for the blimp is quite low, there is no remote control system or communication between the camera and the operators on the ground. The camera's intervelometer is set to acquire images every 5 seconds. It may take 5 to 10 minutes to unreel the blimp to the desired altitude. Once the desired altitude is achieved, one person walks the blimp along the stream trying to position the blimp directly over the stream channel at 50 m and 100 m altitudes (separate flights). The 50 m flights provide high resolution whereas the 100 m flights provide more context.

Post Processing

Control

All post processing of control, GPS and total station data was done in LGO (Leica Geo Office). The raw topographic data, survey control has been post-processed and cleaned and all transformed to a common coordinate system (UTM Zone 11N, NAD 1983 projection). To improve the positional accuracy of all points, the GPS base station locations for each reach were corrected (post-processed) using Opus (http://www.ngs.noaa.gov/OPUS/) observations at nearby permanent base-station coordinate observation recording sites. Once an adjusted base station position was acquired, this was used to adjust all the survey data in LGO. The adjusted control network and blimp aerial target values have been exported to an ASCII format *.csv files and should be used in future monitoring and for the georectificaiton of the aerial photography.

Bathymetry

The bathymetric data consists of a combination of GPS and total station data. Both have been registered in the same coordinate system (UTM Zone 11N, NAD 1983 projection). The topographic data points collected with the GPS and total station, were separated from the control points and exported from LGO in an ascii format, which can be used to construct TINs and digital elevation models of bathymetry from. The data were checked in LGO for any obvious blunders or busts. Digital elevation and terrain models were not included in this scope of work. Bathymetric data was collected from all five surveyed reaches (CC1 – CC5). Roughly 3939 points were surveyed with an average of 788 points per reach and an average point density of 0.32 points/m2.

Topography

The raw topographic data from the TLS has been delivered in a point cloud format and no digital elevation or terrain models have been included in this scope of work. The TLS post-processing was done in Cyclone. First, all scans in each reach were co-registered to a common assumed local coordinate system and then transformed onto the same coordinate system as the control and bathymetry data (i.e. UTM Zone 11N, NAD 1983 projection). Next, noise in the scan data was manually filtered including vehicles, people, survey equipment and other features that do not represent the landscape. Then key plans were produced in Cyclone, to easily visualize the survey workflow and datasets within Cyclone. A free Cyclone viewer has been provided with this data (see Cyclone folder), and the databases (*.imp files) can be loaded and viewed in that. To facilitate use of the point cloud data in other point cloud software4, the point clouds were exported for each reach into a *.pts format, which is a generic ASCII point cloud format.

The *.pts versions of the processed point clouds are fine for point cloud software, but at file sizes ranging from 1 to 4 GB, they cannot be practically used in any GIS applications. Most CAD and GIS programs are not designed to handle the high-density point clouds produced by TLS data. We ran our own point-cloud decimation algorithm to reduce the point clouds from an average of 219 points/m2 down to 1 point per 0.5 m x 0.5m cell (i.e. 4 points/m2) and down to 1 point per 3 m x 3 m cell (i.e. 0.11 points/m2). These are data densities that standard CAD and GIS packages can handle for digital terrain and elevation modeling. The decimation algorithm produces a variety of outputs:

- At the center of each cell: minimum elevation, maximum elevation, mean elevation, elevation range, standard deviation of elevation, detrended (for local slope) standard deviation of elevation, detrended mean elevation, and a point count (i.e. point density)
- It also exports the coordinate value (x,y,z) of the absolute minimum elevation point and absolute maximum elevation point

Each of these outputs can be used to produce surface models. For example the elevation range is a good indication of vegetation heights, the max is a good model of the tree canopy and can be used to make a terrain model (analogous to first return from airborne LiDaR), and the minimum is a reasonable approximation of a bare earth topography.

Aerial Photography

Aerial photography was not post-processed as part of this scope of work. However, the blimp photographs are organized by reach and the aerial target control points have been post-processed into the

[4] Note that while the Cyclone Viewer is free, a fully functional commercial license is $10,000 per year. Many cheaper and some open source alternatives exist.

UTM Zone 11N, NAD 1983 projection. The workflow for georeferencing the imagery essentially involves choosing the best images from the 200-500 images of each reach that provide a complete coverage of the reach. Depending on the flight altitude, this will typically range from 5-20 photos per reach. The 'best images' are those that are the least oblique, have good focus, good exposure, and contain at least 5-6 identifiable aerial control targets. Using techniques described in Vericat et al. (2009), the images can be individually georeferenced and then mosaiced together to provide a snapshot of the reach. The finished products are typically not as clean as aerial imagery acquired from fixed-wing air-crafts with onboard GPS tracking systems, and exhibit variable exposures and orientations. However, imagery processed in this manner is typically higher resolution and of comparable or better positional accuracies then traditional aerial imagery. Two reaches of Charley Creek (reach 2 and reach 4) have been georeferenced as examples of this process. The remaining reaches will be completed as part of the 2010 work plan.

Example Analyses

BARE-EARTH DEM

To construct bare-earth DEMs from hybrid data sources (e.g. scan data, GPS and total station data) requires a high degree of post processing. Both manual and automated methods are available. Manual methods require going through point cloud data and distinguishing between ground points and vegetation points. As over 113 million points were collected, automated methods are preferable. Automated algorithms include using decimation algorithms like those described above to attempt to differentiate shots of the ground from those of vegetation. Minimum elevations in a vegetated area are the best approximation of the ground surface, but will generally over-estimate ground elevations. Filtering techniques used for scan data are analogous to those used for airborne LiDaR data.

As an example, we took the 46.6 million TLS points from Reach CC_01 and 945 bathymetry points and attempted to derive a bare-earth DEM. A boundary of the wetted channel was digitized from the outline of the bathymetry points. Within this boundary all TLS points (primarily water surface shots) were discarded and only the bathymetry points were kept. Next, we ran the point-cloud decimation algorithm described above to create a 50-cm resolution data set (105,692 points; See Figure 4 Top) and a 3 m resolution data set (7635 points). We used the detrended elevation range metric from the 50-cm resolution data set to derive a surface indicative of vegetation heights (Figure 5 – Bottom).

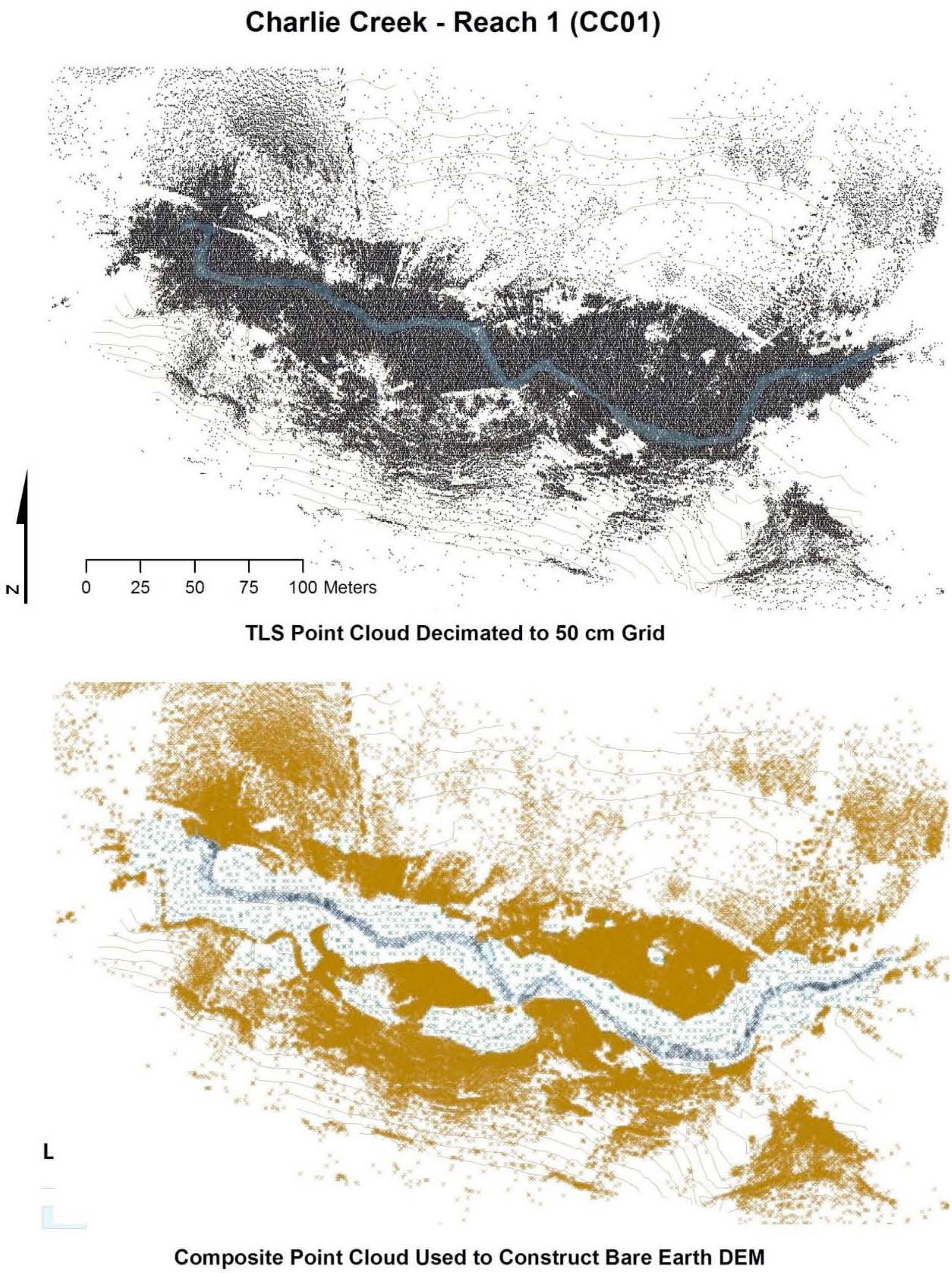

Figure 4. Examples of point cloud data derived from ground based LiDaR surveys in reach 1 of Charley Creek.

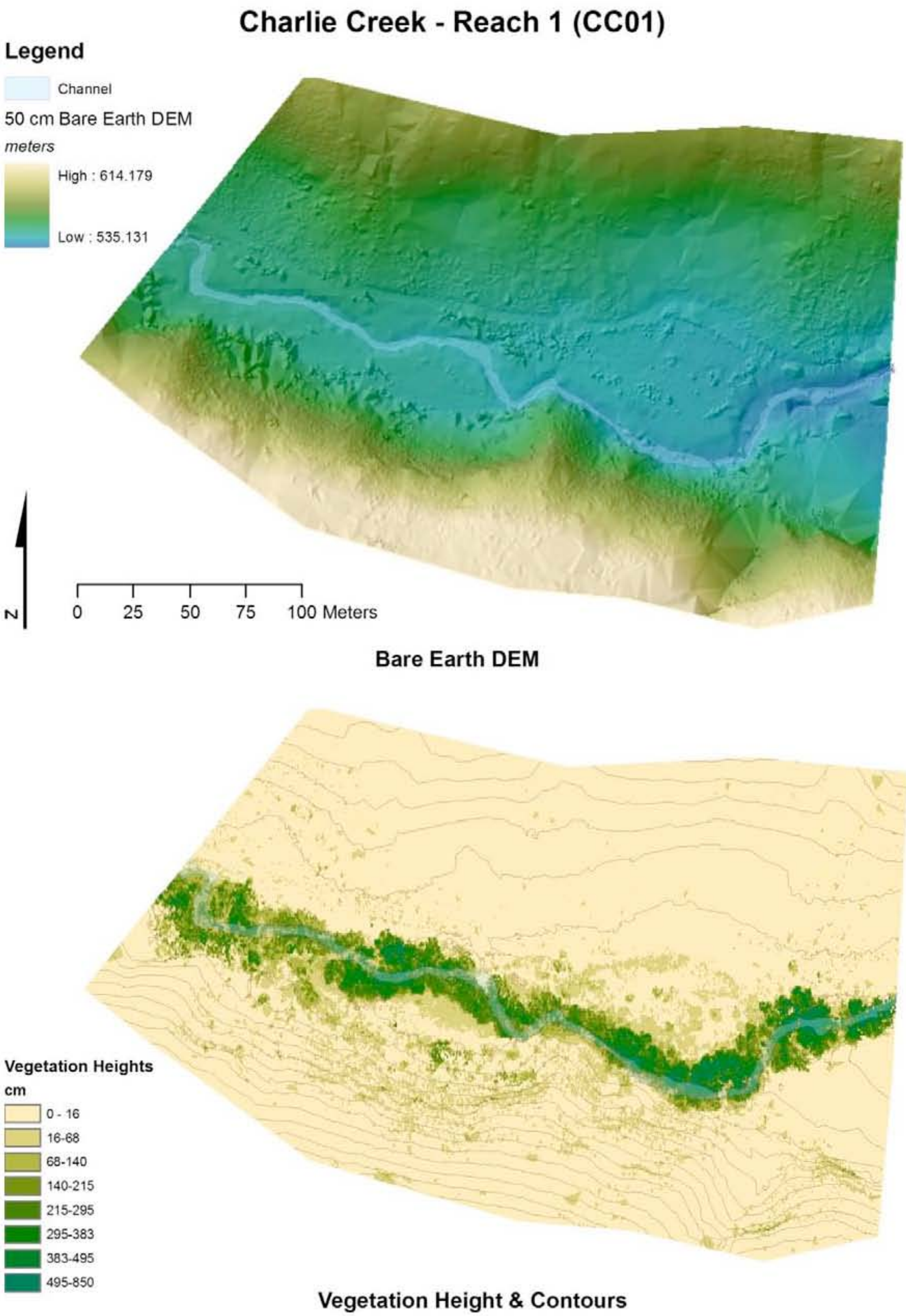

Figure 5. Examples of bare earth digital elevation models (top) and vegetation layers (bottom) derived from ground based LiDaR surveys in reach 1 of Charley Creek.

Aerial Photography

As shown in Figures 6 & 7, the aerial photography is of an adequate resolution (generally 3 to 10 cm) that manual digitization of stream features, individual trees, boulders, habitat units, and/or vegetation classification is possible.

Figure 6. Example photo from Reach CC-03 showing variation in riparian vegetative cover and in-channel habitat units.

Figure 7. Example photo from Reach CC-03 with mixed conifer and deciduous riparian vegetation.

Reach CC_04

Using the methods described in Aerial Photography Post Processing above, an example of the post-processing of the blimp aerial photos and mosaiced final product is shown below (Figure 8). In this example, five images provide a complete coverage of the reach.

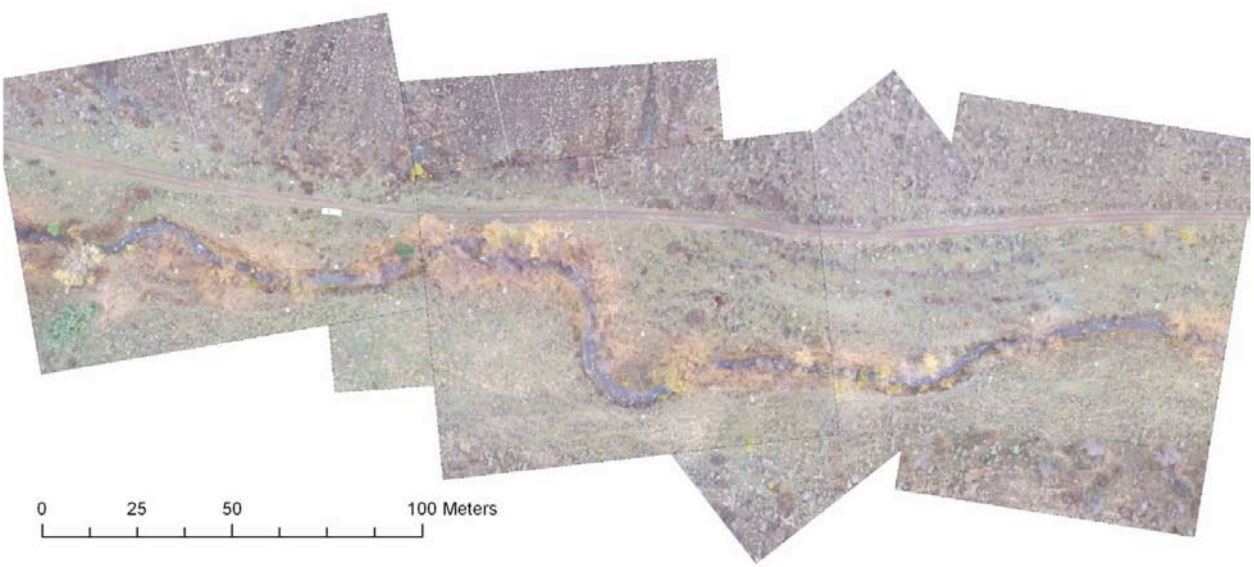

Figure 8. Georeferenced Aerial Blimp Photography for CC_04 Reach.

CHANGE DETECTION

If the topographic survey methods are repeated for the same reaches at later dates in time, digital elevation models derived from each survey can be produced and differenced to produce DEMs of difference (DoD). DoDs can be used to estimate the net volumetric change in a reach through time (Figure 9). From a geomorphic perspective, these represent the change in storage terms (due to erosion and deposition) of a sediment budget. In Wheaton *et al.* (2009b) methods are described for accounting for uncertainties in the individual DEMs, such that confidence can be developed in distinguishing changes due to geomorphic processes from changes due to noise. In Wheaton *et al.* (2009a) masking techniques for budget segregation and interpreting geomorphic changes in terms of fish habitat quality are described. The data provided in this deliverable, will be well suited to both these types of analyses, provided that future monitoring campaigns collect similar types of data.

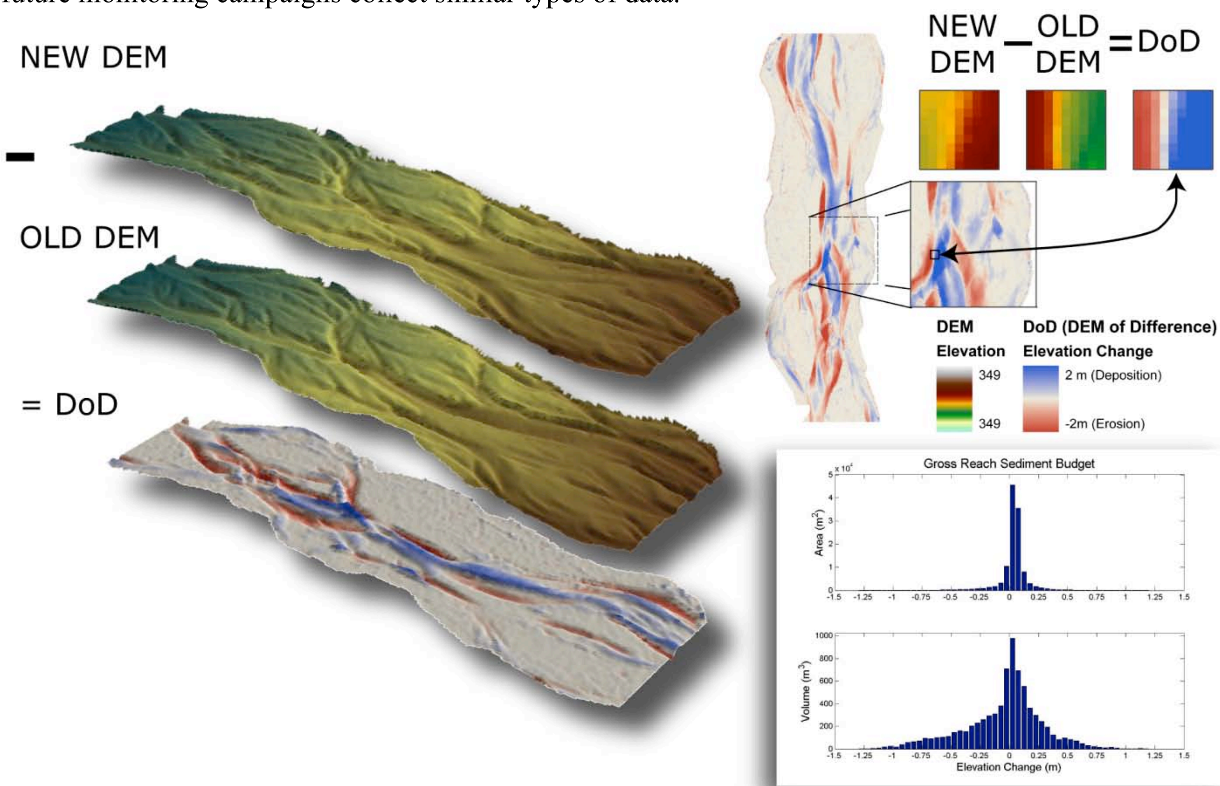

Figure 9 – Calculation of a DEM of Difference (DoD) from two DEMs (from Wheaton (2008)).

Recommended FUTURE MONITORING PROTOCOLS & Analysis

For any change detection monitoring, we recommend that similar field protocols to those described here be employed. Based on the experience with this field campaign, we think that at a minimum the following amount of time should be budgeted for each crew for each reach:

- Control Network – 2 Man Crew with GPS and TS @ 2 days per reach in first year 0.5 day per reach in subsequent years; This crew should go ahead of the other crews to recover former ground control, establish the TLS and TS instrument setup locations, clear line of sight as necessary, and post process the data to pre-load into TLS, TS and GPS for their surveys; In the first year, some effort should be made to establish more permanent and stable benchmarks (a minimum of 3 or 4 at each reach) and build redundancy into the control network

- TLS Surveys – 2 Man Crew with TLS @ 2 days per reach; 3 for CC-05; add more time to acquire detailed surveys of individual woody debris or habitat units; focus could shift from broad context scans to just scanning areas that are changing (e.g. woody debris placement) to save time
- Total Station Surveys – 2 Man Crew w/ robotic TLS @ 3 days per reach; 5 for CC-05; this would allow enough time to increase point densities from 0.2 – 0.4 points/m2 up to the
- Blimp Survey – 2 Man Crew w/ Blimp, aerial targets, GPS and TS@ 1 day per reach

Once a restoration treatment plan is in place, specific design hypotheses should be identified that will help more clearly define the requirements of the geomorphic and change detection monitoring. The monitoring should be designed to appropriately test these hypotheses. Therein some time should be allocated to the refinement and development of methods for analyzing the data and deriving useful metrics from it.

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Appendix 7. Comparison of five different methods of georectification of blimp-acquired aerial photography.

By Eric Wall, Utah State University

Abstract

Using lighter-than-air blimps to acquire (and possibly georectify) aerial photography is becoming more common in resource management. Though it is typically a more affordable implementation than alternatives, it can require more front-end preparation as targets must be set and surveyed if georectification is to be performed. Methodologies associated with the georectification process warrant study to identify the optimal balances of time invested and accuracy of georectified images.

The time invested in georectification and the resulting accuracy of images is investigated. A series of blimp photos is georectified using five different methods to form a mosaic image of a stream and its riparian area. The five methods are compared and contrasted to identify strengths and weaknesses of each. The first method involves using established control points. The second method uses established control points and common features among photos. The third method involves strategically cropping the photos and then using established control points. The fourth and fifth methods use existing georeferenced aerial photography, but the fifth combines that information with common features between photos. Methods one and three proved to achieve the best balance between time invested and accuracy achieved, and method three was deemed the best of the five methods.

Keywords: blimp, georectify, georectification, RMSE, aerial photography, stream monitoring

Introduction

As lighter-than-air blimps (hereafter referred to as blimps) become more common and their applications become more diverse, investigation into the best practices for using such systems is warranted to ensure that appropriate methods are being used in the field and later in processing once the photos have been taken. Though significant costs can be saved using blimp systems to provide aerial photography, there is often a front-end time investment for these systems because they require that aerial targets must be placed and surveyed for use as control points if the photography is to be georectified. Depending on the terrain and location, this simple-sounding preparation can be quite time consuming and potentially costly depending on the size of the team sent into the field and the equipment used (e.g. professional-grade survey equipment) to survey the targets.

Objectives

The primary objectives of this study are to compare and contrast five different methods of georectification that might be used in combination with acquired blimp photography to map the streambed and riparian area of streams. Specifically, the error associated with each georectification method, the time involved, and qualitative measures of visual alignment will be investigated. The examined georectification methods are:

- Method 1 – Attempt to georectify the blimp photos using GPS control points recorded with an RTK GPS system
- Method 2 – Attempt to georectify the blimp photos using a combination of GPS control points and landscape features common across the photos
- Method 3 – Crop the photos to eliminate the periphery (i.e. eliminate parts of the photos far away from the control points) and then attempt to georectify them using the GPS control points

- Method 4 – Attempt to georectify the blimp photos using existing georeferenced aerial photography and no GPS control points
- Method 5 – Attempt to georectify the blimp photos using a combination of existing georeferenced aerial photography and landscape features common across the photos

A secondary objective of this experiment was to compare methods one, two, and three among themselves to determine if any single method is preferable to the other two. An additional secondary objective of this experiment was to compare the first three methods to the last two. If methods four and five are negligibly different than one, two, and three, then sending field crews to set and survey aerial targets might be an unnecessary step in the process of acquiring blimp photography for georectification.

Image Processing

Georectification of blimp photos was performed in ArcGIS 9.3.1. This software offers a visual environment in which users can click corresponding parts of photos to properly align and georectify them. The software also estimates error associated with the resulting transformations as a Root Mean Square Error (RMSE). RMSE is calculated as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{n}(\tilde{x} - x_i)^2 + (\tilde{y} - y_i)^2}$$

where n is the number of control points used, $\tilde{x}$ and $\tilde{y}$ are the transformed coordinates of each point, and x_i and y_i are the coordinates of the point assumed to be true. For each photo, the set of usable control points was maximized and then strategically decimated to obtain the optimal combination of control point geometry, satisfactory visual inspection, and low RMSE values.

Experiment

Data Acquisition and Experimental Design

Fifty control points spanning nearly 600 meters of stream were placed in two rows running parallel to a small stream in southeastern Washington State. The lower and upper rows were placed approximately 10 and 20 meters away from the stream, respectively, both rows in a northerly direction from the location of the streambed. The two rows were staggered relative to each other. An RTK GPS system was used to record locations of the control points for later use in georectification. A blimp was flown with an attached camera at an approximate height of 100 meters and 216 photos were collected. The blimp flown for this experiment is assumed to be typical of existent blimp/camera systems. Twelve photos were selected as candidates for georectification in order to create a mosaic image of the stream and riparian area. Each photo was picked based on overall stream coverage, the number of control points included in the photo, and how level the photo appeared to be at the moment it was taken. The twelve photos were georectified five different times with five different methods to create the stream mosaics. A summary of the different methods is displayed in Table 1. For the first method, the photos were georectified using only the GPS control point data collected in the field. The second method used a combination of the GPS control points collected in the field and landscape features common between adjacent blimp photos. The third method involved cropping the blimp photos to exclude features on the periphery (far away from the control points) and then using the GPS control points for georectification. The fourth and fifth methods were based on using existing georectified aerial photography (EGAP) with one meter resolution. For method four, the images were georectified based solely on the existing georectified one meter aerial photography. For method five, the images were georectified using the existing georectified aerial photography and common features between adjacent blimp photographs. For each method, time required for georectification per photo was estimated. Root Mean Square Error (RMSE) was calculated for each photo and used to compare the different methods.

Results and Analysis

Method four proved the fastest method, averaging roughly four minutes per photo. It should be noted however, that because of the nature of the study site, it was extremely difficult to find more than three or four control points per photo with this method. The study stream is dominated by a thick riparian area that obscures nearly the entire stream. The stream is also surrounded by sparsely populated sagebrush on either side. This made it very challenging to identify features suitable for use as control points and it was often necessary to rely on a small number of points (e.g. three) when performing georectification under this method. While method four proved fastest, it was fast because the small number of usable points made it so. It should also be mentioned that the small number of control points concentrated near the road made the edges of these photos especially distorted based on visual inspection. Methods one and three were the second most time efficient, averaging five to six minutes per photo. While not as fast as method four, these two methods had much smaller errors, as indicated by RMSE measures and visual inspections. In fact, methods three and one had the lowest and second lowest RMSE values, respectively. Methods two and five proved to be extremely time consuming, as both methods averaged 14 minutes per photo. Method two, though time consuming, proved to be nearly as accurate as method one (one centimeter of difference between average RMSEs) but was almost three times as costly in terms of time invested in georectification. Additionally, using common features between adjacent blimp photos was problematic as inherent error in the first georeferenced photo was carried and compounded across the mosaic as georectification continued and photos were added to the mosaic. Due to this compounding effect, the last blimp photo to be georectified was often clearly distorted. RMSE values associated with each photo are shown for the different methods in Figure 1. Cumulative RMSE values calculated by adding each new RMSE to those of the previously georectified photos is displayed in Figure 2. Finally, a qualitative, visual inspection was conducted to compare the results of the five methods. Consistent with the RMSE measures, methods one and three seemed to maintain proper alignment and perspective better than the other methods. For these two methods, objects lined up more consistently and provided the most favorable visual alignment between photos.

Discussion and Conclusions

Though it was anticipated that the methods employing common features among blimp photos (methods two and five) would take longer, it was not expected that it would take nearly three times as long as other methods. The methods based on EGAP, though they turned out to be less than optimal in this application, might be better suited to applications where better EGAP images can be acquired such as cities or more populated areas. If higher quality EGAP images could be acquired for an area with more useable features than the study stream, this method might be more viable. As it was at the study site, however, it proved too difficult to find an acceptable number of control points based on the one meter aerial photography that was available. Resolution was not the only factor to contribute to the difficulties encountered with the EGAP methods. Even when a potential common feature (e.g. an isolated plant or a specific stream bank location) could identified, there was often uncertainty as to whether that feature would have remained unchanged in the time period between the EGAP and our blimp survey photos. This brings to focus the idea that if this method were implemented, it would be important to consider the morphology of features at the time scales between the sets of photos being compared. It is also important to note the compounding effects of using common features between blimp photos as used in methods two and five. Under these two methods, as photos were added to the mosaic and georectified (in reference to each other) the error of each photo was taken on by the mosaic and errors compounded across the consolidated image. Whatever error was inherent in the first georectified photo was transferred to the next, then compounded by the error inherent in the second photo, and so on it continued down the line. By the time the final photo was georectified, a visual inspection revealed that the images were clearly distorted. Though method four was the fastest method, methods one and three offered the best balance of efficiency and accuracy based on RMSE values. Method three, the method based on cropping the photos and then using GPS established control points, had the lowest RMSE values and only required an extra 30 seconds per photo for cropping. In the opinion of those conducting this experiment, it is also the most visually appealing. For these reasons, method three was determined to be the optimal method.

Table 1. Description of the five methods used within ArcGIS to georectify blimp photos and piece together the photo mosaic.

Method	Description
1 – GPS Control Points (GCP)	Only using the GPS control points collected in the field
2 – GCP + Common Features	Using the GPS control points collected in the field in combination with features common to adjacent blimp photos
3 – Cropped GCP	Only using the GPS control points collected in the field after cropping the blimp photos to remove areas far away from the control points
4 – Existing Georefererenced Aerial Photography (EGAP)	Using features common to existing georeferenced one meter imagery and the captured blimp photos
5 – EGAP + Common Features	Using EGAP in combination with features common to adjacent blimp photos

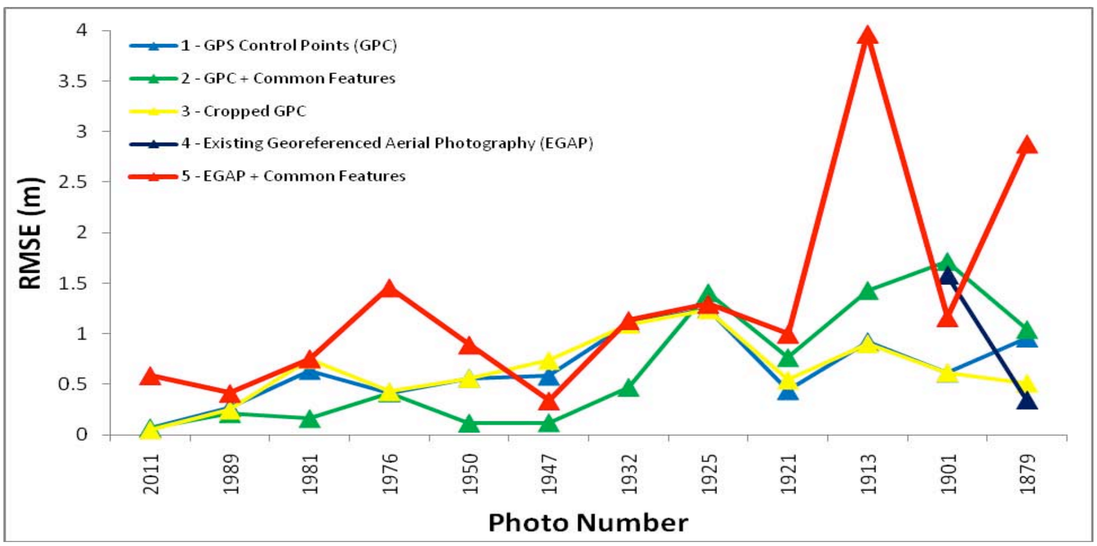

Figure 1. RMSE associated with each photo for each method of georectification. Photo numbers taken directly from the camera's naming system. Due to the difficulty of finding useable control points under method 4, RMSE values could not be calculated except for the two photos indicated.

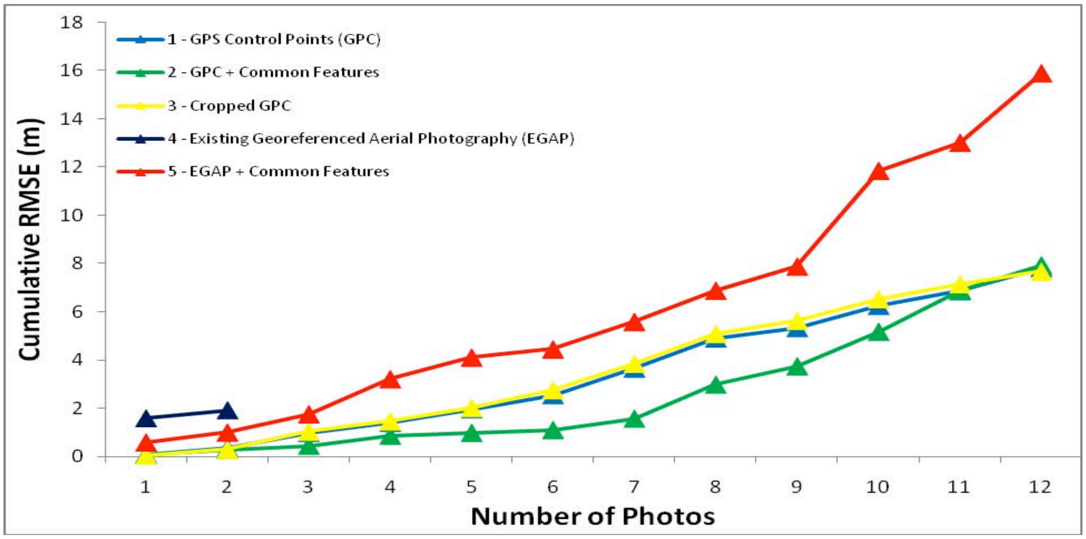

Figure 2. Total RMSE for each method as successive photos were added to the mosaic. Due to the difficulty of finding useable control points under method 4, RMSE values could not be calculated for all photos.

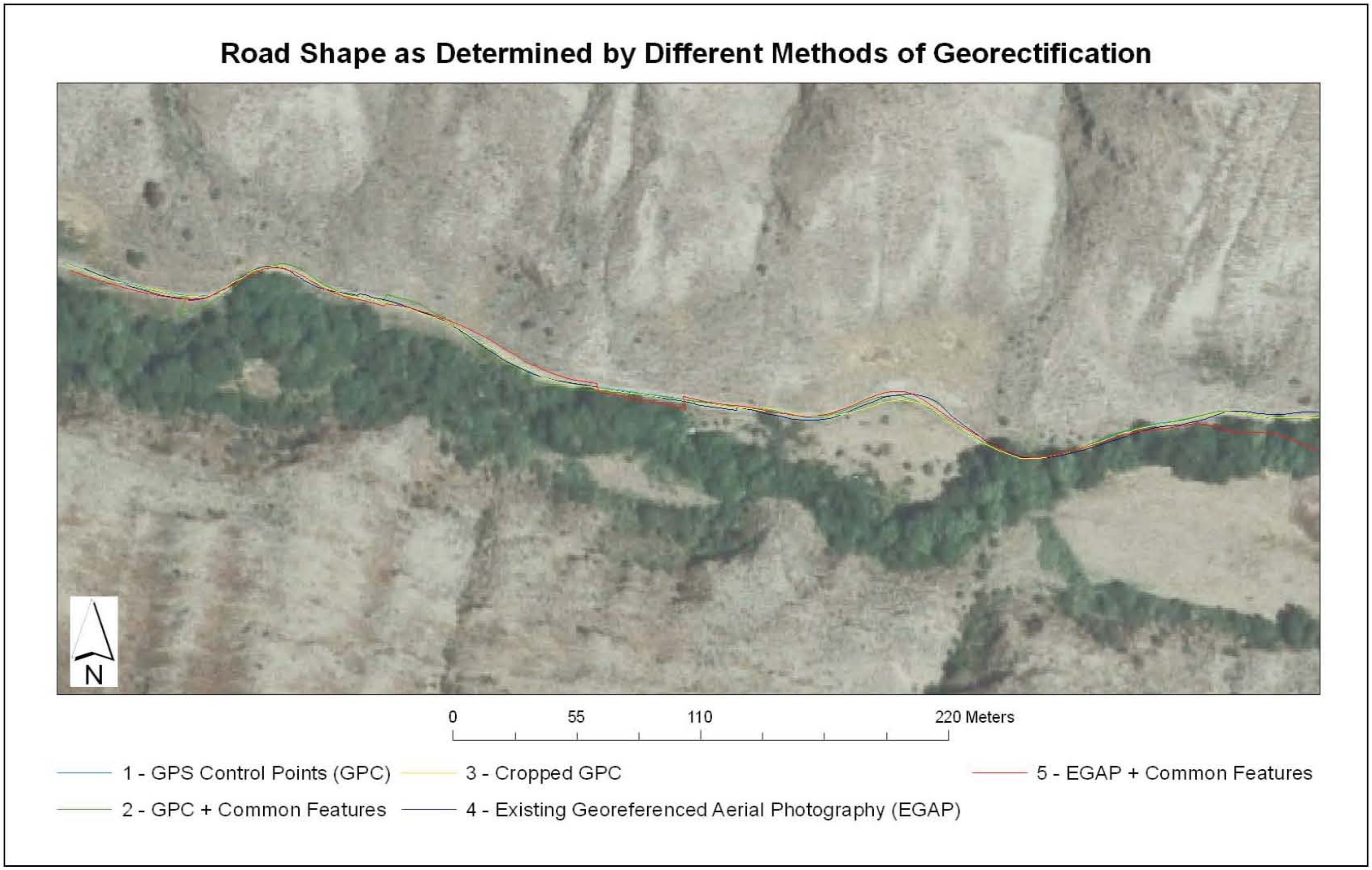

Figure 3. Differences in road shape after georectification by the five different methods.

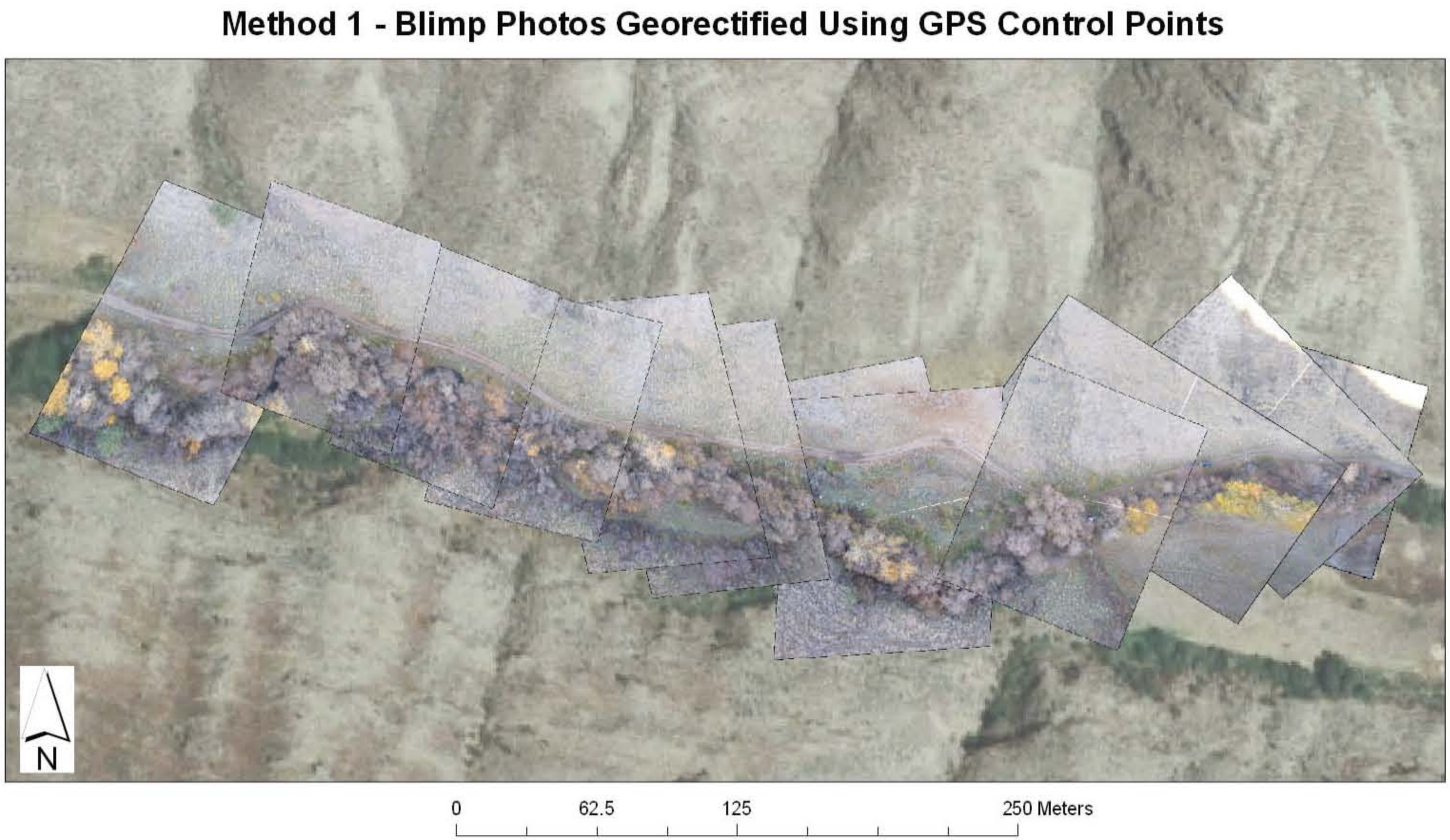

Figure 4. Stream mosaic as generated by method one.

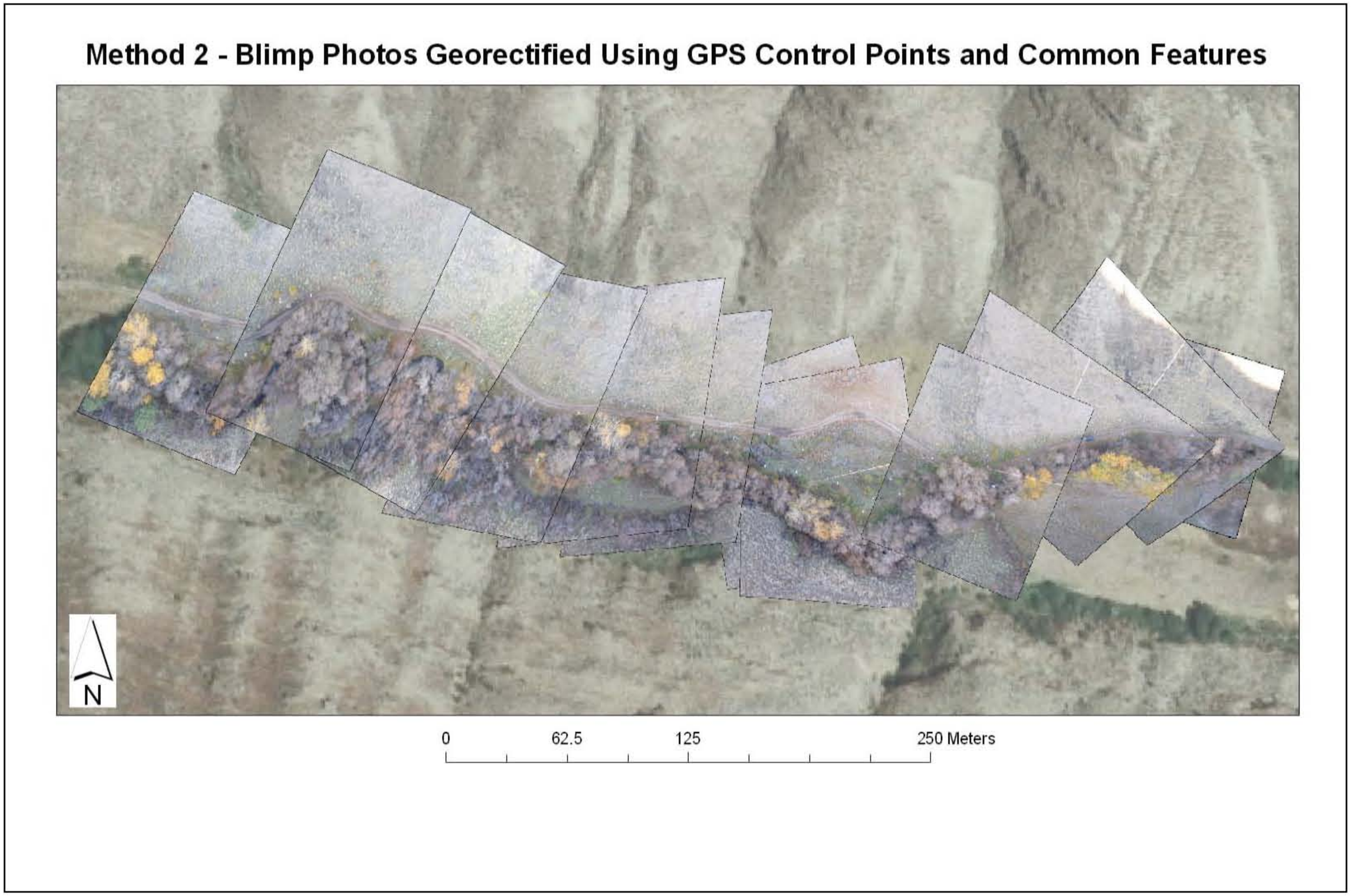

Figure 5. Stream mosaic as generated by method two.

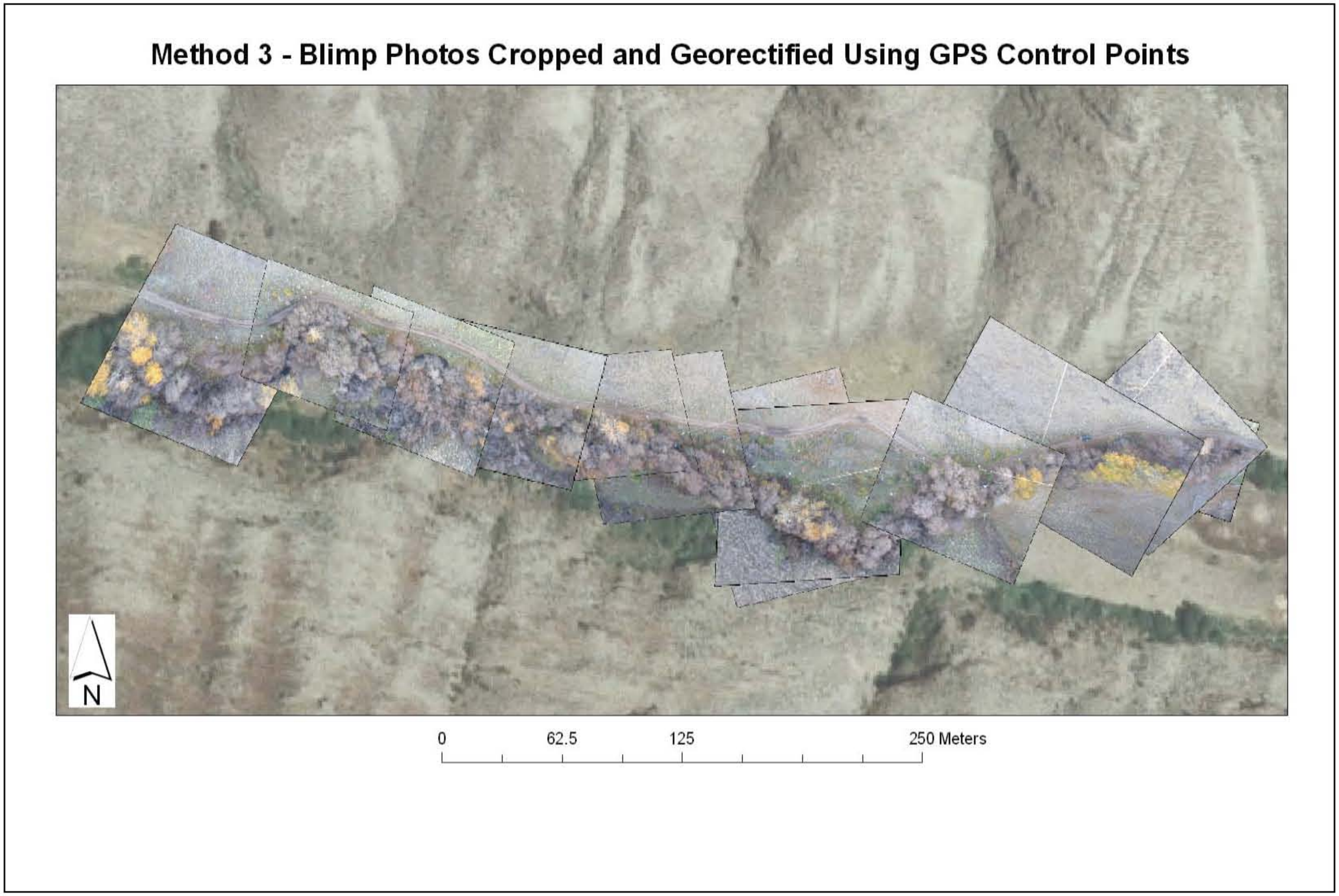

Figure 6. Stream mosaic as generated by method three.

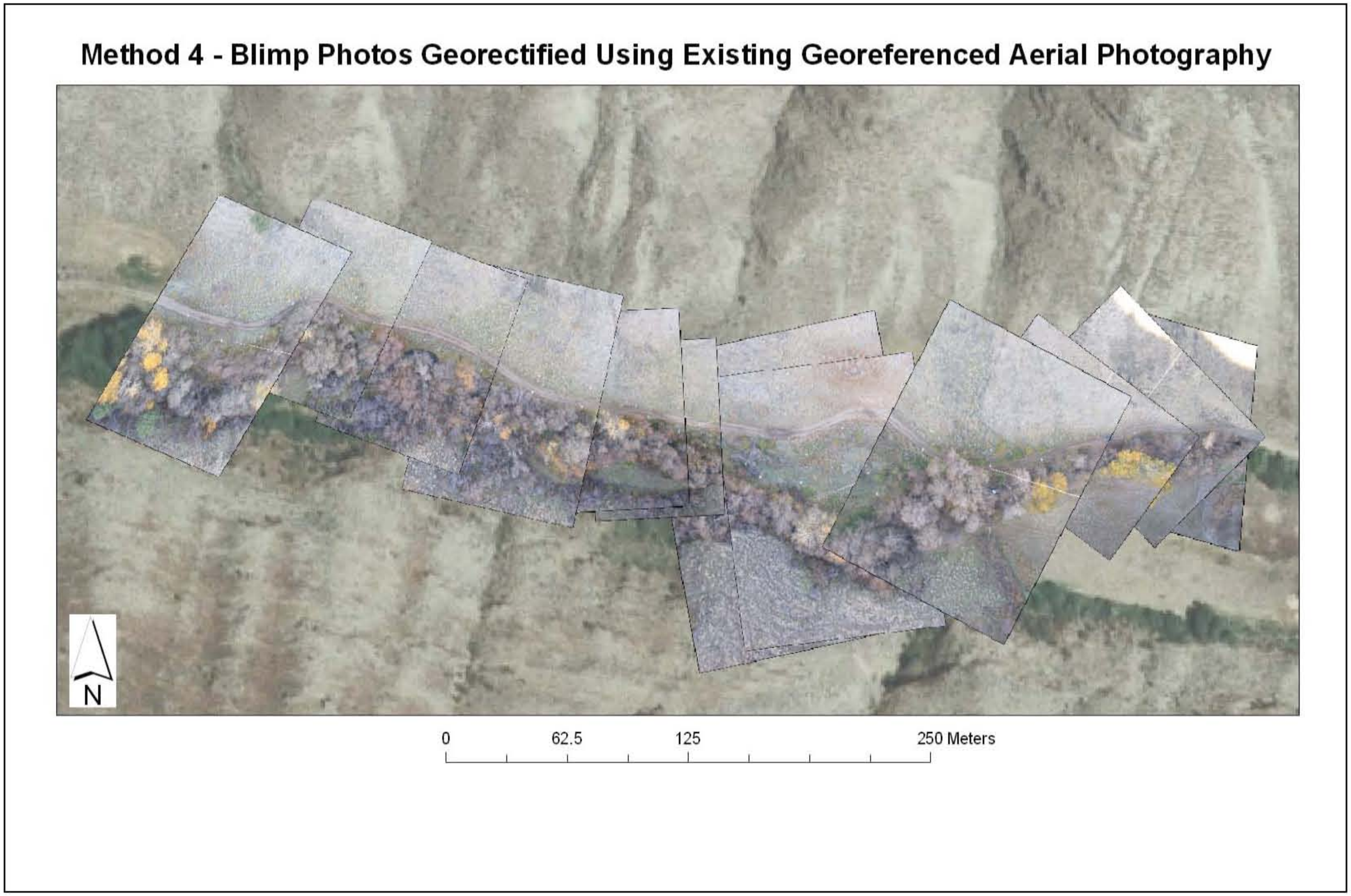

Figure 7. Stream mosaic as generated by method four.

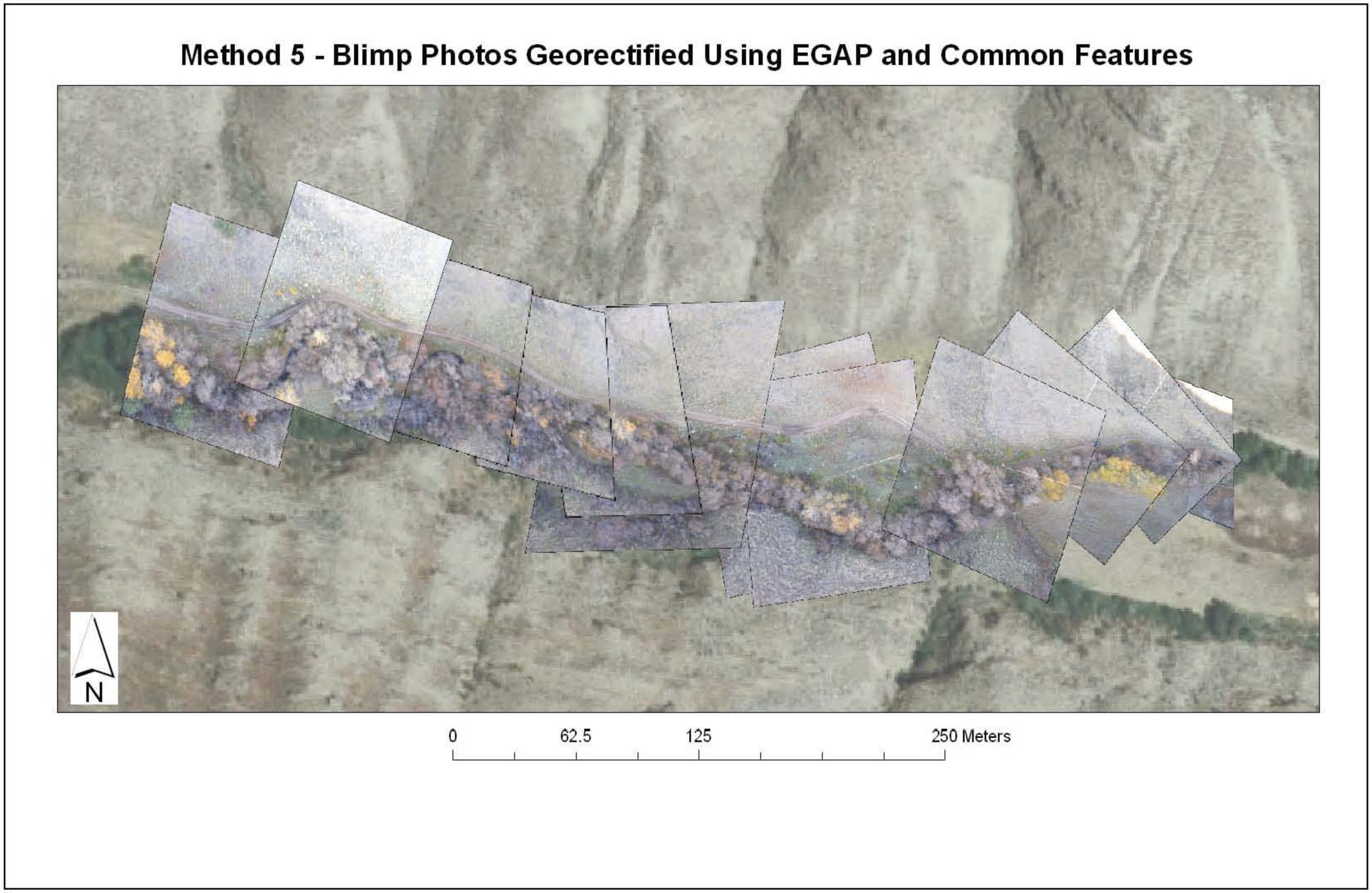

Figure 8. Stream mosaic as generated by method five.

Appendix 8. Draft chronological work plan budget detail for monitoring, equipment, and project management for Phase 3 of the Asotin Creek IMW (Mar 2010-Sept 2010).

Start Month	Work Category	Work Item	Budget Category	Description	Rationale
March	Monitoring	Annual Fish and Habitat Monitoring, equipment maintenance, data entry, and training	Government	Cooperative partnership between IMW and the ***Asotin Creek Assessment Project***. IMW fish and habitat sampling to be jointly conducted by contract and WDFW	WDFW staff to assist all IMW fish and habitat sampling, and participate in training for IMW related activities, which will increase knowledge transfer, and provide for greater consistency in meeting project objectives. Wages include a 10% contingency for overtime due to remote sampling sites.
June	Monitoring	Annual Fish Tagging and Abundance Estimates	Contractual	Costs to conduct juvenile fish sampling for treatment and control sites as per the study design (12 sites summer season)	Yearly sampling of treatment and control streams required using three pass mark recapture estimates. Proposing two sessions per year (i.e. summer and fall) to estimate seasonal growth rates and survival. This proposal is for the summer season only.
July	Monitoring	Annual Stream Habitat and Riparian Surveys	Contractual	Costs to conduct habitat field sampling for treatment and control sites as per the study design (12 permanent and 12 random sites per year)	Yearly sampling of riparian and stream habitat in treatment and control sites required to maintain experimental design consistency and implementation
July	Monitoring	Annual Aquatic Invertebrate Surveys	Contractual	At each stream habitat survey site collect drift and benthic aquatic insects (24 sites x 2 samples). Samples are processed in the lab.	Data used to determine diversity indices, food availability, and aquatic health. Will also be used to model juvenile steelhead growth and assess productivity of habitat types
Aug	Monitoring	Annual Mobile Antenna Surveys	Contractual	Use of mobile antenna to detect PIT tagged juvenile steelhead in treatment and control sections	Re-sighting of juvenile fish between tagging and recapture events will increase the precision of survival estimates.
-	Monitoring	ATV maintenance	Equipment	Maintenance of 4 ATVs provided by WDFW	Provide upkeep and replacement of parts for ATV use

-	Monitoring	Antennas	Equipment	Replacement PIT tag antennas	Floods and debris likely to damage some antennas and or cables
-	Monitoring	PIT tags	Equipment	4000 8-23 mm PIT tags /year for adult and juvenile tagging program	PIT tags will allow us to determine numerous life history metrics for adult and juvenile life stages
-	Monitoring	Miscellaneous equipment	Equipment	Miscellaneous equipment needs such as seine nets, pit tag needles, waders, etc	Frequently used equipment will require regular replacement
March	Project Management and Coordination	Asotin IMW Coordinator	Contractual	Coordination and management of all IMW related activities between different federal, state, county, and private agencies	One entity should be responsible for project coordination to maintain consistency in implementation of IMW. Contract to start at end of Phase II Feb 28, 2010).
March	Project Management and Coordination	Database development, data entry, QA/QC	Contractual	Responsible for all IMW data collected during project.	Data will be housed in Access databases based on database structures to improve regional data consistency.
March	Project Management and Coordination	Annual Data Analysis and Design Review	Contractual	Annual IMW design review and data analysis, including mark recapture abundance estimates, power analysis, geomorphic and spatial analysis, modeling of fish habitat relationships	Data analysis and reporting required each year to identify potential issues, resolve technical aspects of experimental design, summarize data, and develop and understanding of fish response to restoration activities
March	Project Management and Coordination	Field Surveys	Contractual	IMW coordinator to participate in field surveys throughout the year	Field supervision required to ensure consistency and data quality
March	Project Management and Coordination	Travel/Technical Meetings	Contractual	IMW Manager and Coordinator travel expenses to attend 4-6 RTT meetings a year and participate in public outreach, and landowner meetings	Required to update the RTT on the progress of the IMW and present results and stay informed about community perception of the IMW project.
May	Project Management and	Training	Contractual	All field crews to participate in sampling, safety, and IMW specific training	Important to have crews understand the objectives of the IMW and to meet and discuss survey techniques and safety issues

	Coordination				
Sept	Project Management and Coordination	Annual Reporting	Contractual	Summarize activities in annual report to funding agencies, technical committees, and interested parties	Annual reporting required to update progress of the IMW, highlight findings to date, and describe logistic constraints and possible solutions
March	Restoration Implementation	Design a Restoration Plan	Contractual	A key goal this year is to develop a detailed restoration design/plan for the three proposed treatments in Charley Creek	The Asotin IMW has an approved experimental design and monitoring plan but has yet to develop a detailed restoration plan. The specifics number, type, and placement arrangement of treatments needs to be fully developed. We plan to have a minimum of three geomorphologists conduct field assessment and make recommendations on the specific design elements.
March	Administration	Contract Monitoring	Government	The Walla Walla Community College will be responsible for managing all funding for Phase III of the IMW project	The College is best suited to provide funding management duties (6% charge of total budget)