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Methow Intensively Monitored Watershed 2012 Annual Report

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Columbia-Snake Salmon Recovery Office
Pacific Northwest Regional Office, Boise, Idaho

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U.S. DEPARTMENT OF THE INTERIOR

PROTECTING AMERICA'S GREAT OUTDOORS AND POWERING OUR FUTURE

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Cover Photo: Methow River looking north from Twisp, Washington.

Date: May 21, 2007 Photo by: Ronald Gross

Methow IMW Partners

U. S. Geological Survey – Columbia River Research Laboratory

University of Idaho - Cooperative Ecosystem Study Unit, Fish and Wildlife, College of Natural Resources

U. S. Bureau of Reclamation – Technical Service Center

NOAA's Northwest Fisheries Science Center

U. S. Fish and Wildlife Service – Winthrop National Fish Hatchery

U.S. Fish and Wildlife Service - Abernathy Fish Technology Center

U. S. Forest Service – Okanogon-Wenatchee National Forest

Washington Department of Fish and Wildlife

Douglas County Public Utility District

Washington Department of Ecology

Yakama Nation

Methow Conservancy District

Upper Columbia Salmon Recovery Board

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Acronyms and Abbreviations

Action Agencies	BPA, Reclamation, and the Corps
AFTC	Abernathy Fish Technology Center
AMH	anti-Mullerian hormone
APR	Annual Progress Report
AREMP	Aquatic-Riparian Effectiveness Monitoring Program
ATP	aquatic trophic productivity
BACI	Before-After-Control-Impact
BiOp	Biological Opinion
BPA	Bonneville Power Administration
CHaMP	Columbia Habitat Monitoring Program
CSRO	Columbia-Snake Salmon Recovery Office, Reclamation, Pacific Northwest Region
Corps	U.S. Army Corps of Engineers
DCPUD	Douglas County Public Utility District
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
FSH	follicle stimulating hormone
IMW	Intensively Monitored Watershed
ISAB	Independent Science Advisory Board
ISEMP	Integrated Status and Effectiveness Monitoring Program
ISRP	Independent Science Review Panel
LH	lutenizing hormone
NOAA Fisheries	NOAA’s National Marine Fisheries Service

NWFSC	Northwest Fisheries Science Center
PIBO	Pacfish/Infish Biological Opinion
PIT	passive integrated transponder
PNAMP	Pacific Northwest Aquatic Monitoring Partnership
Reclamation	Bureau of Reclamation
RM	river mile
RME	research, monitoring, and evaluation
RPA	Reasonable and Prudent Alternative
TSC	Reclamation’s Technical Service Center, Denver, CO
UCSRB	Upper Columbia River Salmon Recovery Board
U of I	Cooperative Ecosystem Study Unit-University of Idaho Fish and Wildlife, College of Natural Resources
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USGS-CRRL	U.S. Geological Survey-Columbia River Research Laboratory
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington Department of Ecology
YN	Yakama Nation

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Executive Summary

Reclamation's Methow Intensively Monitored Watershed (IMW) 2012 Annual Report describes research, monitoring, and evaluation (RME) program goals, methods, and results that apply specifically to tributary habitat improvements in the Methow River basin as related to the 2008/2010 Federal Columbia River Power System Biological Opinion (FCRPS BiOp) (NOAA Fisheries 2008). The FCRPS BiOp is implemented by the Action Agencies (Corps of Engineers, Bonneville Power Administration, and the Bureau of Reclamation). Information in this Report is presented in a way that is consistent with the Action Agencies' tributary habitat RME framework. Appendices provide additional detail on methods and results.

IMWs are key elements of the programmatic monitoring approach developed by the Pacific Northwest Aquatic Monitoring Partnership (www.pnamp.org), the FCRPS BiOp Action Agencies, and NOAA's Northwest Fisheries Science Center to evaluate management questions at the reach and watershed landscape and fish population level. Each IMW project in the PNAMP portfolio, by design, may have a unique set of problems, and approaches to analyze the problems. The complete portfolio of IMW results is intended to provide evaluations and tools that can be used to plan, evaluate, and modify as necessary habitat improvement projects in habitat and fish population geographic domains outside of the IMW domains.

The Methow IMW monitoring program has four basic elements: 1) organization of multiple Federal, State, Tribal, and local entities to implement and monitor habitat improvement projects cooperatively; 2) a Before-After-Control-Impact (BACI) monitoring design that uses explanatory models to plan and design monitoring experiments associated with habitat improvement project implementation; 3) a data management project that organizes data from numerous monitoring projects for use in models; and 4) the development of an annual report that describe the program process and analytical results.

The 2012 Annual Report, our first report, describes the monitoring philosophy and methodology, summarizes the status of project implementation, and presents details of implementation in Appendices. Progress includes 1) development of a collaborative monitoring and reporting program; 2) substantial development of explanatory models and testing of some major hypotheses concerning environmental controls on fish populations; 3) a first version of a database manager software tool; 4) summaries of fish population status that indicate that current freshwater habitat is probably limiting fish population size; and 5) pre-project monitoring results for four large habitat treatment projects.

In 2013, the Methow IMW partners will conduct an extensive analysis of pre-project implementation data. We will use the pre-project data to calibrate our models, run the models with planned post-project habitat implementation designs, and prepare a post-project monitoring plan based on the model predictions. Post-project monitoring will take place for the period 2013 to 2016. Two treatments and two controls are planned for the Middle Methow River. One treatment study and a watershed-scale carrying capacity analysis are planned for the Twisp River.

1. Introduction

Habitat improvement and protection has been a centerpiece of salmon and steelhead and other ecosystem conservation efforts in the Pacific Northwest for decades (NRC 1996; Stouder et al. 1997; Lichatowich 1999; Knudsen et al. 2000; Lynch et al. 2002; Montgomery et al. 2003; Wissmar and Bisson 2003). Indeed, habitat improvement is an essential component of virtually all draft and completed Endangered Species Act (ESA) fish recovery plans, habitat conservation plans, and subbasin plans. Habitat improvement actions are a key tenet of NOAA’s National Marine Fisheries Service (NOAA Fisheries) recommendations to protect and restore natural ecological function to support and encourage healthy, naturally producing fish and wildlife populations. Habitat protection and improvement strategies are intended to improve survival, productivity, abundance, genetic diversity, and distribution of salmon and steelhead, both in the short term and the long term. Habitat improvement also helps reduce the potential effects of climate change. As the climate warms, tributary streams can provide refugia of cool water for salmonids in the watershed. Implementing actions that increase streamflows and maintain and create riparian buffers for summer shading will create or help protect thermal conditions that are suitable for cold-water species such as salmon and steelhead (ISAB 2007).

Based on this backdrop of science and management information, the most recent Biological Opinion (BiOp) issued by NOAA Fisheries (NOAA Fisheries 2008) for the operation of Federal dams on the Columbia and Snake rivers (the Federal Columbia River Power System or FCRPS) does not rely simply on hydrosystem improvement actions. Although the BiOp initially focuses on improvements in dam passage, e.g., performance standards and action plans to achieve 96 percent dam survival for juvenile spring migrating fish and 93 percent for summer migrating fish, some effects from dam operations will remain even with these passage improvements. As a result, the FCRPS BiOp takes an “All H” approach to fish mitigation, building on the base of hydro actions, but also including tributary and estuary habitat improvement, hatcheries and hatchery improvements, and harvest. The Bonneville Power Administration (BPA), the Bureau of Reclamation (Reclamation), and the U.S. Army Corps of Engineers (Corps) (referred to as the Action Agencies) all spend significant portions of their BiOp implementation budgets on habitat improvement, collectively totaling $180 million annually. Associated with these actions is research, monitoring, and evaluation (RME) for habitat, which averages an additional $25 million annually.

Given the large number of habitat improvement actions needed to address the BiOp, and the high costs associated with implementing those actions, it is critical that the effects of those actions be measured in order to determine if the actions are cost effective and they are doing what they are intended to do. Because it is not possible to measure the effects of every action, nor is it possible to measure the status of every population within the Columbia River Basin, the Action Agencies developed a monitoring framework that identifies the type and extent of monitoring needed to address the BiOp (BPA 2013).

Reclamation's Methow Intensively Monitored Watershed (IMW) 2012 Annual Report describes RME program goals, methods, and results that apply specifically to tributary habitat improvements in the Methow River basin as related to the FCRPS BiOp. The FCRPS BiOp is implemented by the Action Agencies. Information in this Report is presented in a way that is consistent with the Action Agencies' tributary habitat RME framework. Appendices provide additional detail on methods and results.

The Methow River Basin is located on the east side of the Cascade Range in north-central Washington. The Methow River drains about 1,890 square miles and flows about 86 river miles from the crest of the Cascades (elevation 8950 feet) to its confluence with the Columbia River at river mile (RM) 524 (elevation 775 feet). The Basin five distinct subbasins or watersheds: the Upper Methow River above Winthrop, the Chewuch River at Winthrop, the Middle Methow River between Winthrop and Twisp, the Twisp River, and the lower Methow River below Twisp including three significant tributaries (Beaver Creek, Libby Creek, and Gold Creek) (Figure 1). The Methow River IMW is home to two ESA-listed populations of anadromous fish covered under the FCRPS BiOp: endangered Upper Columbia River spring Chinook salmon (*Oncorhynchus tshawytscha*) and threatened Upper Columbia River steelhead (*Oncorhynchus mykiss*).

The Methow IMW design focuses on how projects operate on habitat to increase available food supply to listed salmonids in the context of a fish food web. The design strategy is to use models to guide the planning of field work as well as to support the analysis of projects and ultimately the redesign of treatments in an adaptive management framework (see Section 4.1, Figures 2 and 3). The effects of habitat projects on listed fish growth rates and survival will be placed in the context of a full-life cycle model (Appendix B).

The Methow IMW partners have collaborated for the past five years on monitoring activities that have helped shape the IMW design. Reclamation staff has organized annual meetings to discuss plans, methods, and results. The major monitoring efforts include a fish habitat monitoring program, a fish production monitoring program, a barrier removal and steelhead passage survival and genetics study, a channel complexity pre-treatment fish food web and fish production study, a nutrient enrichment pre-treatment primary and secondary production study, a hatchery steelhead rearing study, and a steelhead relative (hatchery versus wild) reproductive success study.

Five Reclamation-funded fish production projects are underway to implement the IMW design. First, an aquatic trophic productivity model is under development. The model will be tested first using data from a channel complexity pre-treatment fish food web and fish production study. After recalibration, the model will be used to predict changes in fish production due to three habitat treatment projects: two channel and floodplain complexity projects, and a nutrient treatment project. The fifth project is the development of a data harvester tool that will gather model data from multiple sources and prepare it for use in the model. The harvester will also be used to develop reports. Project data and methods will be documented using tools developed by the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) (http://www.pnamp.org/topics/2).

Numerous habitat improvement projects have been implemented in the Methow River IMW within about the last 10 years by Federal and State agencies and local partners, ultimately to increase the abundance of ESA-listed salmon and steelhead. Methow habitat improvement projects described in this report and its appendices address, for example, replacement of barriers to fish migration with rock vortex weirs; culvert replacement; providing access to side channels for refuge and rearing for juvenile fish; riparian improvements to stabilize eroding streambanks and provide shade to lower water temperature; placement of large woody debris; and reconnecting channels with floodplains.

Two studies have shown positive trends in fish abundance as a result of habitat improvement projects. An extensive monitoring effort in Beaver Creek, after a fish barrier was removed, has demonstrated the recolonization of wild steelhead spawners above the barrier (Appendix C). Monitoring of a levee removal and side channel reconstruction project at Elbow Coulee in the Twisp River shows an increased abundance of listed spring Chinook and steelhead in a now highly productive floodplain environment (Appendix D).

Large channel complexity treatment projects were initiated in 2012 in the Middle Methow River. Post-treatment data collection and analysis will begin in 2014. The Middle Methow pre-treatment monitoring results (Appendices E3 and E4) will be incorporated in a fish habitat and fish production study design. The schedule and first set of analyses for that design are described in Appendix E5. Pre-treatment data collection for the nutrient treatment project has been supplemented in 2012 in preparation for a 2013 treatment. The final RME design for this treatment will be completed in 2013.

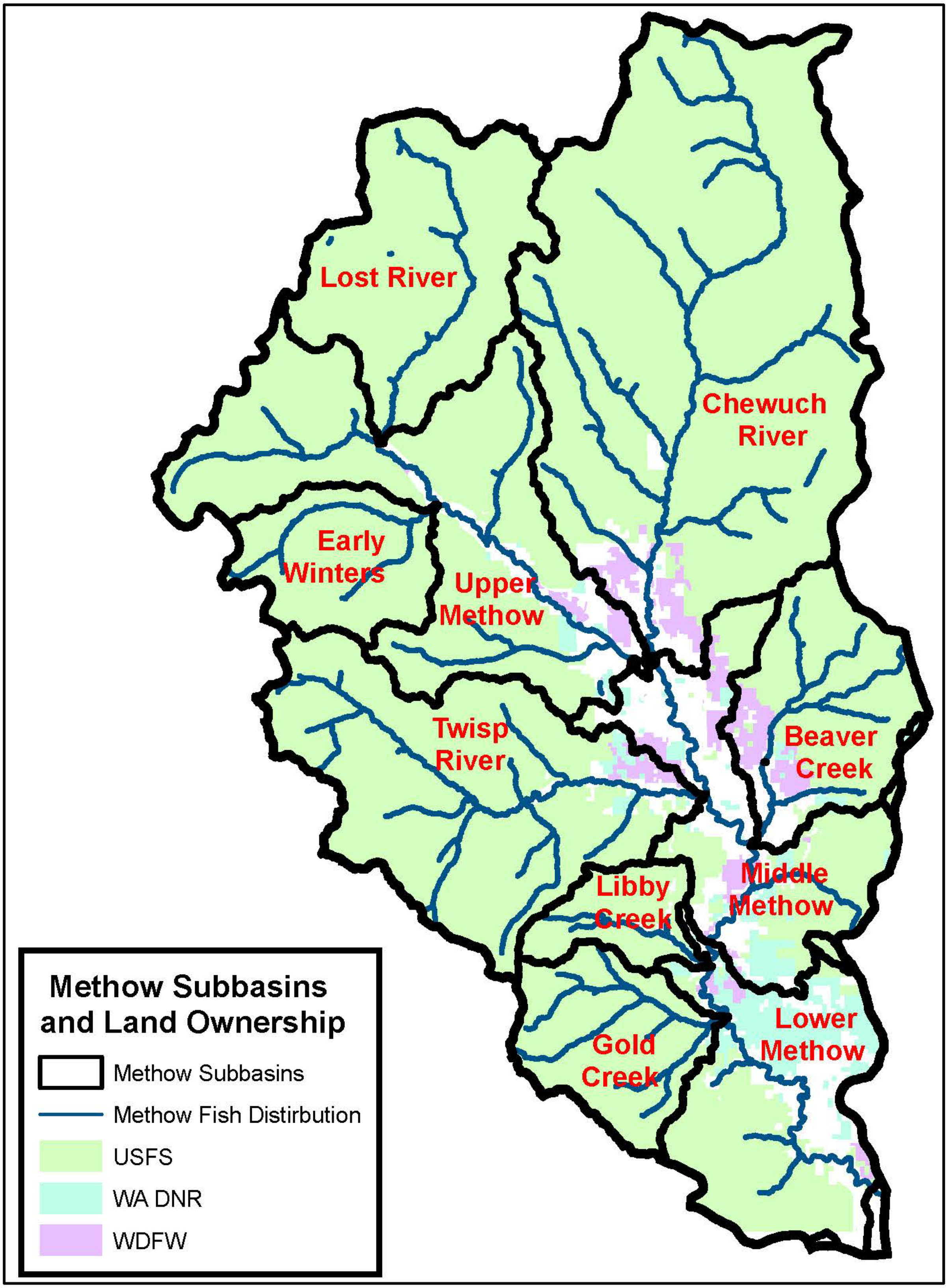

Figure 1. The Methow River IMW Major Tributary Subbasins.

The Methow IMW Report starts with an explanation of the IMW structure: the IMW concept, monitoring coordination, and methodology. The scientific basis for the IMW approach and the Methow IMW organizational structure are discussed in appendices A and B. Appendix B also describes the primary evaluation tool, the aquatic trophic production (ATP) model. The 2012 status of habitat project implementation and RME is presented and summarized. Appendices C, D, and E provide substantial detail on three projects. The detailed project monitoring designs structured around the ATP model will be reported in the 2013 Annual Report as an additional appendix

2. The Intensively Monitored Watershed Concept

IMWs are key elements of the programmatic monitoring approach developed by the Pacific Northwest Aquatic Monitoring Partnership (www.pnamp.org), the FCRPS BiOp Action Agencies, and NOAA's Northwest Fisheries Science Center to evaluate management questions at the landscape and fish population level. Reclamation's research coordinator participates on the PNAMP Steering Committee and its IMW Subcommittee which developed a regional strategy for IMWs (http://www.pnamp.org/document/1432). PNAMP organized a July 2008 workshop to help implement this regional strategy (http://www.pnamp.org/document/1651). PNAMP is planning a second IMW workshop in early December 2012. The basic premise of the IMW is that the complex relationships controlling a fish population's response to habitat conditions can only be understood and quantified by concentrating monitoring and research efforts at an appropriate spatial and temporal scale.

Generally, the Action Agencies have defined the watershed scale, for the purpose of implementing an IMW in the Columbia River Basin, as the area occupied by one population of an evolutionary significant unit of salmon, or of a distinct population segment of steelhead. To tease out the effects of watershed improvement projects on target fish populations, the IMW project is conducted over multiple years, at multiple spatial scales, in response to multiple habitat treatments of ample size to affect a measurable response at multiple life-stages of the populations. Additionally, fish population and habitat models are used to plan and analyze data collected in field research experiments and monitoring.

The IMW approach has broad scientific support in the Pacific Northwest Region. The Independent Science Review Panel (ISRP) and the Independent Science Advisory Board (ISAB) recommended the use of IMWs for large monitoring programs over wide geographic areas like the Columbia River Basin, with inclusion of probabilistic habitat and fish sampling. The ISRP and ISAB have also recommended mathematical modeling and food web analyses in an IMW framework (http://www.nwcouncil.org/library/isab/2011-1/).

Like the ISAB/ISRP, Oregon's Independent Multidisciplinary Science Team recommended standardization of monitoring terms and data metrics; basic research to fill information gaps; landscape assessment tools and other tools for aggregating data from IMWs; statisticians to develop sound experimental designs; and centralized data management (IMST 2007). Similar recommendations for an IMW approach have come from the Washington Independent Science Panel and the PNAMP.

3. Coordination for the Methow IMW

The Methow IMW is a collaborative monitoring effort among the Upper Columbia River Salmon Recovery Board (UCSRB), the Methow Conservancy District, the Washington Department of Fish and Wildlife (WDFW), the Washington Department of Ecology (WDOE), the Douglas County Public Utility District (DCPUD), the Yakama Nation (YN), the U.S. Fish and Wildlife Service (USFWS), the Northwest Fisheries Science Center (NWFSC), and the U.S. Forest Service (USFS). Reclamation's Columbia-Snake Salmon Recovery Office (CSRO) funds its RME work through agreements with the U.S. Geological Survey (USGS) – Columbia River Research Laboratory (USGS-CRRL), the Cooperative Ecosystem Study Unit – University of Idaho Fish and Wildlife, College of Natural Resources (U of I), and the Methow Conservancy District.

CSRO's monitoring coordinator organizes regular coordination meetings with Methow monitoring partners, and through its agreements, directs and funds data management and modeling services, and conducts reach-scale monitoring activities associated with Reclamation's habitat and hatchery funded programs. The WDFW, through funding from DCPUD, is collecting fish population data to assess improvements in State hatchery projects, including a relative reproductive success study of hatchery and wild steelhead in the Twisp River; the USFWS is working with the NWFSC, Reclamation, and USGS-CRRL to collect data on hatchery improvements at the Reclamation-funded Winthrop hatchery; the YN, through BPA funding, is collecting data on nutrient supplementation projects and coho reintroduction projects; Reclamation's Technical Service Center (TSC) received three years of funding to model Methow River physical processes such as flow and temperature with respect to climate change effects; the WDOE funded The Wild Fish Conservancy to conduct a long-term water quality study, including an intensive network of temperature data loggers; and the USGS is collecting social, physical, and biological data to evaluate a decision analysis model for natural resource decisions in the Methow River that will be used for climate change analyses using down-scaled climate data.

The full extent of Methow monitoring programs has been documented in the Methow Subbasin Monitoring Inventory, prepared by John Crandall, Wild Fish Conservancy, for the Methow Restoration Council (Crandall 2009).

4. The Research, Monitoring, and Evaluation Methodology

4.1 Guiding Scientific Principles

The Methow IMW design is based on three guiding scientific principles. The first principle states that theory guides the development of both qualitative and quantitative models of how systems function. The models then guide experimental design, monitoring, hypothesis testing, and data identification. The second principle says that complex resource management such as those involving habitat improvement projects for anadromous species questions usually require well-designed field experiments to promote learning. The third principle is that the systematic knowledge that is derived from well-designed experiments often suggests new theory and revisions to the models that can be used to formulate new hypotheses and newly designed field experiments.

Reclamation began the process of developing its modeling approach with a thorough review of the current state of Columbia River salmon population modeling. More recently (February 2011), Reclamation hosted a modeling workshop in Portland, which brought together leading salmon modelers (see Appendix A). Finally, Reclamation staff actively participates as a steering committee member of the PNAMP in the planning and development of regional monitoring programs including the development of IMWs. Further details on the IMW design can be found in Appendix B.

Reclamation-funded models will create and test hypotheses about how habitat projects affect fish survival and production. The models will be used to compare the likely effectiveness of a project or combinations of projects at varying spatial scales. The models will be tested using fish and fish habitat data associated with habitat improvement projects. A complimentary database project will track habitat and fish population data before and after habitat project treatments.

Reclamation, USGS-CRRL, and U of I developed the following RME framework for the collaboration among the Methow monitoring entities (Figure 2).

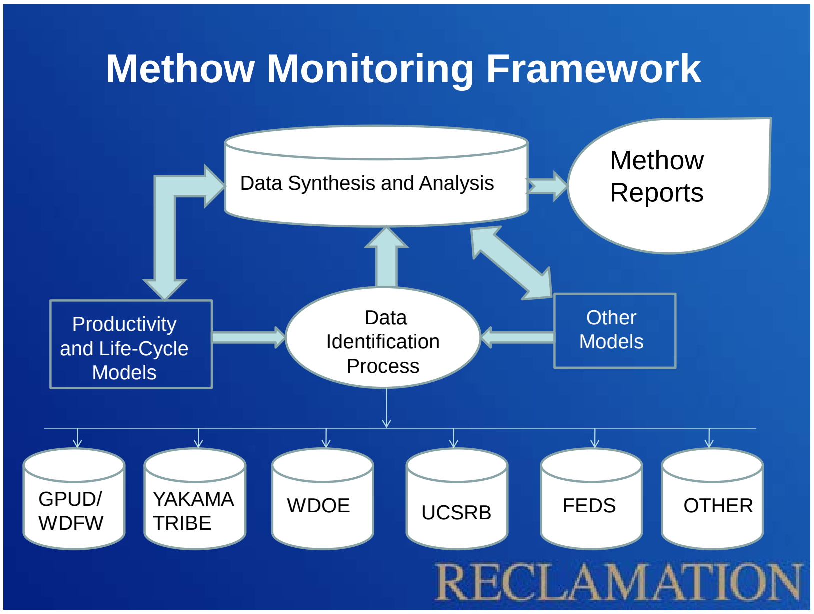

Figure 2. Methow IMW monitoring framework. The models identify the data needed for analysis. A data harvester collects the data from the entities that house the data.

The primary model is the ATP model. Reclamation-funded researchers use the system dynamics software Stella© (http://www.iseesystems.com/) to code the complex mechanistic interactions among habitat and fish populations in the ATP model. Stella© supports mapping and modeling; simulation and analysis; and communication tools including text, graphs, tables, and reports. We chose the commercial systems dynamics software Stella® because its stock and flow diagrams provide visual representations of the system dynamics and because free run-time versions of the software are available.

The core ATP model will be driven by separate ‘actor’ or treatment modules for each of the main Methow River habitat treatments (Figure 3). Each actor module will connect to the ATP model at the mechanistic points that are affected by the treatment type. For example, a large woody debris treatment is expected to affect bed scour. Bed scour is used several places in the ATP model such as detachment of periphyton, dislodging eggs from spawner redds, or transporting invertebrates from the river benthos to the active river flow as invertebrate drift food for column feeding salmonids. Actor modules will be run independently or simultaneously to reflect combinations of treatments.

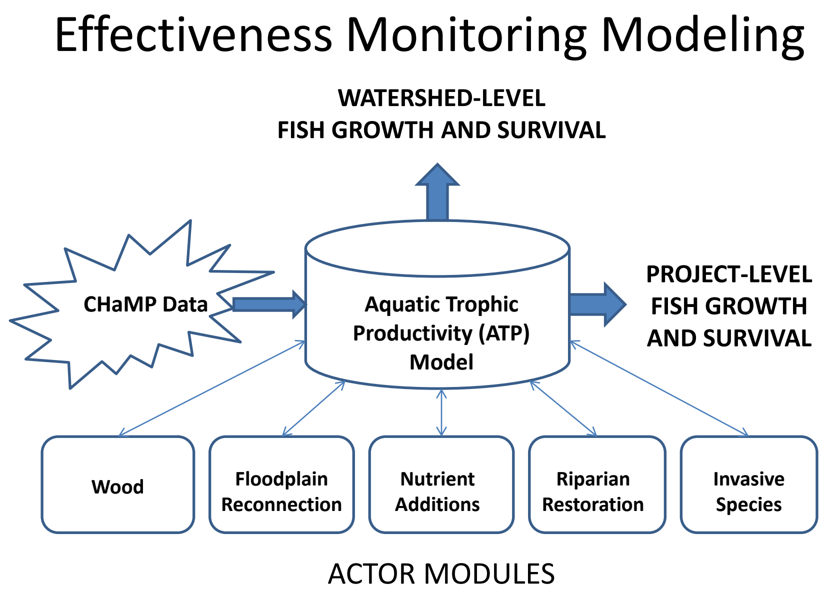

Figure 3. The Methow IMW model structure. The treatments (actors) have hypothesized effects on parameters of the ATP model. Columbia Habitat Monitoring Program (CHaMP) provides parameter estimates to the model. Both CHaMP and the ATP model can also provide feedback to the design of the treatments. CHaMP plus ATP enables scaling up combined actor effects to the watershed level.

4.2 The Reach and Watershed Scale Designs

Reclamation and USGS-CRRL are developing explanatory models to guide the scientific evaluations of fish and habitat relationships at reach and watershed scales (Appendix B). The models are designed to represent the physical, chemical, and biological processes that theoretically determine fish population responses used to predict responses to treatments. We start with the representation, calibrate the model, and use the model to predict fish responses to habitat treatments based on the treatment design (MADMDA Process, Figure 4). We learn from the model predictions and design the monitoring based on the 'explanations' derived from the model. After treatment, we measure the actual changes due to the design and incorporate these data into a new model prediction. If the model fails to predict the correct response, we reevaluate the model.

The Model, Analysis, Design, Monitor, Data and Adapt Process

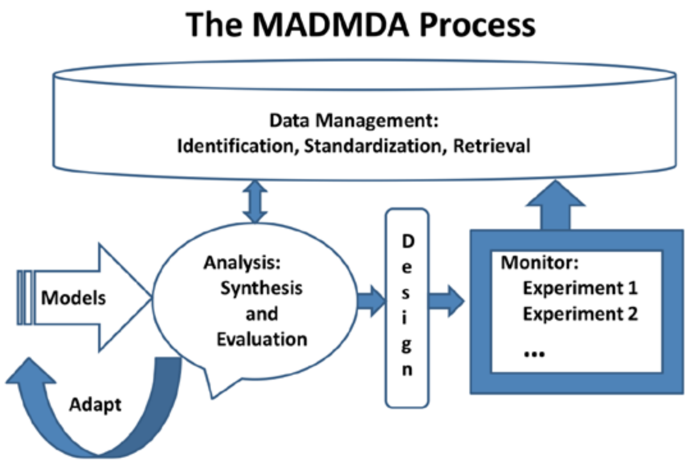

Figure 4. The MADMDA Analytical Process.

The ATP model takes an energetic approach to modeling fish food webs by linking fish production explicitly to the transfers of organic matter between different components of a stream food web. The framework of the ATP model is fashioned after the pioneering lotic ecosystem model of McIntire and Colby (1978) and McIntire et al. (1996), whereby food web dynamics are explicitly linked to the environmental conditions of the stream and adjacent riparian habitats. Similar to McIntire, we examine stream production as changes in the biomass of periphyton, detrital, secondary, and tertiary trophic stocks, and the elaboration of the coupled processes that affect those changes in production.

Field experiments will be conducted to parameterize, calibrate, and test (validate) each model component. The model will then be modified as needed to reflect empirical findings. We will use the ATP model to quantify how habitat restoration projects change fish production by affecting the underlying mechanisms represented in the model. Habitat data will be collected in association with habitat improvement actions (reach-scale) and by the Columbia Habitat Monitoring Program (CHaMP). A multi-agency water quality data collection program provides essential model data, and a multi-agency fish survival analysis feeds a regional full life-cycle model (Figure 5).

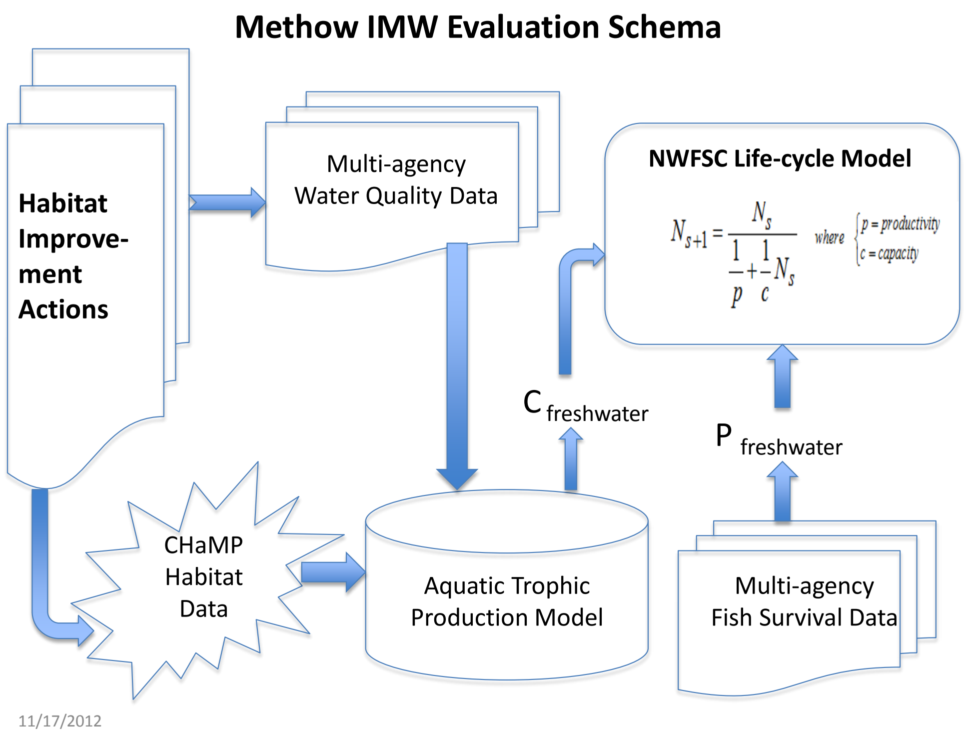

Figure 5. The Methow Analytical Design.

Fish survival and fish habitat carrying capacity will be evaluated at both the reach and watershed scales (Figure 6 and Figure 7). Middle Methow habitat treatments will be evaluated using a Before-After-Control-Impact (BACI) design. A watershed-scale carrying capacity analysis will be conducted in the Twisp River Basin using a variety of monitoring techniques and data sources (see Figure 7).

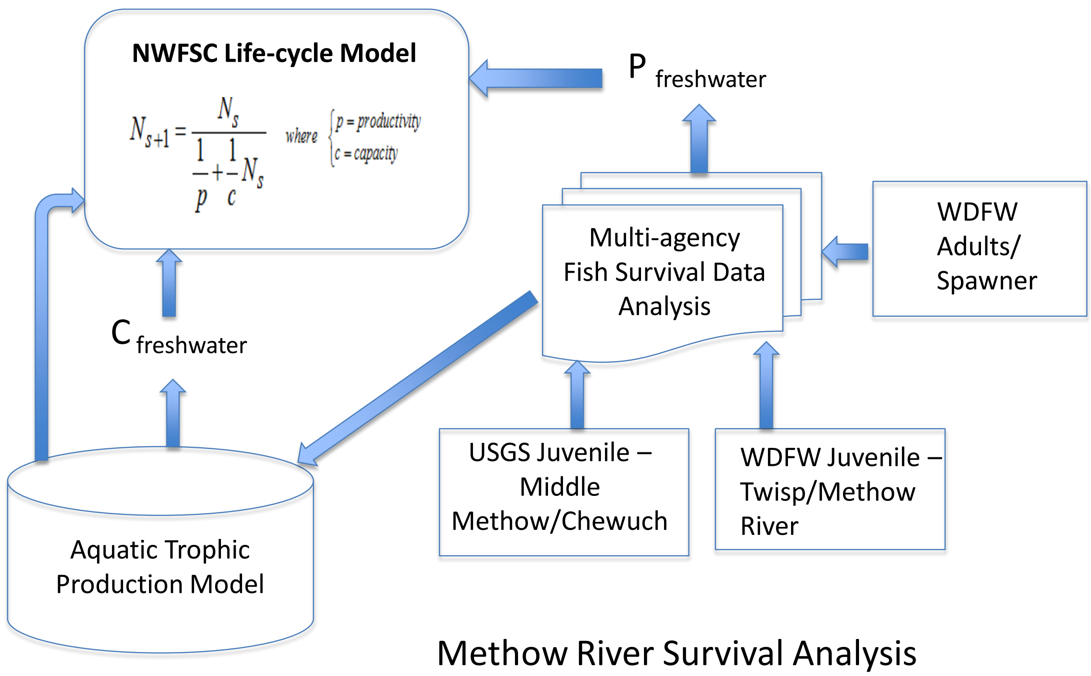

Figure 6. Data sources and flow for the fish survival analysis.

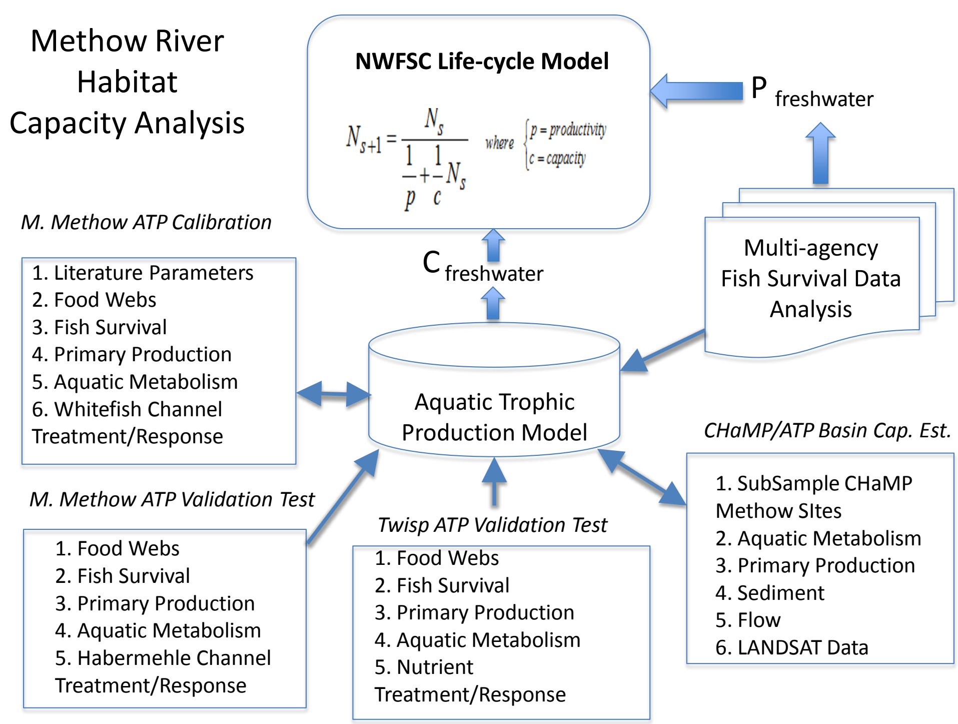

Figure 7. Data sources and flow for the habitat carrying capacity analysis.

4.3 Tributary Habitat Improvement Projects

The Action Agencies have provided technical assistance, or funded many habitat improvement projects in the Methow basin (Figure 8). Habitat projects are completed with multiple partners.[1] Habitat projects are meant to improve habitat for ESA-listed salmon and steelhead in the Methow basin. The projects address specific factors that control the growth of the Methow salmon or steelhead populations. These projects help satisfy Reasonable and Prudent Alternative (RPA) action 35 in the FCRPS BiOp. The FCRPS BiOp RPA 35, Table 5 specifies the Action Agency Methow basin habitat improvement goals of 6 percent habitat quality improvement for the Methow River spring Chinook population and 4 percent for the Methow River steelhead population by 2018.

[1] Habitat project partners include the Upper Columbia Salmon Recovery Board, the Methow Salmon Recovery Foundation, Washington Department of Fish and Wildlife, Yakama Nation, Trout Unlimited, BPA, U.S. Forest Service, U.S. Fish and Wildlife Service, and NOAA Fisheries.

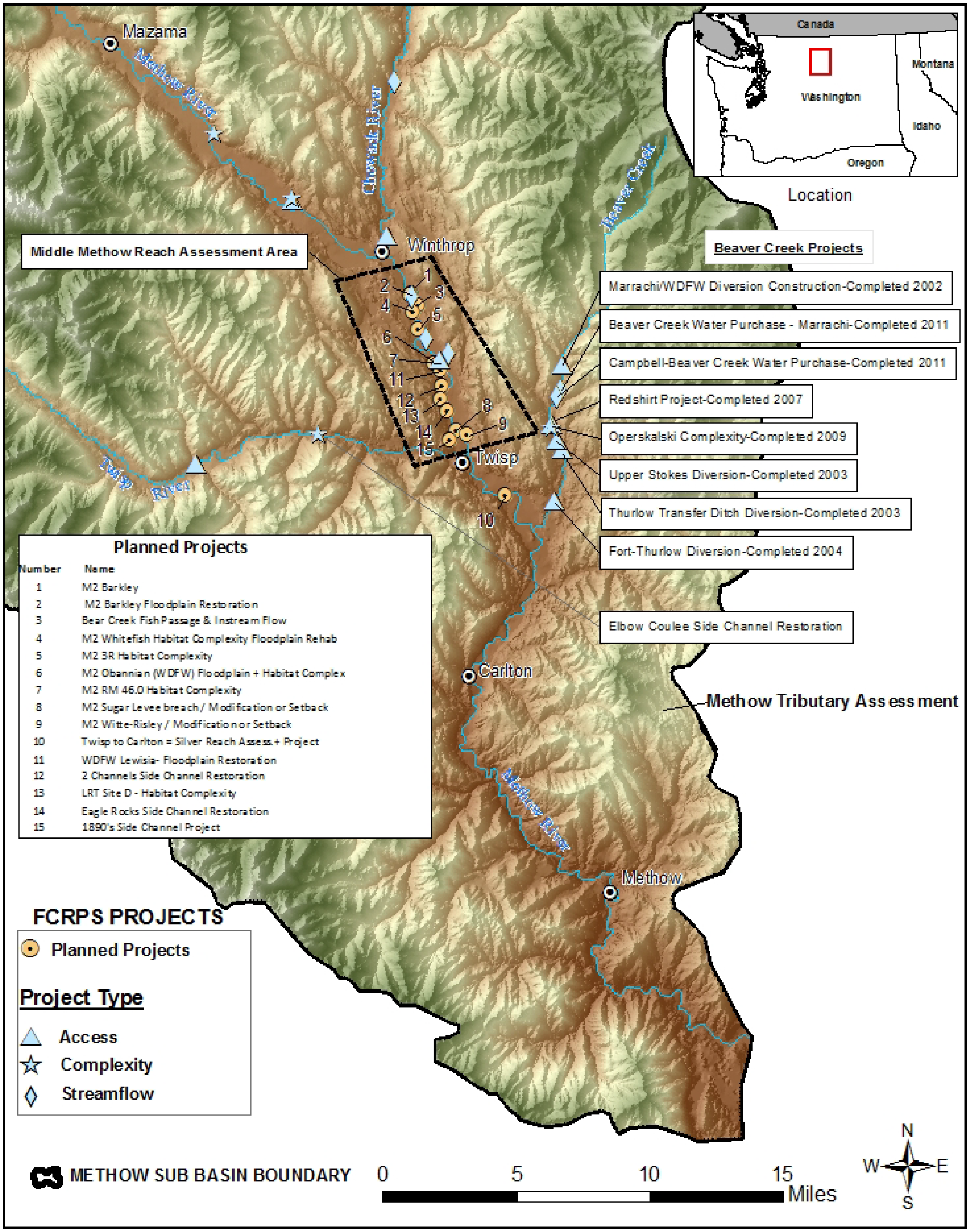

Figure 8. Map of the Methow basin showing Action Agencies habitat improvement projects completed since 2007.

Table 1 shows the metrics associated with completed and planned projects in the Methow basin.

Table 1. Metrics associated with tributary habitat improvement projects supported by the Action Agencies in the Methow basin 2007-2011.

Completed Actions	Metrics
Flow (Acre-feet)	973.4
Flow (cfs)	101
Complexity (Miles)	5.5
Riparian Habitat (Acres Improved)	32.3
Riparian Habitat (Acres Protected)	135
Riparian Habitat (Stream Miles Improved)	4.4
Riparian Habitat (Stream Miles Protected)	3.6
Screens (Number)	4
Access (Miles)	95.6

4.4 Expert Panel Project Evaluation and the RME Program

Tributary habitat improvement projects in the Methow basin are evaluated in several different ways. The discussion here is focused on the Expert Panel Process used for the 2008/2010 FCRPS BiOp.

First, local experts identify habitat/environmental factors that currently limit adult pre-spawn and egg-to-smolt survival within tributary streams. Experts use information contained in recovery plans, subbasin plans, watershed plans, limiting factors analysis reports, monitoring data, and personal knowledge and experience to help identify habitat/environmental factors limiting adult and juvenile Chinook salmon and steelhead. The experts determine the current function of each limiting factor as a percentage of properly functioning condition and assign weights to each factor. The weights reflect the importance of each factor to fish survival. For example, if two factors, fine sediment and large wood, are currently functioning at 30 percent of optimal condition, the local experts may weigh fine sediment higher than large wood, because fine sediment has a relatively greater effect on fish survival than large wood in that particular area.

Next, the Expert Panel estimates changes in limiting factor habitat conditions associated with habitat improvement actions implemented with funding or technical assistance from the Action Agencies as required by RPA 35 of the 2008/2010 FCRPS BiOp. Changes in habitat conditions estimated by the Expert Panel are converted to changes in habitat quality by the FCRPS BiOp Action Agencies using a process adopted by representatives of the Federal Agencies and sovereign States and Tribes who participated in the Habitat Collaboration Workgroup that helped develop the 2007 FCRPS Biological Assessment (FCRPS Comprehensive Analysis, 2007, Appendix C). The Methow basin Expert Panel has rated projects for the entire BiOp period.

4.4.1 RME Link to Project Evaluation

The primary purpose of the tributary habitat RME program is to measure the effects of habitat implementation projects on listed fish populations. Did a project or projects address the limiting factors intended? What was the population response to the project(s)? Which projects provide the greatest benefits and the lowest cost? The IMW framework is designed to answer these questions scientifically at the population level.

The Action Agency IMW programs have been developed through a regional collaboration with Federal, State, Tribal and local governments. Action Item 3, Outcome G, of Objective 4 of the PNAMP's strategy encourages Federal and State governments to select and fund clusters of habitat actions in IMWs in order to ensure that RME can detect change from the actions in terms of salmonid populations (http://www.pnamp.org/document/1060). The strategy identifies the distinguishing features of the IMW approach in contrast to general effectiveness monitoring activities:

- integrative watershed-scale evaluations
- assessment of fish population responses to habitat actions evaluated at the watershed scale in terms of causal or correlative relationships
- results from rigorous designs used to adequately address confounding factors and experimental controls or reference conditions

The tributary RME program provides information to support the Expert Panel process. In the IMW framework habitat and fish status and trend monitoring, implementation and compliance monitoring, and project effectiveness monitoring intersect with many of the Expert Panel evaluations to refine expert opinion about habitat/environmental factors that limit fish survival at the population level, and to inform the habitat project scoring process. Through an annual IMW reporting process, Expert Panels will have science available to inform judgments about changes in fish habitat conditions associated with habitat improvement projects.

4.5 Reclamation's Pre-project Physical Habitat Assessments

The past several years of tributary habitat implementation experience have led the Action Agencies to conclude that certain technical studies significantly improve the odds of constructing biologically successful habitat improvement projects. Based on this information, Reclamation began to complete tributary and reach assessments. These studies characterize ecosystem conditions, geomorphic parameters, baseline conditions, and other factors for identifying, prioritizing, and implementing successful habitat improvement actions. In the Methow basin, Reclamation completed the following assessments:

- Methow Subbasin Geomorphic Assessment
- Middle Methow Reach Assessment
- Big Valley Reach Assessment

These documents can be found at http://www.usbr.gov/pn/programs/fcrps/thp/ucao/index.html.

The information in these assessments has been and continues to be used to help design and build projects that are self-sustaining and *work with* the physical processes of the Methow River.

5. RME Results in the Methow IMW

This document is meant to be responsive to several of the RME RPA actions in the 2008/2010 FCRPS BiOp[2]. While focused on the IMW results, we also report relevant information that is organized as identified in "A Framework for the Research, Monitoring, and Evaluation (RME) Associated with Tributary Habitat Restoration and Protection" (BPA 2013). This enables the reader to understand the IMW results within the larger monitoring context. To this end, we report on implementation and compliance monitoring, fish and fish habitat trend monitoring, and habitat effectiveness monitoring at the project and watershed levels.

[2] Specifically, this work contributes to RPA actions: 56 [monitor and evaluate tributary habitat conditions and limiting factors], 57 [evaluate the effectiveness of tributary habitat actions], 63 [monitor hatchery effectiveness], 64[investigate hatchery critical uncertainties], 71 [coordination], 72 [data management] and 73 [implementation and compliance monitoring]).

5.1 Overview of the Structure of Habitat RME

The objective of habitat RME is to help answer specific management questions regarding habitat improvement actions, their effectiveness, and benefits (Figure 9). For example, managers need to know the specific factors and threats that currently limit fish survival in a particular location. They also need to know which actions are most effective at addressing the limiting factors and the relationships between various habitat actions and fish survival. Answers to these questions will inform management and assist with funding decisions.

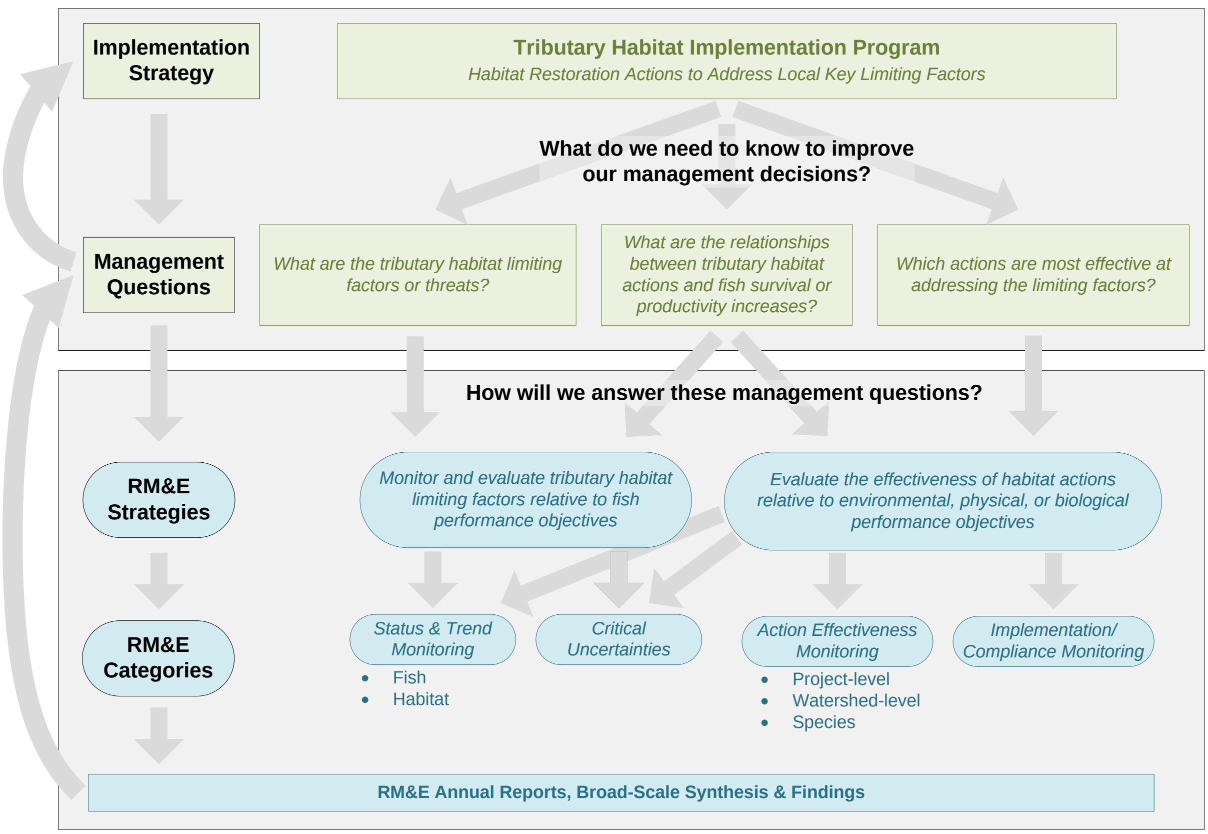

Figure 9. Linkages between tributary habitat implementation management questions and RME processes.

The next step is to determine how the management questions will be addressed. This is accomplished by linking specific questions to appropriate RME strategies (Figure 9). For example, because habitat restoration requires information on the factors that currently limit fish survival, an appropriate strategy is to use status and trend monitoring or critical uncertainties research, or both, to identify limiting factors within the population. There are four categories of tributary habitat RME being implemented to address these management questions and strategies.

Status and trends monitoring is used to determine the current status of fish populations and their habitat. This type of monitoring also measures fish and habitat over a number of years so that trends can be developed and managers can tell if a fish population is increasing in size, decreasing in size, or remaining stable. The same concept applies to habitat conditions. Managers can use status and trend information to determine if a particular limiting factor or habitat impairment (e.g., fine sediment in a spawning reach) has improved, become more degraded, or remained steady over a period of several years. Analyzing the combination of fish and habitat status and trends reveals relationships between the two.

Implementation monitoring verifies that a project did what it intended (e.g., created X linear feet of riparian habitat with some specified structure, or corrected water temperature impairments for some fish life stages). Compliance monitoring revisits the implementation site at an appropriate time thereafter (e.g., five year intervals over 20 years for atypical riparian habitat improvement project) and verifies that a structure or improved habitat condition is still in place and is functioning.

Action effectiveness monitoring occurs at various spatial scales. Project level action effectiveness monitoring is where an individual habitat action (e.g. culvert replacement or riparian planting project) is monitored for its effects at the local scale. Project level monitoring can be rolled up and combined to assess the benefits of different types of habitat projects – for example, the benefits of barrier removal (e.g. culvert replacement) as a category of habitat action. Watershed action effectiveness monitoring is used to determine how a suite of actions in a larger geographic area has collectively affected a larger component of a fish population's habitat. IMWs are part of watershed action effectiveness monitoring, developing relationships between habitat conditions and fish status.

The Methow River IMW includes three fish status and trend monitoring programs (the WDFW-salmon and steelhead, the USFS-bull trout, and the USFWS-bull trout); four habitat status and trend monitoring programs (BPA and the NWFSC's CHaMP, the USFS's Aquatic-Riparian Effectiveness Monitoring Program [AREMP] and its Pacfish Infish Biological Opinion [PIBO], and the WDOE's water quality monitoring program; and five effectiveness monitoring programs (the UCSRB's salmon recovery program, the WDFW and DCPUD's Habitat Conservation Program, the YN Natural Production Program, the BPA and NPPC's Fish and Wildlife Program, and the Reclamation-funded FCRPS's fish and fish habitat monitoring program). These programs and major monitoring site locations are displayed in Figure 10. Each of these programs contributes data and analysis to the Methow IMW. This section describes some important results through 2011 from select programs; the development of models to contribute to the synthesis of this information; and an introduction to two experimental designs intended to answer key management questions and provide data to test the models.

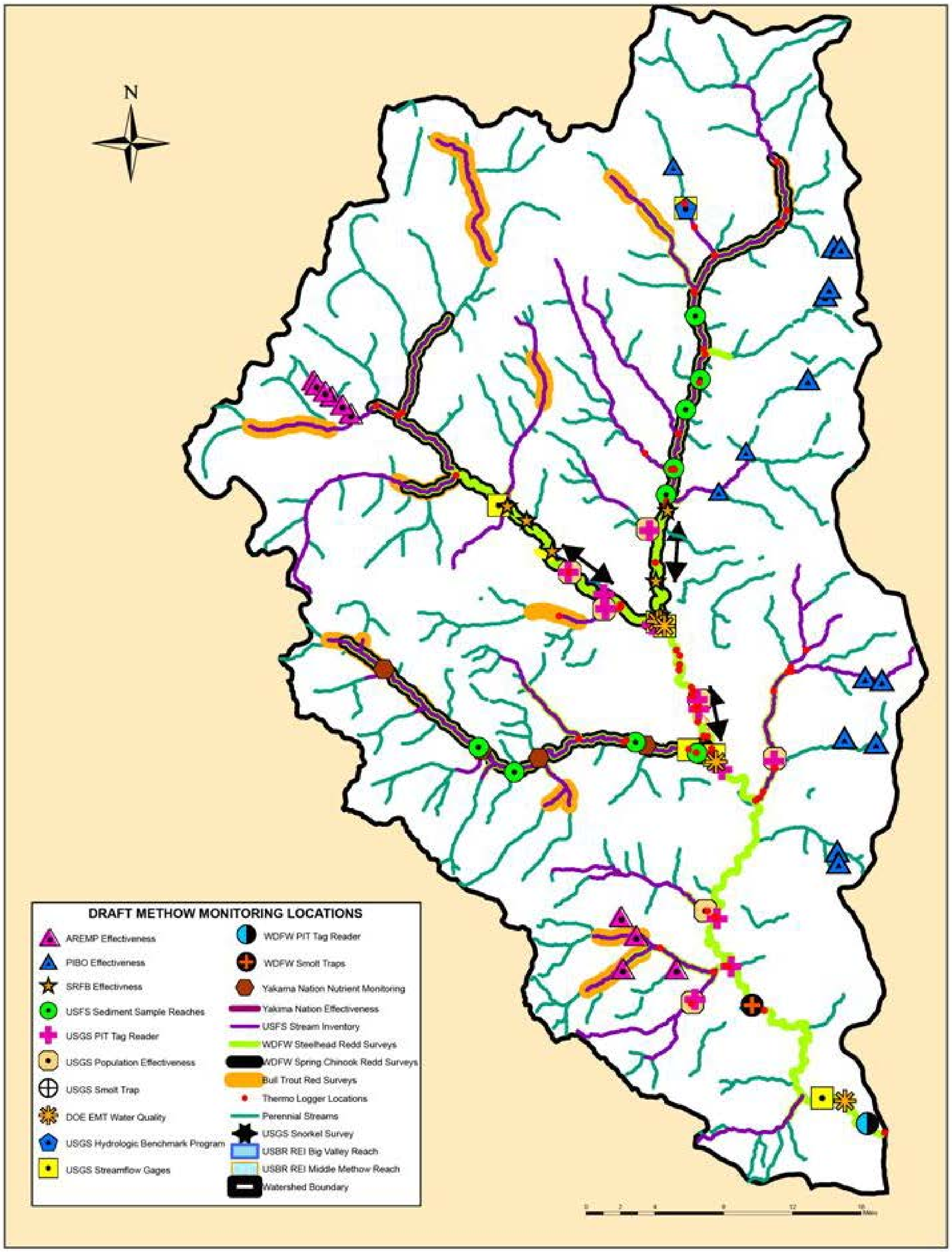

Figure 10. Location of monitoring efforts occurring throughout the Methow subbasin (Crandall 2009).

5.2 Implementation and Compliance Monitoring

Implementation monitoring is addressed, in part, by Annual Progress Reports (APRs) produced by the Action Agencies for the FCRPS BiOp. APRs contain tables of projects and associated metrics for completed habitat improvement projects associated with the FCRPS BiOp. Where Reclamation provides technical assistance to partners, an additional annual report documents habitat improvement projects completed with Reclamation involvement (http://www.usbr.gov/pn/programs/fcrps/thp/other/index.html). Finally, the Expert Panels, at each 3-year cycle, "look back" at completed projects from the last cycle.

Compliance monitoring is accomplished through proper contract oversight and by managing project information in databases (e.g. PISCES, TAURUS, Reclamation's database). From time-to-time, Reclamation reviews projects for engineering purposes (to ensure that designs are working as intended and to improve future project designs). Reclamation habitat staff live in Salmon and Boise, Idaho; Twisp and Wenatchee, Washington; La Grande and John Day, Oregon. These people have personal knowledge of the habitat improvement projects that Reclamation supports. Finally, various groups (e.g., Washington State Salmon Recovery Board Reach Scale Effectiveness Monitoring Program) are independently monitoring habitat projects.

5.3 Fish Status and Trend Monitoring

Fish status and trend data are used to aid in the development of long-term relationships between habitat conditions and fish performance (e.g., survival, abundance, biomass, or growth). The objectives of fish population status and trend monitoring are to: (1) measure and track over time the total number of spawners (including both hatchery and natural-origin fish), the number of natural-origin recruits produced, adult productivity (adult recruits per spawner) of the population, and egg-to-smolt survival prior to reaching the mainstem Columbia River habitat; and (2) develop relationships between the status of the population (e.g., egg-to-smolt survival) and habitat quality and quantity (capacity) conditions. The second objective will help fish-habitat models.

Two important fish population status and trends collected for at least one population of every major population group of listed fish are the number of adult spawners (fish in) and the number of smolts produced (fish out). With these data, one can estimate egg-to-smolt survival based on assumptions or measurements of pre-spawning mortality, females/redd, and fecundity.

5.3.1 Salmon, Steelhead Status and Trend Monitoring

Salmon and steelhead population status and trend monitoring in the Methow IMW is performed by the WDFW for DCPUD that operates Wells Dam immediately downstream of the Methow River. The monitoring contributes to the Hatchery RME component of

DCPUD's Habitat Conservation Plans, which are analogous to the BiOp that the Action Agencies operate under). These programs provide the fish-in/fish-out data at the watershed and population scales. These data are important to the IMW because they provide the most basic fish status information for this watershed. Over time, these data will be important to track as habitat projects continue to be implemented.

The WDFW operates two screw traps in the Methow River basin. Reclamation/USGS operate a third screw trap. Reclamation, USGS, and WDFW have also installed numerous passive integrated transponder (PIT)-tag readers that contribute to survival estimates of smolts out (Figure 11).

Figure 11. Location of fish monitoring gear already in place or planned in the Methow River watershed by WDFW or USGS. Depicted as existed by the end of FY2010. The restoration reach is denoted as "M2", P or p = large or small PIT-tag interrogation system (PTIS), and S = smolt trap.

The following figures and tables describe the adult status and trends and some preliminary analyses of smolt pre spawner.

Adult Return Trends

Figure 12 and 13 describe the adult spawner abundance of Upper Columbia River steelhead and spring Chinook salmon in the Methow basin. Estimates are of naturally produced adult returns and are taken from the US v. OR TAC Joint Staff Reports. Although steelhead adult abundance appears to be improving, spring Chinook salmon abundance shows no discernable trend over this period.

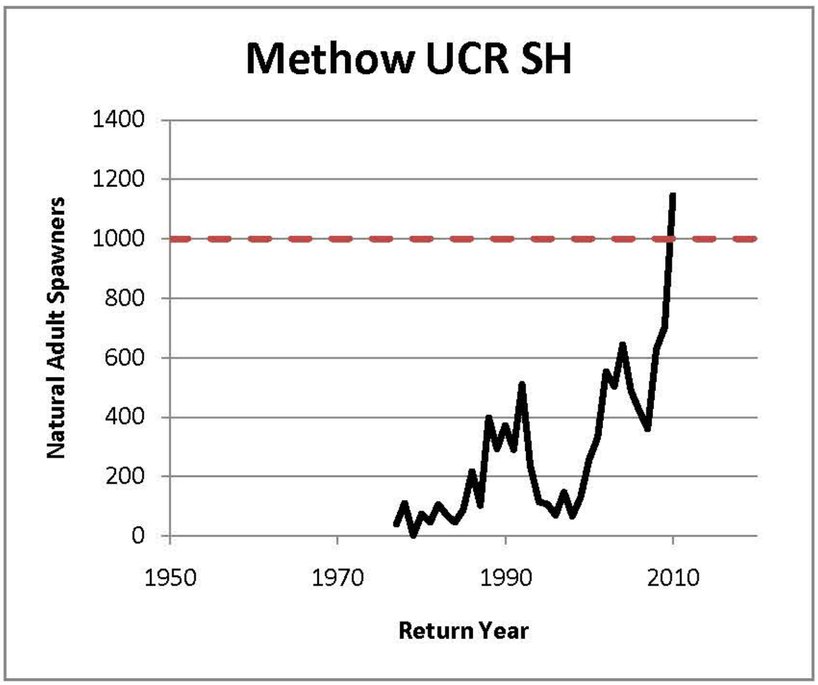

Figure 12. Returns of naturally produced adult Upper Columbia River steelhead in the Methow basin. The dotted red line indicates the minimum abundance for recovery.

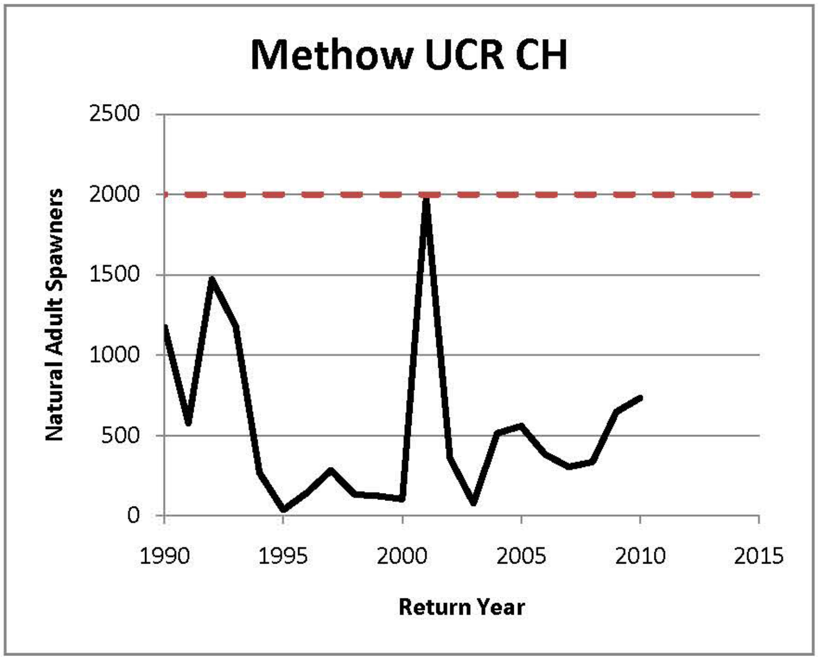

Figure 13. Returns of naturally produced adult Upper Columbia River spring Chinook in the Methow basin. The dotted red line indicates the minimum abundance for recovery.

Spawner Population Data

Listed Upper Columbia spring Chinook and summer steelhead populations in the Methow River basin are affected by a number of human caused factors including freshwater and estuarine habitat degradation, hatchery fish competition and gene introgression, dams, water quality degradation, predation, and human harvest. The Northwest Fisheries Science Center estimated spawner abundance and population growth rates for both species in 2010 (Table 2 and Table 3).

Table 2. Estimated spawning abundance for Upper Columbia spring Chinook populations.

Population	Total Spawners 5-year geometric mean, *range*			Natural Origin Spawners 5-year geometric mean		% Increase Natural Current vs. Prior
	Listing 1991-1996	Prior 1997-2001	Current 2003-2008	Prior 1997-2001	Current 2003-2008	
Wenatchee River	167	470 *119-4,446*	800	274	489	78%
Entiat River	89	111 *53-444*	253 207-317	65	111	71%
Methow River	325	680	358	282	402	43%

* From Table 6, *Status review update for Pacific salmon and steelhead listed under the Endangered Species Act*, Michael Ford (ed.), Tom Cooney, Paul McElhany, Norma Sands, Laurie Weitkamp, Jeffrey Hard, Michelle McClure, Robert Kope, Jim Myers, Andrew Albaugh, Katie Barnas, David Teel, Paul Moran and Jeff Cowen, Northwest Fisheries Science Center, Conservation Biology Division *Operations, Management and Information Division, December 10, 2010.

Table 3. Estimated spawning abundance for Upper Columbia summer steelhead populations.

Population	Total Spawners 5-year geometric mean, *range*			Natural Origin Spawners 5-year geometric mean			% Increase Natural Current vs. Prior
	Listing 1991-1996	Prior 1997-2001	Current 2003-2008	Listing 1991-1996	Prior 1997-2001	Current 2003-2008	
Wenatchee River	1880	696 *343-1665*	1891 *931-3608*	458	*326 (241-696)*	**819 *(701-962)***	151%
Entiat River	121	265 *132-427*	530 *300-892*	59	*46 (31-97)*	**116 *(99-137)***	152%
Methow River	1184	1935 *1417-3325*	3504 *2982-4394*	251	*162 (68-332)*	**505 *(361-703)***	212%
Okanogan River	723	1124 *770-1956*	1832 *1483-2260*	84	*53 (22-109)*	**152 *(104-197)***	187%

* From Table 6, *Status review update for Pacific salmon and steelhead listed under the Endangered Species Act*, Michael Ford (ed.), Tom Cooney, Paul McElhany, Norma Sands, Laurie Weitkamp, Jeffrey Hard, Michelle McClure, Robert Kope, Jim Myers, Andrew Albaugh, Katie Barnas, David Teel, Paul Moran and Jeff Cowen, Northwest Fisheries Science Center, Conservation Biology Division *Operations, Management and Information Division, December 10, 2010.

Spring Chinook and Summer Steelhead: Egg to Emigrant Juvenile Population Data by Brood Year

Juvenile production is very low. Table 4 shows brood year smolt production for the Twisp River where a weir and smolt trap maintained by WDFW provide the best estimates of fish in and fish out. Figure 14 and Figure 15 compare Twisp River spring Chinook and summer steelhead egg to emigrant data to similar data averaged for other Pacific Rim streams.

Table 4. Steelhead egg-to-smolt data (WDFW; red values calculated from data).

STH Twisp River Brood Year Production							
Brood Year	**Redds**	**Estimated Eggs**	**Age-1**	**Age-2**	**Age-3**	**Age-4**	**Smolt/Egg**
2003	606	3849312	241	1787	1357	58	0.00089
2004	254	1166876	79	3192	500	198	0.0034
2005	452	2806016	292	2686	2102	113	0.00185
2006	384	2452992	81	4712	2223	336	0.002997
2007	82	418774	42	10217	2812	441	0.032266
2008	182	1078350	76	2295	769	74	0.00298
2009	352	2147200	61	4725	1806	147	0.003139
							0.00679
							Avg smolts/ Redd

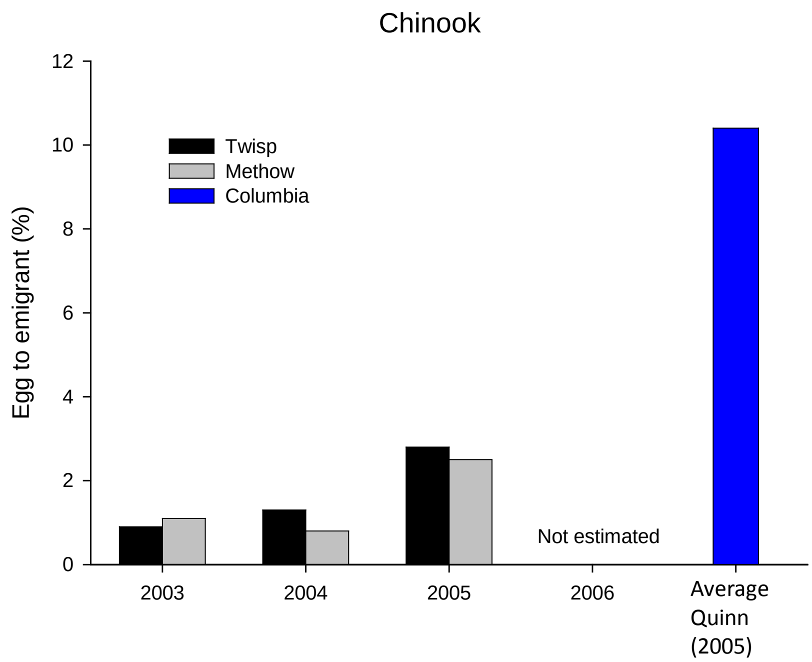

Figure 14. Twisp River spring Chinook egg to emigrant (age 0 + age 1) percentage compared to data from numerous streams across the Pacific Rim (Quinn 2005).

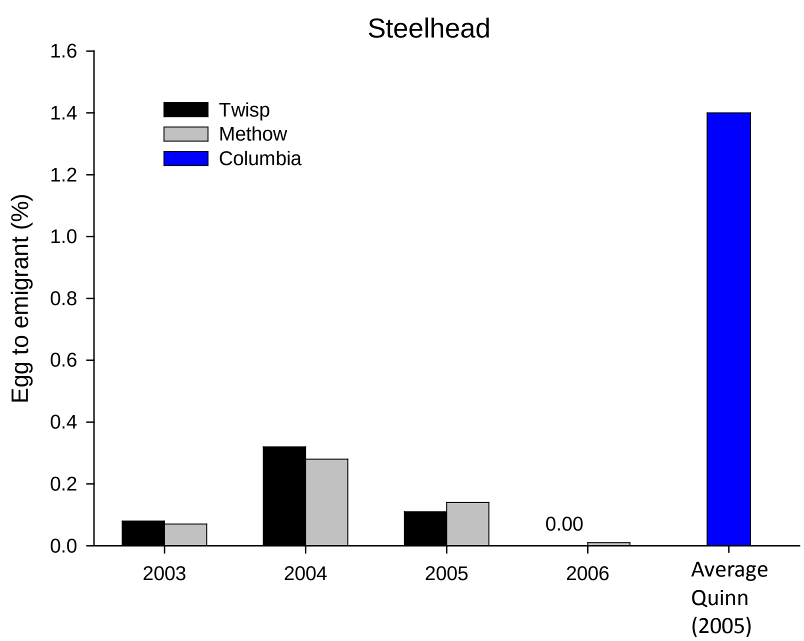

Figure 15. Twisp River steelhead egg to emigrant percentage compared to data from numerous streams across the Pacific Rim (Quinn 2005).

Spring Chinook and Summer Steelhead: estimating intrinsic productivity (p) and environmental carrying capacity (k) using smolt versus redd juvenile population data

We calculated intrinsic productivity (p) and environmental carrying capacity (k) from brood year emigrant and redd data in the Methow River and the Twisp River, a major Methow tributary. Table 5 through Table 8 shows the production by brood year. Screw trap data has been expanded to develop the production estimates.

Table 5. Twisp River Spring Chinook Brood Year Production.

Twisp River Spring Chinook Brood Year Production					
Brood Year	**Redds**	**Estimated Eggs**	**Age-0**	**Age-1**	**Total Age 0 + Age 1**
2003	18	81558	1596	723	723
2004	135	496530	1323	5092	6415
2005	54	233874	6974	3532	10506
2006	84	288372	5645	15660	21305
2007	30	128182	4168	5547	9715
2008	79	268711	7139	4793	11932
2009	34	100694	3282	1842	5124
			Red=calculated data		

Table 6. Methow River Spring Chinook Brood Year Production.

Methow River Spring Chinook Brood production					
Brood Year	**Redds**	**Estimated Eggs**	**Age-0**	**Age-1**	**Total Age 0 + Age 1**
2002	1105	4235465	14192	26044	40236
2003	462	2167026	8170	15306	23476
2004	543	1933506	19247	15869	35116
2005	566	2069906	17490	33710	51200
2006	922	3362156	2913	28857	31770
2007	293	1182195	4083	5163	9246
2008	373	1365130	2948	9302	12250
2009	461	1823944	1602	29610	31212
				Red=calculated data	

Table 7. Twisp River Summer Steelhead Brook Year Production.

Twisp River Summer Steelhead Brood Year Production							
Brood Year	Redds	Estimated Eggs	Age-1	Age-2	Age-3	Age-4	Total Smolts
2003	606	3849312	241	1787	1357	58	3443
2004	254	1166876	79	3192	500	198	3969
2005	452	2806016	292	2686	2102	113	5193
2006	384	2452992	81	4712	2223	336	7352
2007	82	418774	42	10217	2812	29	13100
2008	182	1078350	76	2295	907	74	3352
2009	352	2147200	61	4540	1806	147	6554
					Red=calculated data		

Table 8. Methow River Summer Steelhead Brood Year Production.

STH Methow River (Excluding Twisp) Brood Year Production							
Brood Year	Redds	Estimated Eggs	Age-1	Age-2	Age-3	Age-4	Total Smolts
2003	2019	12824688	1596	4872	2459	106	9033
2004	917	4350518	1883	9082	1277	343	12585
2005	1685	10460480	2030	12775	868	1064	16737
2006	785	5013795	639	6313	3819	322	11093
2007	740	3779180	3194	25135	4686	272	33287
2008	867	5136975	1238	11764	2484	318	15804
2009	1030	6283000	3338	12957	2951	378	19623
					Red=calculated data		

The plotted data (Figures 16 - 21) point to the possibility of fitting Ricker curves to the data. For spring Chinook, we examined both total trap data (age 0 + age 1) and just age 1 data. In all cases, the curves indicate possible density dependence suggesting the freshwater habitat is limiting. The steelhead data, but also the Twisp total spring Chinook production, have what appear to be significant outliers.

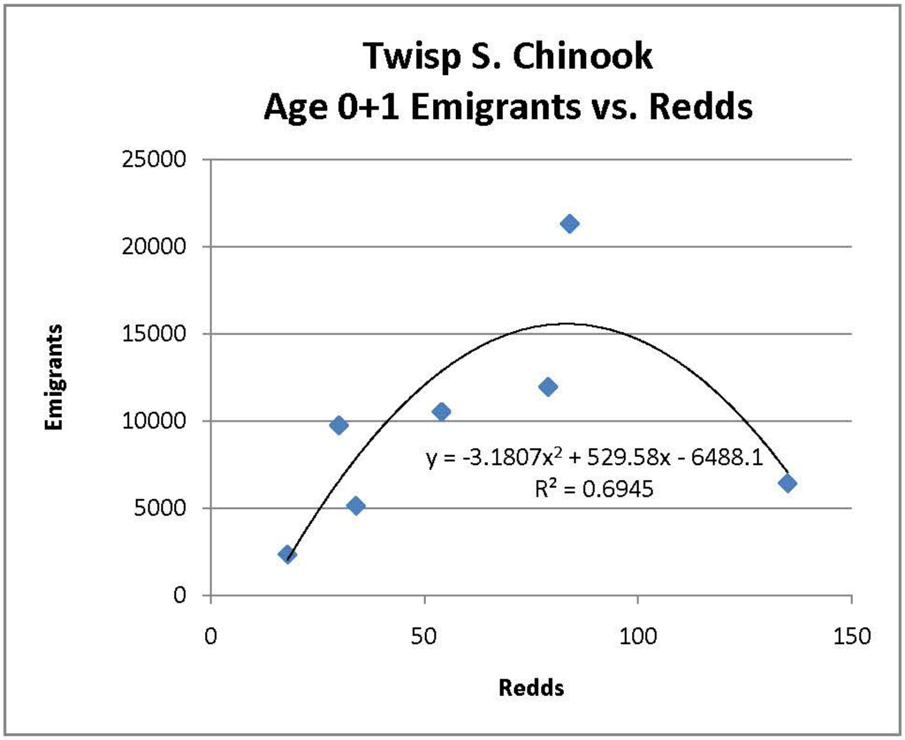

Figure 16. Twisp River spring Chinook total emigrants (age 0 + age 1) versus redds.

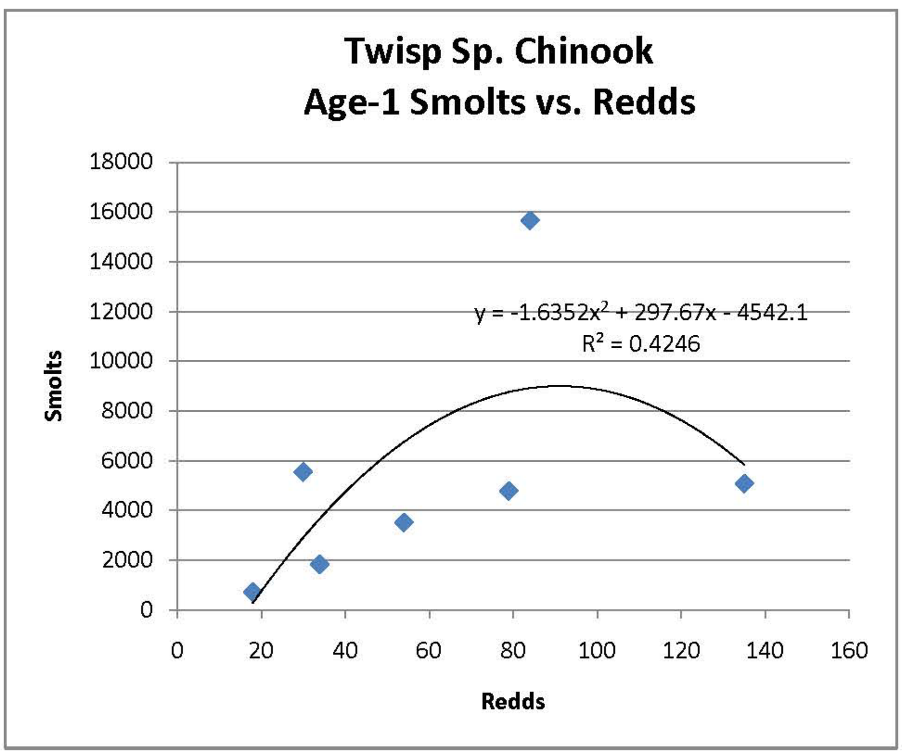

Figure 17. Twisp River spring Chinook age 1 emigrants versus redds.

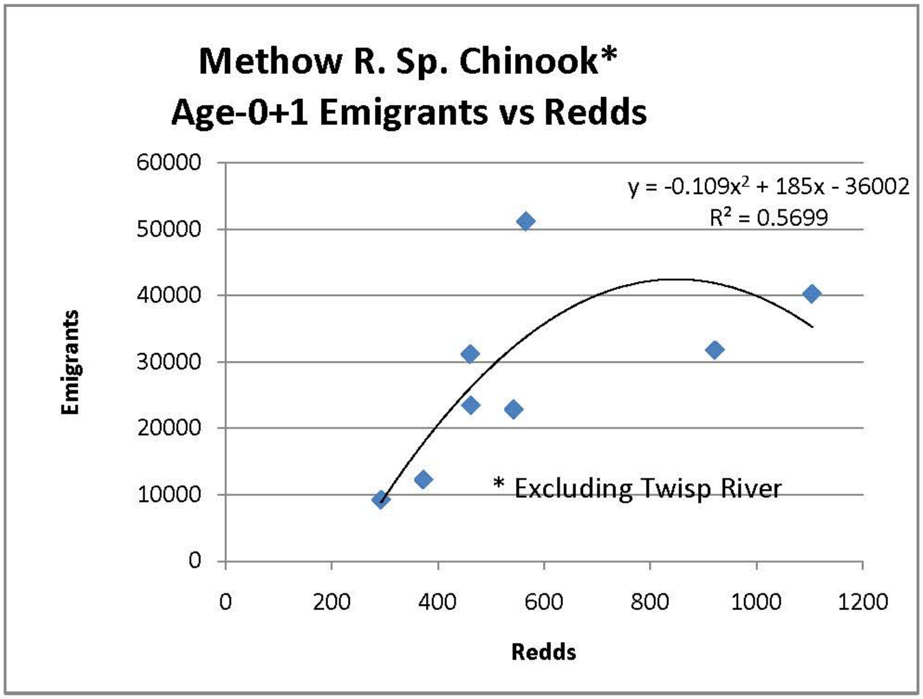

Figure 18. Methow River spring Chinook total emigrants (age 0 + age 1) versus redds.

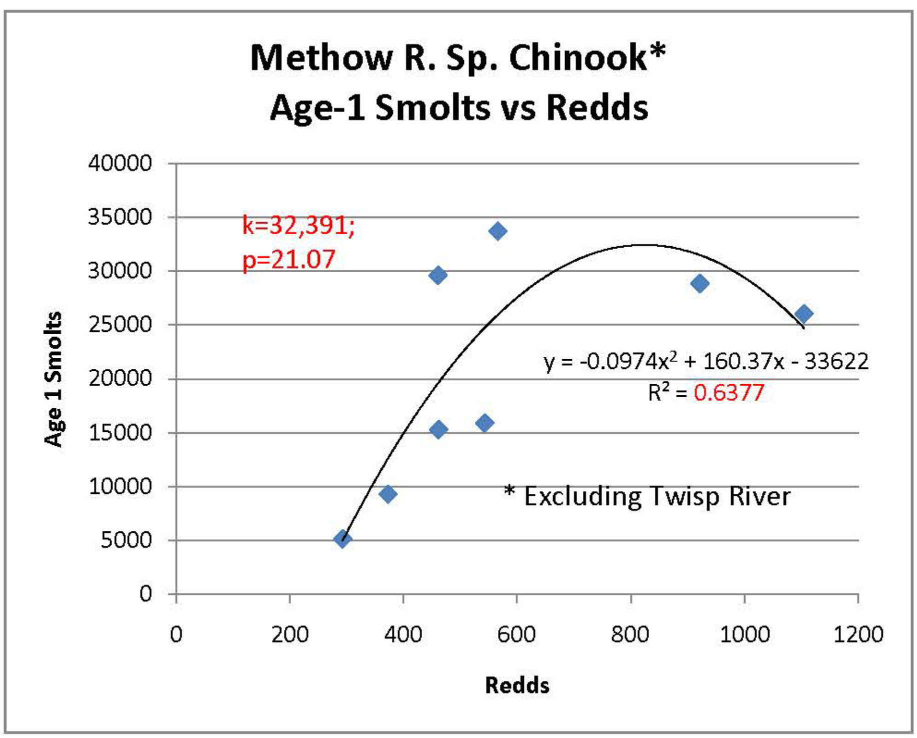

Figure 19. Methow River spring Chinook age 1 emigrants versus redds.

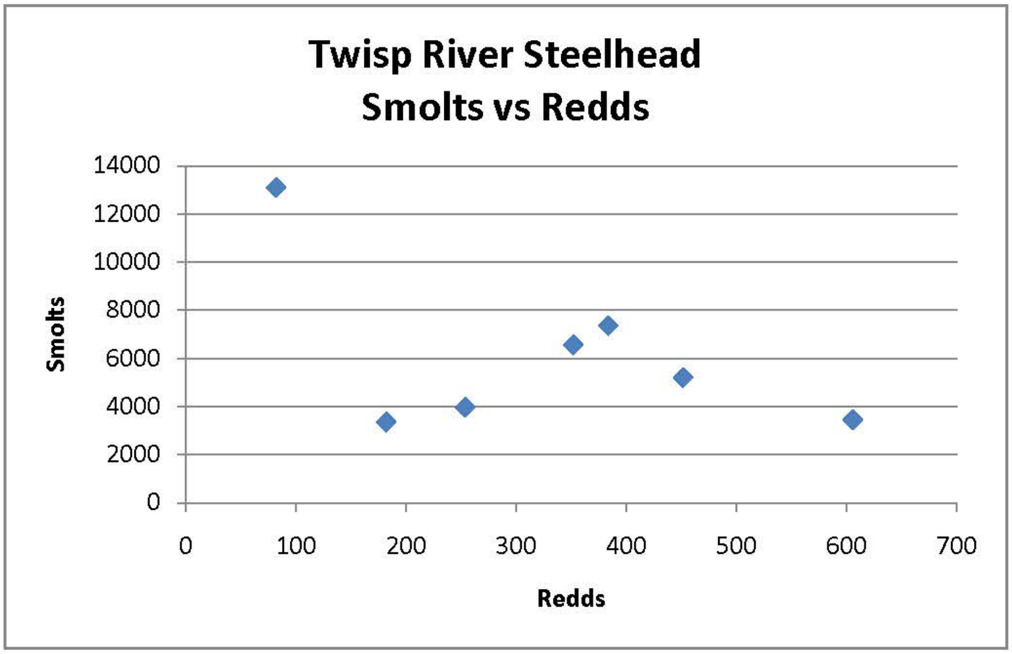

Figure 20. Twisp River summer steelhead smolts versus redds.

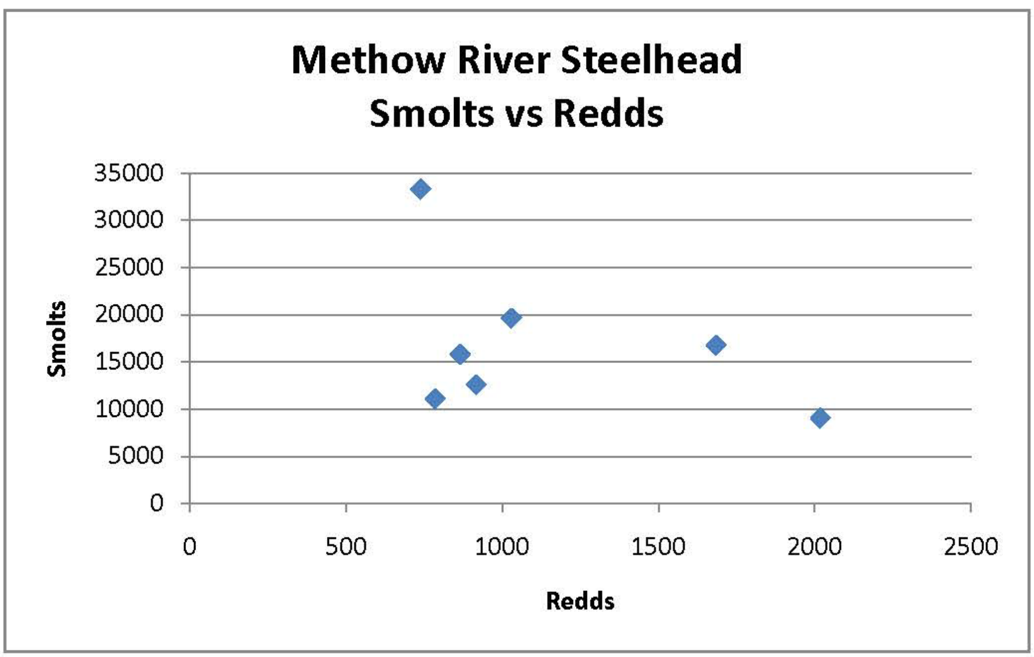

Figure 21. Methow River summer steelhead smolts versus redds.

Table 9 below shows the estimated intrinsic productivity (p) and the juvenile carrying capacity (k) derived from fitting the Ricker curves. We also calculated an adjusted p value from the Ricker curve using the largest juvenile production for the period of record as an estimate of carrying capacity when this number was greater than the carrying capacity calculated from the Ricker curve. The estimates of p and k from the Ricker curve were obtained by fitting a linear regression line to ln (smolts/redd) versus redds. In most cases, this method of generating a Ricker curve provided a poor fit (low r^2). In the case of steelhead, a Ricker curve fit the data very well. The ATP model is designed to estimate changes in biomass relative to habitat conditions. We plotted the Twisp River total spring Chinook (age 0+1) fish biomass data (not expanded). The spring Chinook fish biomass and fish numbers had similar plots indicating that biomass is distributed similarly to numbers. We also fit a Ricker curve to the biomass data.

Table 9. Methow Spring Chinook and Summer Steelhead Production Summary.

Methow River Production Summary							
Species/ Stock	**Avg smolts/ Redd (data)**	**Ricker p@.2k/r^2**	**Adjusted Ricker p at .2k (data)**	**Ricker k**	**k(data)**	**Ricker Redds @.2k**	**Min Redds (data)**
Twisp Sp. Ch Age 0+1**	178.6	255.5/0.38		10958	21305	9	18
Twisp Sp. CH Age 1	89.9	78.7/ 0.02	229.6	12500	15660	32	18
Methow (no Twisp) Sp. CH Age 0+1	48.3	41.23/ 0.02	43.7	195148	51200	927	293
Methow (no Twisp) Sp. CH Age 1***	35.4	21.07/ 0.00	21.9	32391	33710	307	293
Twisp STH	35.5	91.04/ 0.71	83.9	7401	13100	16	42
Methow STH	17.8	51.9/ 0.71	47.1	17550	33287	68	740
Twisp Sp. Ch Age 0+1 Biomass (g)	NA	321.7/ 0.5	NA	12735	24081	8	18

*A linear regression of ln(smolts/redd) versus redds
**Age 0+1 = Total of Age 0 and Age 1 fish
***Methow Age 1 Spring Chinook p and k calculated from a polynomial equation

Improving Estimates of Juvenile Detection Efficiencies

The USGS recently conducted a smolt survival analysis based on PIT-tag detection data (draft Open File Report). USGS used Monte Carlo simulations to estimate detection rates for different PIT-tag release group sizes based on detection efficiency estimates at each detector derived from large group releases of tagged hatchery fish. The analysis compared the effect on survival estimates of different size release groups and additional detectors (Figure 22 and Figure 23). Somewhat surprisingly, we realize only modest changes in detection probability with the additional detectors modeled in the simulation exercise.

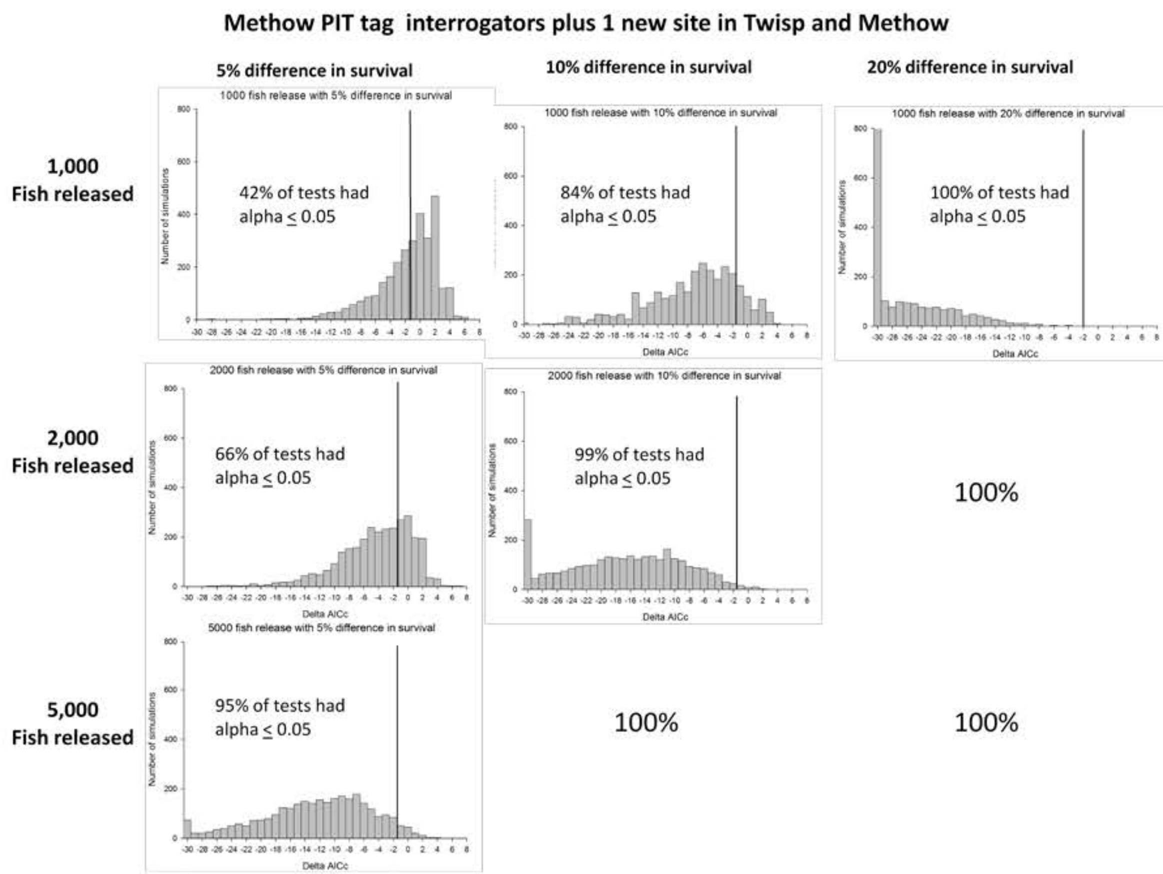

Figure 22. The Delta AICc between two models (phi(g*d) p(d) and phi(d) p(d)) for 3,000 simulations to determine differences in survival (5%, 10% and 20%) between two groups (treatment and control) using the current PIT tag interrogators (n=6) and Twisp River screw trap encountered for fish released in the Twisp River.

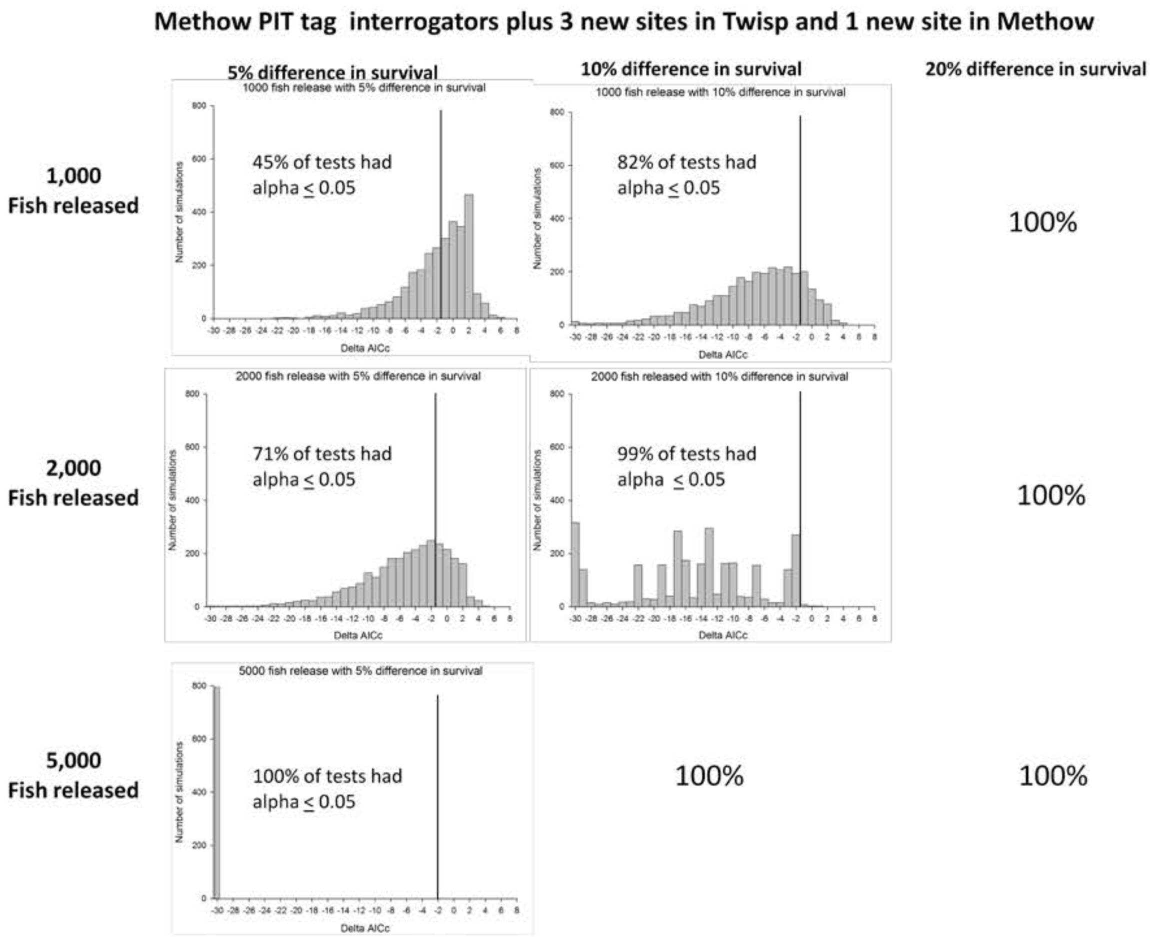

Figure 23. The Delta AICc between two models (phi(g*d) p(d) and phi(d) p(d)) for 3,000 simulations to determine differences in survival (5%, 10%, and 20%) between two groups (treatment and control) using the current PIT tag interrogators (n=10) and Twisp River screw trap encountered for fish released in the Twisp River.

5.3.2 WDFW/DCPUD/BPA Twisp River Steelhead Relative Reproductive Success Study[3]

DCPUD and the Action Agencies are conducting a steelhead hatchery-wild relative reproductive success study in the Methow River. WDFW is conducting the study in the Twisp River. Data and findings from this study will be integrated into the IMW.

[3] Information taken from Monitoring the Reproductive Success of Naturally Spawning Hatchery- and Natural-Origin Steelhead in a Tributary of the Methow River Annual Progress Report for the Period: 1 August 2010 – 31 July 2011 Prepared by: Charlie Snow, Benjamin Goodman, Todd Seamons, Charles Frady, and Andrew Murdoch, Washington Department of Fish and Wildlife, 600 Capitol Way, North Olympia, WA 98501-1091.

What have we learned to date?

a. WDFW found no significant differences in arrival time at the Twisp River weir between hatchery and wild female steelhead in 2009 ($P = 0.96$), 2010 ($P = 1.00$), or 2011 ($P = 1.00$). Similarly, there were no differences in arrival time between hatchery and wild male steelhead in 2009 ($P = 0.17$), 2010 ($P = 1.00$), or 2011 ($P = 1.00$).

b. WDFW evaluated differences in the run-timing, spawn-timing, age-composition, length-at-age, sex-ratio, and spawning distribution in an effort to determine whether differences existed between hatchery and wild fish that may explain differences in observed relative reproductive success, should they occur. WDFW found significant differences in female spawn timing based on fish origin and year ($P< 0.01$). However, all differences were among years and there were no significant differences between fish of different origin within years ($P = 0.44$-1.0). There were no significant differences in redd distribution based on fish origin among years ($P = 0.13$). The proportion of female steelhead within the hatchery and wild populations released upstream of the Twisp River weir was not significantly different for the 2009 ($P = 0.751$) and 2011 broods ($P = 0.325$), although 2010 brood hatchery origin fish contained a significantly greater proportion of females ($P < 0.001$) than did the wild population.

c. No significant differences in the salt-age composition were detected between male and female hatchery and wild steelhead of the same brood year ($P = 0.25 – 0.84$).

d. Wild fish generally had a greater mean fork length within years compared to hatchery origin fish of the same gender and salt-age, but a statistically significant difference was only detected between 1-salt male fish within the 2009 brood ($P < 0.01$).

e. WDFW found no significant difference between the fecundity of hatchery and wild fish within brood years ($P = 0.06$), but fecundity was significantly different between hatchery and wild fish across years ($P < 0.001$).

f. In general, WDFW found few differences between the hatchery and wild fish released upstream of the Twisp River weir that would influence productivity.

5.4 Fish Habitat Status and Trend Monitoring

The objectives of tributary habitat status and trend monitoring are to: (1) measure and track the quality and quantity of habitat within tributary habitat used by selected fish over time; (2) develop relationships between the status of the population (e.g. egg-to-smolt survival) and habitat quality and quantity conditions in the IMW fish populations; and (3) develop data summaries and maps that will assist the Expert Panels and other regional technical bodies in identifying habitat impairments and limiting factors across the Columbia River Basin.

The Methow IMW has four long-term habitat status and trend monitoring programs: AREMP, PIBO, Integrated Status and Effectiveness Monitoring Program (ISEMP), and CHaMP (Figure 24). AREMP and PIBO use a five-year rotating panel design at randomly chosen sample sites. ISEMP and CHaMP use a mixture of annual and rotating panels.

5.4.1 USFS AREMP/PIBO Habitat Status and Trends Studies

The USFS AREMP is a multi-federal agency monitoring program that was initiated in 2000 to assess the condition of watersheds within the Northwest Forest Plan area by collecting information on upslope, riparian, and in-channel attributes within each watershed. The program samples watersheds within the Northwest Forest Plan area on USFS Regions 5 and 6, Oregon/Washington State Office of the Bureau of Land Management, and on National Park Service lands.

The PIBO effectiveness monitoring program for aquatic and riparian resources was developed in 1998 in response to monitoring needs addressed in the BiOps for bull trout and steelhead. The primary objective is to determine whether priority biological and physical attributes, processes, and functions of riparian and aquatic systems are being degraded, maintained, or restored in the PIBO area. The program samples within the interior Columbia River Basin on lands managed by USFS Regions 1, 4, and 6 and the Idaho and Oregon/Washington State Offices of the Bureau of Land Management.

The Action Agencies are reviewing the potential relationships between PIBO data and other independently sampled parr survival data. For streams in the Snake River basin above Lower Granite Dam, a recent analysis (Paulsen and Fisher, unpublished data 2012) shows that "Models to account for differences in survival had broadly similar results, with the PIBO metrics accounting for about 12 percent of the variation in survival among populations." In the near future, similar parr data sets may be available for the Methow River basin to support similar analyses.

5.4.2 NWFSC/BPA ISEMP/CHaMP Habitat Status and Trends Studies

The Northwest Fisheries Science Center's ISEMP was created in 2003 to develop a Columbia River Basin RME program that can efficiently collect information to address multiple management objectives over a broad range of scales. The program is funded by BPA. This RME program assesses the status of anadromous salmonid populations, their tributary habitat, and the long-term effects of fish management actions, and habitat improvement. The CHaMP is a Columbia River basin-wide habitat status and trends monitoring program, funded by BPA, and built around a single habitat monitoring protocol with a BPA program-wide approach to data collection and management which meets FCRPS Action Agency (2010) programmatic prescriptions for habitat monitoring. CHaMP was developed by the ISEMP program to capture habitat features that drive fish population biology. It will result in systematic habitat status and trends information that will be used to assess basin-wide habitat condition. The habitat status and trend information will be correlated with biological response indicators such as fish density or fish abundance to evaluate habitat management strategies. CHaMP is integrated with ongoing PNAMP and Recovery Planning efforts, as well as the collaborative process across Columbia River Basin fish management agencies and tribes and other State and Federal agencies that are monitoring anadromous salmonids and/or their habitat

ISEMP sampled 25 sites in the Methow River basin in 2011. Twenty CHaMP habitat sites will be sampled in 2012 and 2013 (for additional information, see http://www.champmonitoring.org/Program/RetreiveProgramDocumentFile/1/Lessons%20Learned%20Annual%20Reporting/1474751431, page 29). No fish sampling is planned. Habitat status and trend assessments will be completed after the 2013 sampling season.

The ISEMP data in the Methow covers only one year. The CHaMP 2011 Pilot Year Lessons Learned Project Synthesis Report maps habitat quality for the Methow River Basin using a habitat quality index score averaged across a larger geographic area by extrapolating site-level data to all reaches of similar valley classification. The report cautions that the classification is provisionary because of lack of standardization across the geographic areas.

Reclamation plans to contract CHaMP assessments at reach-level habitat project implementation sites to extract data for use in its aquatic trophic productivity model (see Appendix B). The project will assess our ability to scale up food production metrics at other CHaMP sites.

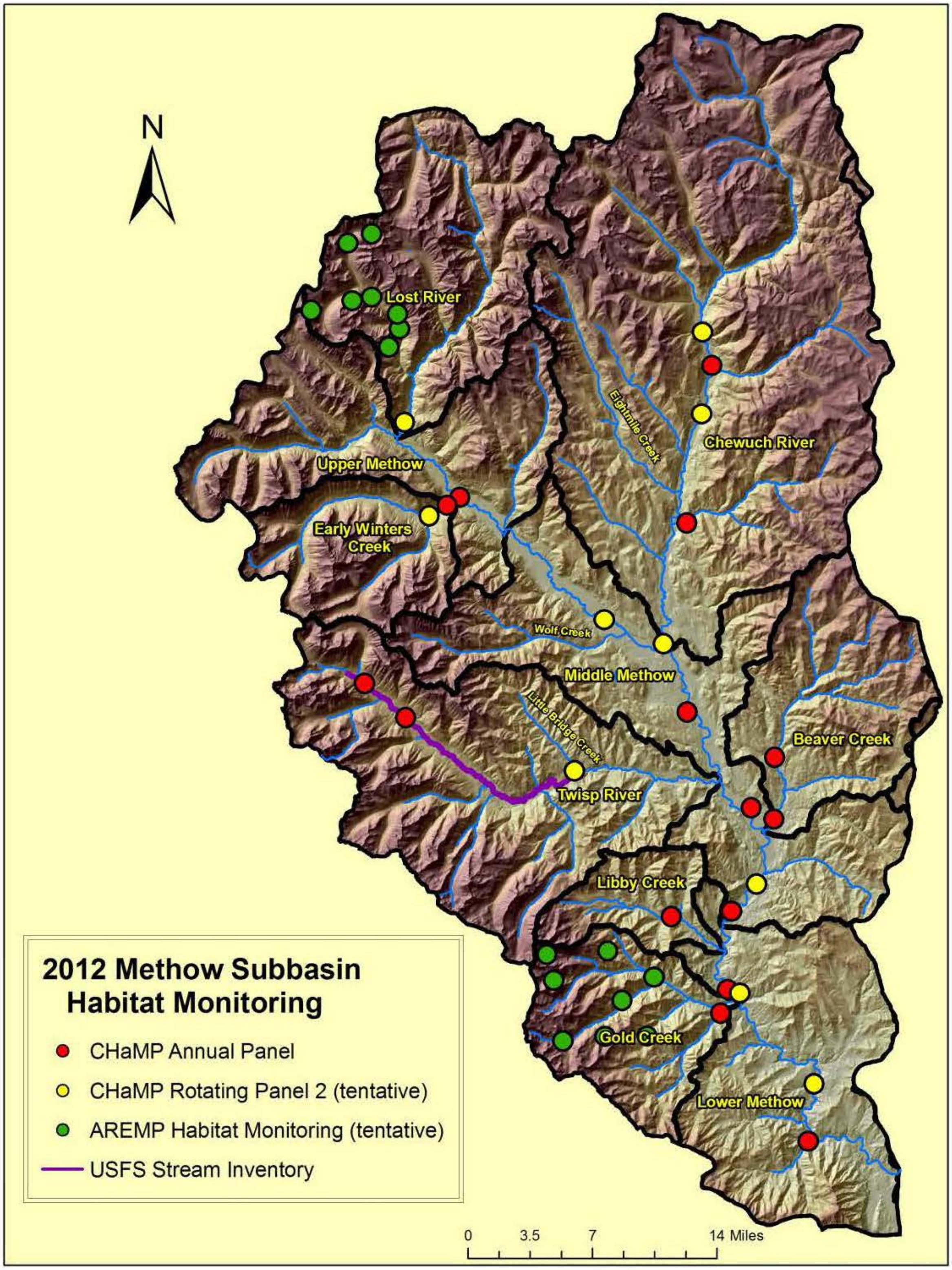

Figure 24. 2012 Methow Subbasin Habitat Monitoring.

5.5 Project Level Action Effectiveness Monitoring

Habitat action effectiveness monitoring measures the effect of a habitat improvement project or the effects of multiple projects, on the local habitat conditions, and can also monitor the fish that use the habitat.

5.5.1 Beaver Creek Projects

Beaver Creek is located about 5 miles downstream from the town of Twisp, Washington (Figure 8). A series of relatively small irrigation diversion dams impeded upstream and downstream passage of salmon, steelhead, and bull trout in Beaver Creek except during high runoff periods in the spring. Five diversions were replaced with a series of rock vortex weirs designed to pass fish. Adult and juvenile fish now can travel unimpeded year-round and under all flow conditions between the Methow River and cold water habitat in the upstream reaches of Beaver Creek. Detailed reports can be found in Appendix C.

What have we learned to date?

a. At least 10 species of fish were collected throughout Beaver Creek in 2004-2005; the predominant species was juvenile rainbow trout/steelhead. About 3,300 were PIT tagged. Fewer brook trout, Chinook salmon, coho salmon, bull trout, and cutthroat trout were collected and tagged. Other fish species collected included smallmouth bass *Micropterus dolomieu*, bridgelip sucker *Catostomus columbianus*, longnose dace *Rhinichthys cataractae*, shorthead sculpin *Cottus confuses*, and mountain whitefish *Prosopium williamsoni*. Except for the shorthead sculpin, most of these fish species were collected only in the lower 1 km of Beaver Creek.

b. Anadromous steelhead entered the re-opened habitat in Beaver Creek in 2005, the first spawning season after barrier removal. Tagged juvenile *O. mykiss* moved upstream past the rock vortex weirs mostly during the spring and summer months. Of the 3,699 juvenile *O. mykiss* tagged, 88 *O. mykiss*, 20 brook trout, and one coho salmon were recorded passing upstream (Martens and Connolly 2010). Some *O. mykiss* ascended the series of rock vortex weirs quickly, while others took up to 87 days to move upstream (Connolly et al. 2010). Some delay in movement was noted at flows of < 0.32 m/s (Martens and Connolly 2010). Delay may indicate that the juvenile fish were utilizing the habitat below the weir for rearing and resting during upstream movement. The smallest documented fish moving upstream was a 77 mm *O. mykiss*.

c. Counts of steelhead into Beaver Creek decreased from 2005 to 2007 and then increased in 2008. These counts appear to follow other monitoring data such as redd counts in Beaver Creek and adult return counts to Wells Dam.

d. Tag migration and interrogation data indicate that adult steelhead were migrating into upper Beaver Creek in 2007 and 2008, 2 to 3 years after barrier modification.

e. The migration of steelhead is associated with significant changes in the population genetic attributes at the first monitoring site (UBR1) upstream from the barrier in 2008 and 2009 within approximately one generation. Sites further upstream did not show significant changes in population genetic attributes by 2008 and 2009, and likely require more time for the successful colonization of more individuals.

f. Migration data from juvenile steelhead tagged in Beaver Creek that returned to Beaver Creek as adults indicated the establishment of the full expression of anadromy in the study area.

g. Juvenile *O. mykiss* in Beaver Creek have two distinct anadromous life-history strategies. One strategy is to overwinter in Beaver Creek and outmigrate as larger smolts the next spring. The second strategy is to migrate from Beaver Creek in the fall and apparently overwinter in the Methow River or elsewhere downstream.

h. PIT-tag data indicate that juvenile steelhead that remained in Beaver Creek until smolting contributed more to the smolt population, but at somewhat older ages than those fish that left Beaver Creek in the fall or winter months. However, preliminary data suggest that adults from age-0 juvenile steelhead that migrated from Beaver Creek in the fall or winter return as steelhead adults at a higher rate. If this finding holds for the next brood year, future work will investigate the hypothesis that steelhead that overwinter in Methow tributaries produce smolts with poorer condition factors than smolts produced from fish that rear in the larger mainstem rivers. The study will attempt to identify environmental factors in the tributaries that results in poorer condition so that these factors can be addressed by tributary habitat rehabilitation projects.

5.5.2 Elbow Coulee Project

Reclamation funded the design for the Elbow Coulee side-channel re-connection project in the Twisp River, a tributary to the Middle Methow River. More than 50 years ago, a portion of the floodplain and side channel near Elbow Coulee was cut-off from the mainstem Twisp River by a levee. In September 2008, a project was initiated to reestablish connection to the river by breaching the levee.

The Elbow Coulee Side Channel Restoration Project was implemented to meet the following objectives: 1) reestablish a side channel to the Twisp River at river mile 6.6; 2) increase habitat complexity and large woody debris recruitment potential; 3) reduce stream energy to increase the potential for the accumulation of sediment and wood in the Twisp River; and 4) increase rearing habitat for native juvenile salmonids. Project reports can be found in Appendix D.

What have we learned to date?

a. Three years of monitoring results (2008-2011) obtained since post-construction indicate that all four objectives have been met and that the project provides habitat for spring Chinook salmon, steelhead, and potentially bull trout.

b. High flows activated the side channel each year.

c. In 2011, beaver constructed two dams just downstream of the flow monitoring site. Listed fish species were observed using the ponds almost immediately. This change in habitat type has increased habitat complexity within the channel through increased pool habitat, wetted width, and large woody debris.

d. Young-of-the-year spring Chinook salmon and steelhead were observed each year using the side channel.

e. More fish are using the side channel than before the project.

f. Water temperatures are conducive for fish rearing.

g. Although these qualitative findings are hopeful, future Reclamation-funded model and field studies of fish and fish habitat will support the quantification of fish production in association with a much larger Yakama Nation BACI designed nutrient treatment study, paired CHaMP habitat evaluations, and WDFW's operation of a screw trap near the mouth of the Twisp River. The CHaMP data will be used with an aquatic trophic production model to help quantify the production value of projects like Elbow Coulee.

5.5.3 Yakama Nation Twisp River/Hancock Springs Projects

John Jorgensen, principal investigator for the Yakama Nation's Upper Columbia Basin Nutrient Enhancement Project, Upper Columbia Natural Production Restoration Program, provided the following project summary.

> "The Yakama Nation's Upper Columbia Natural Production Restoration Program is designed to mitigate the loss of natural production of steelhead and Chinook salmon in the Upper Columbia basin following development of the Federal Columbia River Hydropower System. This Program addresses habitat alteration, loss of marine derived nutrients, and the deleterious presence of non-native fishes as three major factors limiting natural production of anadromous salmonids. The Program includes two currently implemented projects in the Methow River Subbasin: The Upper Columbia Nutrient Enhancement Project and the Hancock Springs Habitat Restoration Project.

The Upper Columbia Nutrient Enhancement Project is a large (river-scale) project that evaluates nutrient availability and the status of all trophic levels in 44 km of the Twisp River to assess the degree to which these factors may be limiting natural production. The goal of this project is to: 1) assess current nutrient concentrations and the trophic status of the Twisp River, relative to nutrient limitation on natural production of native anadromous salmonids; and 2) prescribe, implement, and evaluate a 5-year experimental nutrient addition treatment to increase natural production. Based on upcoming results of multi-year, multi-trophic, biomonitoring activities, this project is expected to prescribe and implement experimental nutrient addition, and evaluate biological responses with key biological response metrics in all trophic levels using refined biomonitoring protocols.

The Hancock Springs Project is a smaller (stream-scale) project with the goal of evaluating the effects of sequential and additive habitat restoration and nutrient addition treatments on natural production of anadromous salmonids. Given its small size and stable thermal and hydrologic properties, Hancock Springs is well suited for the investigation of biological responses to physical habitat restoration and nutrient addition treatments at high spatial and temporal resolution not possible at the larger river scale. This project will test and evaluate separate and additive effects of nutrient addition on the magnitude of spawning, and juvenile salmonid abundance, density, growth, survival, and habitat use. This project will also evaluate the anadromous salmonid population response to the removal of brook trout (*Salvelinus fontinalis*), a potentially deleterious, non-native competitor.

Both projects employ a rigorous, multi-trophic biomonitoring program to document current ecological baseline conditions and the array of biological responses to restoration treatments across trophic levels. Biomonitoring includes a comprehensive suite of water quality, nutrient, invertebrate and fish community metrics that are consistently monitored before and after all restoration treatments. A final component of both projects is to assess functions, processes, and linkages within, between, and among trophic levels. The food webs in project waters will be characterized using three complementary techniques: 1) stable isotope analysis of nitrogen (N) and carbon (C) from each trophic level; 2) fish gut content analysis; and 3) annually replicated experimental nutrient addition involving nutrient routing through the food web.

Given the integration of multiple complementary remedial approaches, this Natural Production Restoration Program is expected to provide valuable insight and benefits of restored habitats and ecological conditions to support increased levels of natural production in the Upper Columbia Basin and elsewhere."

What have we learned to date?

a. An ongoing multi-trophic sampling program in the Twisp River is providing a quantitative pre-treatment baseline evaluation.

b. Three years of pre-treatment monitoring in the Twisp River show significantly poor (oligotrophic) nutrient conditions.

c. Trends in Twisp River environmental conditions downstream to upstream provide data to develop a BACI nutrient treatment design.

d. Very high production of listed adult spawning and juvenile salmonid has been observed subsequent to wood and rock placements in the upper half of Hancock Springs.

e. Brook trout are present in large numbers in Hancock Springs and are preying on listed salmonids.

5.5.4 USGS/Reclamation Middle Methow Floodplain Reconnection and Wood Treatment Study

Reclamation is funding the USGS-CRRL in a long-term study of the Middle Methow River and its floodplain side channels to analyze the effectiveness of a channel reconnection and channel wood treatment project. The year 2011 constituted a full pre-treatment year for data collection by the USGS-CRRL in the Middle Methow. While much of USGS-CRRL activities were similar to those in 2008-2010, there were some important changes to ensure a fuller range of data were collected to measure fish response to the planned improvement actions. The new activities included snorkel surveys of three mainstem Methow sites within the treatment reach (M2 Reach: rkm 843.065 to 843.080), conducted multiple times at each site during the year. These sites were directly associated with side-channel complexes, which will be the focus of habitat improvements by Reclamation and the YN. The USGS-CRRL helped initiate and implement an extensive habitat survey of stream margins and banks of the mainstem Methow, including the entire M2 Reach and the adjacent downstream Silver Reach (M3). The survey itself was largely completed by an experienced USFS crew.

What have we learned to date?

a. Habitat patches (main channel and different side channels) within the floodplain landscape hosted very different local food webs, with widely varying amounts of invertebrate food production going to listed salmonid juveniles versus non-target fishes.

b. Juvenile Chinook salmon and steelhead utilized all of these patches, indicating that these species are flexible enough to exploit a range of food resources across a variety of habitats.

c. A greater percentage of the invertebrate food source was consumed by listed salmonids in the side channels when compared to the main channel where sculpin and whitefish dominated the consumption.

d. Carrying capacity estimates for both the main channel and side channels indicate that much greater anadromous salmonid populations could be sustained in these habitats if it turns out that higher densities of fish could somehow take advantage of the unconsumed benthic insect biomass.

e. Habitat complexity treatments (side-channel reconnections and large woody debris placements) are expected to create bed movement that should make more of the benthic invertebrate food available to drift feeding listed juvenile salmonids. Reclamation-funded model and field studies are expected to quantify changes in production that results from the treatments.

5.5.5 Other Habitat Project Monitoring in the Methow Basin

Other entities also monitor salmon habitat improvement projects in the Methow basin. Washington State has a significant monitoring effort that includes some projects that the Action Agencies contributed to (Table 10). The Upper Columbia Regional Technical Team also completed an important 2010 Synthesis Report (Ward et al. 2010).

Washington State projects in the Methow basin monitored in 2008 included projects in the fish passage, constrained channels, channel connectivity, and habitat protection categories. Detailed accounts of monitoring of individual projects in each monitoring category and results were provided in the 2008 Annual Progress Report (Washington Salmon Recovery Funding Board 2009).

For 2009, fish passage and habitat protection projects in the Methow River subbasin were included in a group analysis. In 2010, the only monitoring category analyzed in the Methow River was channel connectivity. Since in 2009 and 2010, projects in the several monitoring categories from numerous subbasins statewide were combined for analysis, the results of specific habitat projects in the Methow River cannot be readily described. Monitoring of fish passage projects was considered completed in 2009 (Washington Salmon Recovery Funding Board 2010). No further monitoring in this monitoring category is anticipated largely because these projects were considered effective. In 2010, the only monitoring category analyzed in the Methow River was channel connectivity, but the analysis included projects from other basins as well. Analysis of channel connectivity projects for 2010 indicated no statistically significant improvements for this category in any of the variables tested. The constrained channels and channel connectivity categories were combined in 2010 into floodplain reconnection projects (Washington Salmon Recovery Funding Board 2011).

Table 10. Projects that the Action Agencies contributed to in the Methow River monitored under the Washington Salmon Recovery Funding Board Reach-Scale Effectiveness Monitoring Program. The project types listed below for the Methow River subbasin were monitored using the BACI design. Information compiled from 2008, 2009, and 2010 annual reports (Washington Salmon Recovery Funding Board 2009, 2010, 2010).

Project Type	Project Name	Location	Project Objective	Summary/Outcomes
Fish Passage	04-1485 Fulton Dam Barrier Removal Project	Chewuch River, Okanogan County	Provide a naturalized river bed to maintain water flow and irrigation rights to Fulton River Ditch Company. Remove existing dam, construct a roughened channel to allow fish passage in 2007. Species of interest: Spring Chinook salmon, bull trout, summer steelhead.	Pre-project monitoring – 2005 (Yr 0) Post-project monitoring – 2007 (Yr 1), 2008 (Yr 2). Monitoring considered completed in 2009. Improved fish passage at all flows to the lower 8 miles of Chewuch River. All projects in this monitoring category were considerd to be fish passable thus exceeding the 80 percent criterion. Changes in salmon densities were mixed.
	04-1489 Chewuch Dam Barrier Removal Project	In Methow subbasin, Okanogan County	Provide improved passage for listed species at all flow levels while maintaining irrigation viability. Increased access to upper 30 miles of Chewuch River. Species of interest: Chinook salmon, bull trout, steelhead.	Pre-project monitoring – 2005 (Yr 0) Post-project monitoring – 2006 (Yr 1), 2007 (Yr 2), 2008 (Yr 3). Monitoring considered completed in 2009. All projects in this monitoring category were considerd to be fish passable thus exceeding the 80 percent criterion. Changes in salmon densities were mixed.
Constrained Channels	06-2239 Fender Mill Floodplain Restoration – Phase I	Methow River, between towns of Winthrop and Mazama, Okanogan County	To re-introduce and utilize natural stream processes to improve habitat for salmon and other native species. Provide off-channel rearing habitat and high flow refugia.	Pre-project monitoring – 2007 (Yr 0) Post-project monitoring – 2009 (Yr 1) Conditions comparable between control and impact reaches. Floodplain reconnection expected in impact reach after levee removal. May require several high flow events to establish floodplain reconnection. Project implemented in 2009.
Channel	06-2239 Fender Mill	Methow River,	To re-introduce and utilize natural	Pre-project monitoring – 2007 (Yr 0)

Project Type	Project Name	Location	Project Objective	Summary/Outcomes
Connectivity	Floodplain Restoration – Phase 1	between towns of Winthrop and Mazama, Okanogan County	stream processes to improve habitat for salmon and other native species. Project will allow high flows to enter two or three separate side channels. Side channels will provide flow to low areas currently charged by groundwater.	Post-project monitoring – 2009 (Yr 1), 2010 (Yr 2) Pre-project monitoring indicated lack of use by fish at sites disconnected from the river. When reconnection is established, it is expected that fish will use the area. Project implemented in 2009, (Year 1 monitoring). By 2010, average improvements are being seen in geomorphic variables, such as vertical pool profile area and mean residual depth, and in juvenile coho and steelhead parr densities. Other variables showed average but nonsignificant declines.
Habitat Protection	02-1650 Methow Critical Riparian Habitat Acquisition	Methow River, between towns of Winthrop and Mazama, Okanogan County	Establish conservation easements on parcels in the river between Mazama and Winthrop to protect Upper Methow Habitat Block. Steelhead and Chinook salmon are expected to benefit.	Pre-project monitoring – 2004 (Yr 0) Post-project monitoring – 2007 (Yr 1) Slow changes in vegetation are expected as shrubs shade out grassy areas containing non-native herbaceous species. The 2009 annual report recommended delaying field monitoring for habitat protection projects for 5 to 10 years.

5.6 Watershed-Level Action Effectiveness Monitoring

The Methow watershed action effectiveness began with a thorough review of the existing data available in the Methow basin and in the scientific literature at large. The development and the design of the Methow IMW builds upon, and was guided by this body of information (see Appendix D).

The objectives of watershed/population-level action effectiveness monitoring are to: (1) determine if the implementation of habitat actions increases egg-to-smolt survival of listed fish; (2) to the degree possible, determine which habitat actions contributed most to the survival increase; (3) confirm functional relationships between fish survival and habitat quality; and (4) identify which actions are most effective at addressing specific habitat impairments or limiting factors. Specifically, these relationships can be used to improve both the productivity and capacity components of a multistage Beverton-Holt model (e.g., Shiraz model). Furthermore, they will assist with the development of life-cycle models (the tributary habitat component of the life-cycle model) and climate-change models.

Reclamation researchers reviewed the UCSRB's habitat action plans, the ecological concerns addressed by each, the evaluation of progress toward addressing habitat functionality based on Expert Panel opinions, and the progress toward assessing habitat function through effectiveness monitoring.

Reclamation researchers identified four projects that could be used to test and calibrate its ATP model and scale up the results to watershed-level action effectiveness: (1) a Twisp River nutrient treatment project under development by the YN; (2) a Hancock Springs habitat and brook trout removal project under development by the YN; (3) a Middle Methow (M2 Reach) large woody debris and channel reconnection project planned and implemented by Reclamation; and (4) a completed Beaver Creek passage barrier removal project, and a future floodplain reconnection project planned and implemented by Reclamation and the Methow River Conservancy.

CHaMP surveys will be conducted at all the treatment sites to characterize the physical habitat. Additional habitat data will be collected by the YN through Accord funding, and by USGS-CRRL and the U of I through Reclamation funding. Fish data will be collected by YN, USGS-CRRL, and WDFW. These data will be analyzed in the ATP model to predict changes in fish productivity and fish habitat carrying capacity due to the treatments.

After calibration and testing of the model, fish productivity and fish habitat carrying capacity will be scaled up to the entire watershed for each of the four watersheds. Hancock Springs is a small watershed that is completely covered by the treatment analysis and therefore, does not need to be scaled up. Likewise, the M2 reach represents a significant portion of the Middle Methow and therefore, does not need to be scaled up.

The Twisp River watershed will be subject of a scaling up exercise. Various data sources for fish and fish habitat will contribute to the calibration or testing of the ATP model at the watershed scale. An extensive fish monitoring program by WDFW operates a weir near the mouth of the river to capture nearly all of the adult steelhead and spring Chinook salmon. WDFW also operates a juvenile fish trap below the weir. Fish and recapture activities by WDFW, USGS-CRRL, and YN occur throughout the watershed. PIT-tag readers have been installed at four locations in the Twisp River and in a major spawning tributary, Little Bridge Creek.

Likewise, fish habitat will be well characterized in the Twisp River watershed. CHaMP has two rotating and two annual panel sampling sites. Reclamation will fund four CHaMP surveys in the nutrient treatment and control sites for two years pre- and post-treatment. The USFS has conducted annual stream surveys for large sections of the mainstem Twisp River. The YN has four years of pre-treatment data on primary and secondary production in all but the upper reaches and tributaries of the Twisp River. The Pacific Biodiversity Institute completed a riparian vegetation and land use and reach-valley classifications for the entire Methow River.

5.6.1 Reclamation-hosted 2011 Regional Modeling Workshop

Reclamation researchers hosted this workshop to help meet its requirement in RPAs 56 and 57 of the FCRPS BiOp to conduct a regional dialogue on the development of use of models. Appendix A summarizes the presentations and findings from of the workshop. Reclamation used the findings and a survey of other regional modeling approaches to guide its model development.

What have we learned to date?

a. A wide variety of habitat-fish models are being used in both retrospective (most) and prospective (seldom) modeling approaches.

b. A Columbia River Basin full life-cycle model is under development by NWFSC and the Action Agencies. This effort will pull from many of the modeling efforts that were presented at the workshop.

c. Some ‘natural experiments’ where recent management decisions, not executed in a structured study design but nonetheless subjected to intensive monitoring through other programs, have been analyzed using models and the model results show great promise for assessing management alternatives.

d. The Action Agencies in the FCRPS BiOp are funding some mechanistic modeling work of habitat and fish relationships in the IMWs. Reclamation is developing a Methow River life-cycle model and a fish population and habitat processes model in a system dynamics framework. These modeling efforts are being tested in 2012.

5.6.2 USGS/Reclamation/University of Idaho Model Development

This project is developing the ATP model which is the primary fish and fish habitat evaluation tool for the Methow IMW. The ATP system dynamics mechanistic model computes the effects of habitat projects on life-stage specific energy transfers in a fish community mediated by community relationships and habitat predictors. The model allows us to study the effects of salmon and steelhead on their environment as well as the effects of the environment on their populations. The ATP model has been parameterized using values obtained from the literature and from Reclamation and USGS studies in the Middle Methow River. The model will be tested through a set of controlled habitat treatment experiments that perturb the energy flows in the environment. We will use CHaMP data, project-level effectiveness data, and information from an aquatic metabolism study to scale up productivity to the basin level. The productivity model is general enough to assess other treatment types in a variety of freshwater environments.

A full life-cycle model is being developed for the Methow IMW. For life stages outside of the Methow River, we will rely on empirical survival estimates that are being used for a Columbia River life-cycle model which is under development and managed through a separate process.

The next steps are:

1. Test the Model using field data from the Methow. Locations where appropriate multi-trophic level data have been collected, such as Hancock Springs and the Twisp River will be key locations for model parameterization and/or validation.

2. Test alternative mitigation and improvement scenarios. Once the model is parameterized and validated, it will be utilized to test alternative mitigation scenarios, such as habitat improvement (e.g., large wood additions and channel reconnections), nutrient additions, and hatchery supplementation.

3. Make a spatially explicit landscape model. This will require developing and parameterizing models in adjacent river segments, and connecting these models via the transport and movement of nutrients, organic matter, and organisms. This step will be a crucial step in evaluating the impact of fish movement on landscape level food web dynamics. Additional data from select CHaMP sites will be collected to test our ability to use the aquatic production model plus CHaMP data to scale up production from the segment to the watershed scale.

This project provides the modeling support needed for the IMW analysis and it helps Reclamation meet its requirements in RPAs 56 and 57.

What have we learned to date?

a. Reclamation is developing a Methow River life-cycle model and a mechanistic fish and fish habitat population process in a system dynamics framework. Model development will be completed by December 2012.

b. Simulations from the model have given us incites into designing field studies.

c. There is a significant body of work in the literature that we have used to parameterize modules in the model.

5.6.3 University of Idaho /Reclamation Database Development and Data Synthesis

The University of Idaho is developing software for the capture of spatially-explicit fish and fish habitat data to provide a seamless annual accumulation of data, and the calculation of parameter values from the data, for inputs to models. The capture software will also gather model output data for model reevaluations and for annual reporting. Annual summary reports will follow the structure of this report with references to more detailed reports. Future summary reports will include basin-wide data synthesis as model development proceeds to provide that capability. Reclamation developed this project to help it meet its requirements under RPAs 56, 57, and 73 of the FCRPS BiOp.

What have we learned to date?

a. University of Idaho, through a contract with Reclamation, began constructing a database to compile important metadata for all datasets that will be available to this project. After evaluating several metadata software tools (e.g., Mercury, Metavist), we identified Morpho as the most current and effective tool for our metadata.

b. The data identification process, through model and analysis development, needs to be done in parallel with the Data Harvester development. The process of getting data to the stage of data basing (data standards and metadata) is labor intensive, yet also redundant which will be improved by automating the process using our code.

c. University of Idaho is developing a data harvester tool to access model data. This pilot approach is being coordinated with PNAMP. Reclamation hired a Methow data coordinator to assist University of Idaho in the initial data and metadata harvest from all the Methow IMW cooperating entities. A field data and parameter list for model data inputs and outputs is under development. The entities are providing data and metadata in a standard format. The use of models as a data identification process greatly facilitates the coordination of data harvest by communicating directly the need and proposed use of the data.

5.6.4 USGS/Reclamation Aquatic Metabolism Study

Stream metabolism, measured via the change in dissolved oxygen over time, provides a feasible means of assessing how ecosystems respond to subsidies such as marine derived nutrients and their impacts on gross primary productivity and ecosystem respiration. In this study, we propose to assess the question: Does stream metabolism (i.e., gross primary production and ecosystem respiration) differ among stream reaches with high densities of spawning salmon compared to stream reaches with low densities or no spawning?

What have we learned to date?

a. To date, we have identified a study design that will allow us to rigorously test the proposed question, identified study sites, and began purchasing necessary equipment.

b. We have identified two sites, upper and lower, in each river to deploy sondes. These two sites within rivers are associated with high and low spawning densities for each respective river and should allow us to account for hydrologic and geomorphic differences among rivers.

5.6.5 Reclamation Climate Change Study

Reclamation's TSC in Denver, Colorado is using its two dimensional (2D) hydraulic modeling capability to develop 2D flow, temperature, and water resident time scenarios for the Middle Methow River treatment project. Much progress has been made by Reclamation and USGS-CRRL to develop a life cycle model that links bioenergetics, life history, population dynamics, and abiotic factors for understanding salmonid production in the Methow River watershed. The TSC hydraulic model will be used to explore and predict the consequences of climate change and various management actions such as species reintroductions and habitat improvement measures.

What have we learned to date?

a. The study site has significant temperature variation where the largest tributary, the Chewuch River, enters the mainstem Methow River. There is a detectable mixing zone at low flow that has spatial variation both longitudinally and laterally across the river. To a lesser degree, there is also vertical variation in temperature on the Chewuch River.

b. The 2D model will be tested to see if we can represent the lateral and longitudinal variation in a depth-averaged approach. We collected temperature data by boat, thermo-profilers, and GPS location. We were able to collect a data set that represents the variations. However, we found challenges in areas of the river with boulders and rapids that prevented safe collection of bottom profiling.

c. We have learned that temperature data can be approached from a spatial and temporal variation to test the 2D model and both data sets have their advantages and disadvantages, but together make a reasonable set for calibration and testing. The spatially diverse set collected by boat has the advantage of data that captures lateral variation. However, the data is difficult to capture with changing solar conditions throughout the day when cross-sections are collected but less of an impact for longitudinal profiles. The temporal data using loggers has the advantage of capturing variations due to changing solar and air temperatures, but is only at a single point in the channel that may be very different from average conditions in the main channel. A forward looking infrared data set will also be used that has spatial variation but only captures surface temperature and does not generate bottom temperature data.

d. Climate change projections generally predict increasing air temperatures across the western United States, with less confidence regarding shifts in precipitation. As air temperatures rise, we anticipate a corresponding increase in water temperatures, which may alter the timing of and available habitat for fish reproduction and growth. The statistical modeling approach outlined in the following section was used to provide estimates of future impacts on water temperature resulting from climate change. The results indicate that increases in stream temperature are expected at time horizons of year 2020, 2040, and 2080, with a mean deviation of 0.81^{o} C by the year 2080. The potential for higher stream temperatures highlights the need to understand impacts to the fisheries in the Methow. The development methodology used for the statistical modeling framework and the results have been submitted for publication to Water Resources Research in spring 2012.

5.6.6 Winthrop National Fish Hatchery Steelhead Smolt Project (BPA Project 1993-056-00)

The goal of this project is to advance hatchery reform throughout the Columbia River Basin by developing fish culture solutions that enable use of locally derived broodstocks for steelhead in hatcheries with rearing environments that preclude standard culture practices. Funding for this project is provided by the BPA (Project 1993-056-00) and the USFWS, and is a collaborative effort between researchers at NOAA Fisheries and USFWS. Other cooperators involved include USGS, Reclamation, and WDFW.

Development of a local Methow River summer steelhead stock addresses a key measure identified during the recovery planning process for threatened upper Columbia River steelhead. To do this successfully at Winthrop National Fish Hatchery, a two year smolt rearing program is needed. This project helps to support these changes to the Winthrop summer steelhead program providing key support to steelhead recovery in the Methow basin and novel scientific information that can be applied to similar situations throughout the entirety of the Columbia River Basin.

The project has two main objectives: 1) improve survival and reduce fitness loss in Columbia River steelhead by minimizing unnatural selection on body size and other smolt characteristics, and 2) identify behavioral and physiological traits under selection through laboratory-scale research. An interim objective for the FY10 funding cycle was to validate endocrine and genomic markers of precocious maturation in male steelhead.

What have we learned to date?

Objective 1: Improve Survival and Reduce Fitness Loss in Columbia River Steelhead Smolts

In both the 2010 and 2011 release years, apparent survival of S2 smolts released from Winthrop National Fish Hatchery to Rocky Reach Dam was significantly (based on non-overlapping 95 percent confidence intervals) higher than the survival for S1 smolts. Apparent survival within the other reaches (Rocky Reach Dam to McNary Dam; McNary Dam to John Day Dam; and John Day Dam to Bonneville) was similar between S1 and S2 smolts. Travel times to Rocky Reach Dam and to Bonneville Dam for S2 smolts were shorter and less variable than for S1 smolts.

Pre-release sampling indicated that S2 smolts (mean FL = 214 and 187 mm) are significantly larger than their S1 (mean FL = 194 and 159 mm) counterparts for both 2010 and 2011 release years. The length frequency plots demonstrate a considerable amount of overlap and also suggest that the S1 distribution has a bimodal characteristic likely indicative of the presence of smaller non migrant parr in the S1 population. Both S1 and S2 steelhead residuals were observed, the frequency of S1 residuals was greater than seen in the S1 group.

Objective 2: Identify Behavioral and Physiological Traits Under Selection Through Laboratory-Scale Research

The recirculating fish culture system at the Manchester Research Station was completed and tested to ensure its suitability for fish culture and behavioral assays prior to establishing research populations of S1 and S2 steelhead sourced from Wells Dam and Winthrop National Fish Hatchery. The brood year 2011 S1 rearing group was stocked into the recirculating fish culture system in April 2011, and the S2 rearing group was produced at Winthrop National Fish Hatchery. The brood year 2011 S2 rearing group was transported to Manchester in June 2011. Behavioral assays were completed and both fish culture and behavioral results are currently being compiled and analyzed.

Interim Objective: Validate Endocrine and Genomic Markers of Early Male Maturation in Steelhead

Our findings demonstrated that yearling Skookumchuck River steelhead that had initiated puberty (were in at least stage I of spermatogenesis) by May, also tended to have elevated expression of pituitary follicle stimulating hormone (FSH) beta and lutenizing hormone (LH) beta, and reduced expression of testicular anti-Mullerian hormone (AMH). However, none of these molecular markers showed clear bimodal distributions. Based on these criteria, the proportion of males initiating puberty in May was 28 percent. This was substantially lower than the estimate of 36 percent found in samples collected from the same group of fish in September when both gamma secretase inhibitor and plasma 11-ketotestosterone levels were bimodally distributed. We were unable to classify about 10 percent of the fish in May because of the quality of testis histology and are working to resolve these samples using a marker of spermatogonial proliferation (first stage of spermatogenesis). However, using a combination of pituitary FSH beta and testicular AMH expression, conservative estimates of the proportion males initiating puberty could be done. This might be sufficient for comparing treatment effects on the proportion of steelhead males maturing in hatcheries at the time of smolt releases.

Samples from juvenile S1 and S2 steelhead prior to release in March of 2011 were collected and the data is currently being compiled and analyzed to evaluate the effectiveness of endocrine and molecular markers as a means of determining smolt and maturation status.

5.6.7 USFWS/Reclamation Artificial Egg Development Study

Anticipating that egg predation and/or egg cannibalism by salmon and steelhead juveniles may be shown to have a positive effect on salmon and steelhead population growth, Reclamation funded the USFWS's Abernathy Fish Technology Center (AFTC) to investigate the viability of using egg analogs to increase natural production of steelhead. The AFTC analyzed egg analog suitability based on size, color, fatty acid composition, and palatability. The study evaluated fish acceptance and growth when offered potential egg analogs. Two experiments were conducted: feeding behavior and feeding trial. The AFTC tested four diet alternatives: (1) steelhead eggs; (2) 2.5 mm commercial diet; (3) 3.0 mm experimental diet; and (4) 3.0 mm experimental diet plus red dye. Feeding behaviors studied included orientation, approach, capture, and ingestion.

What have we learned to date?

a. Experiment 1 demonstrated that eggs are favored over egg analogs, but the differences in preference among the four food choices were not statistically significant. All four diets appear to be potentially viable egg analogs. The 2.5 mm commercial diet was superior in growth, feed efficiency, and Eicosapentaenoic lipid content of whole body lipid. The red dye does not appear to enhance the selection of the experimental diet.

b. Although the commercial diet's performance closely matched the performance of the egg treatment, the commercial diet and the two experimental diets did not elicit as strong a feeding response as steelhead eggs, nor did they match the Docosahexaenoic lipid content in whole bodies of fish fed steelhead eggs.

5.6.8 USGS/Reclamation Steelhead Smolt Decision Model

Reclamation/USGS-CRRL used a decision state model approach to explore the role fall spawned eggs might have on steelhead productivity and smolting. USGS-CRRL used multiple linked models in the R programming language to construct a simulation model that predicts life history choices of juvenile steelhead over different diets, growth patterns, and temperature regimes. This was accomplished by linking a water temperature model, bioenergetics model, and a dynamic state-dependent model which predicts life history trajectories of juvenile steelhead.

What have we learned to date?

a. Addition of eggs to the food supply in the model generated faster growth
b. Caveat: fish were not modeled spatially
c. Addition of coho eggs to diet could alter population structure
d. In some scenarios greater numbers of age1 smolts
e. Importance of emergence date
f. Later emergents will smolt
g. Earlier emergents are predicted to residualize
h. Later emergents could miss egg opportunity

6. Summary

Each IMW in the PNAMP regional portfolio is designed to evaluate listed fish population responses to habitat treatments that address specific limiting factors. Some IMWs have the distinct advantage of designing a large suite of habitat projects to fit a pre-conceived RME design. In other cases, where a large number of similar habitat improvement projects are occurring in a short period of time, ideally in a relatively small watershed, an IMW RME program that tags numerous fish at the project sites and recaptures the tagged fish at fish traps or detects PIT-tags at a detector near the watershed mouth, conceivably can make a robust estimate of changes in survival associated with particular limiting factors that are addressed by the habitat projects.

The Methow IMW project fits somewhere in between these two sideboards. It is a large watershed with a diverse set of habitat projects and therefore, it is not possible to tag fish at projects and develop robust estimates of fish improvements at the watershed scale simply by recapturing fish at the mouth. The exception is the proposed nutrient treatment in the Twisp River which is the dominant treatment in this large tributary watershed. A weir near the Twisp River mouth is used to count adult fish in, and a fish trap also near the mouth plus numerous PIT-tag detectors upstream and downstream of the trap allow enumeration of juveniles out. Otherwise, a different approach is needed to scale the effects of local improvements to the Methow IMW watershed scale.

The Methow IMW partners have collaborated for the past five years on monitoring activities that have helped shape the IMW design (see Appendix B). Reclamation has organized annual meetings to discuss plans, methods, and results. The major monitoring projects include a fish production monitoring program, a barrier removal and steelhead passage survival and genetics study, a channel complexity pre-treatment fish food web and fish production study, a nutrient enrichment pre-treatment primary and secondary production study, a hatchery steelhead rearing study, and a steelhead relative (hatchery versus wild) reproductive success study.

In 2012, Reclamation's continued funding of monitoring by USGS for a large fish passage improvement project in a Methow River tributary, Beaver Creek, has successfully demonstrated, through mark-recapture studies and isotope evaluations, that the project allowed re-colonization of listed summer steelhead to occur, and colonizers are advancing upstream. A separate Reclamation genetics study used microsatellite genetic data to demonstrate that fluvial *O. mykiss* crosses with anadromous *O. mykiss* contributed directly to the establishment of the colonizing population. However, the adult colonization population has leveled off suggesting that some other factor(s) may be limiting reestablishment of the population. See Appendix C for a thorough description of the project implementation and monitoring.

Reclamation funded a post-project monitoring assessment of the Elbow Coulee Floodplain Reconnection and Channel Restoration Project in the Twisp River RM 6.6. The project breached a levee at the upstream entrance and installed a sill to re-establish side channel flows and channel complexity. The habitat improvements have contributed to an increase in abundance of listed spring Chinook and steelhead using the side channel (see Appendix D).

Reclamation also continued to fund a fish food web and fish production study by USGS in a large reach of the Middle Methow River called the M2 Reach. Appendix E summarizes the project planning and monitoring. The 2012 results show that there are significant differences in the production of the main Methow River and several distinct side-channel habitat complexes. Most fish production is dominated by predominately benthic feeding sculpin and mountain whitefish in the main channel. Most side channels have greater listed Chinook salmon and steelhead production. Preliminary data suggest that sufficient benthic invertebrate biomass exist to support larger listed fish populations. The mechanisms limiting the utilization of this potential are being explored. Channel complexity and floodplain reconnection habitat improvements in 2012-2013 will be evaluated in a 2014-2015 monitoring study. A Reclamation TSC 2D hydraulic model study for the Middle Methow River will allow Reclamation to predict potential effects of climate change on flow and temperature in the M2 reach.

Several hatchery program changes and associated monitoring programs are underway in the Methow River. The U.S. Fish and Wildlife's Winthrop National Fish Hatchery and the NWFSC are evaluating a one-year old versus a two-year old steelhead smolt rearing program. Winthrop National Fish Hatchery, in cooperation with Reclamation and USGS, has begun a study of steelhead residualization. The agencies are cooperating on mark-recapture studies of hatchery steelhead. The WDFW steelhead relative reproductive success study in the Twisp River is underway. Preliminary results do not indicate significant differences between life-history traits of hatchery versus wild spawners.

The Methow monitoring program results thus far show that freshwater fish productivity in the Methow River basin is very low (see Figure 9). The main hypothesis is that production is low because food is limiting: either primary and secondary production are low based on YN studies in the Twisp River, or in other cases, secondary production may be sufficient to increase listed fish growth rates but the target fish are not able to take advantage of it, based on the food web and survival studies conducted by Reclamation and USGS in the Middle Methow M2 Reach. The Methow IMW design incorporates these results by focusing on how projects operate on habitat to increase food supply to listed salmonids in the context of a fish food web. The design strategy is to use models to guide the planning of field work as well as to support the analysis of projects and ultimately the redesign of treatments in an adaptive management framework (see Section 4.1, Figures 2 and 3). The effects of habitat project on listed fish growth rates and survival will be placed in the context of a full-life cycle model.

A Reclamation-funded study by USGS developed a steelhead smolt decision model which was tested in 2012. A study using the model showed how coho salmon reintroductions currently underway through a BPA-funded project might provide an egg subsidy to age-0 steelhead that could increase fall and early winter growth rates and greater smolt production the following spring. A Reclamation-funded USFWS-Abernathy Lab evaluated the use of artificial egg subsidies in a laboratory study with the intent of producing egg subsidies for natural stream subsidy experiments.

Five projects currently are underway to implement the model and field study design. First an ATP model is under development (Appendix B-4). The model will be tested first using data from the channel complexity pre-treatment fish food web and fish production study. After recalibration, the model will be used to predict changes in fish production due to three habitat treatment projects: two channel and floodplain complexity projects, and a nutrient treatment project. The fifth Methow IMW project is the development of a data harvester tool that will gather model data from multiple sources and prepare it for use in the model. The harvester will also be used to develop reports. Project data and methods will be documented using tools developed by PNAMP (http://www.pnamp.org/topics/2)

A large channel complexity treatment project will be initiated in 2012. Post-treatment data collection and analysis will begin in 2014. Pre-treatment data collection for the second channel treatment will begin in 2013. Pre-treatment data collection for the nutrient treatment project has been supplemented in 2012 in preparation for a 2013 treatment. Post-treatment data from each project will be used to further test and redesign the model for use in other geographic domains.

Finally several programs fish and fish habitat status and trends and water quality. The ongoing fish status and trend program is working to improve its fish mark-recapture analysis. Numerous PIT-tag interrogators have been added to the Methow River basin to support improvements. The CHaMP fish habitat status and trend program will be initiated in the Methow IMW in 2013, although three sites will be implemented in 2012 to provide crucial information for 2013 planning. The Methow IMW will explore the collection of a few key additional metrics at CHaMP sites in 2013 to test our ability to use the ATP model to scale up production to the full Methow River basin.

In addition to using CHaMP data to scale up fish production, we are conducting an aquatic metabolism study that is designed to predict seasonal net aquatic production differences in the major watersheds of the Methow River basin. We will compare these water quality based predictions of aquatic productivity in the Twisp River with model predictions using CHaMP data and an associated rich set of primary and secondary production data from the proposed nutrient treatment study.

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8. Appendices

Appendix A – Review of Habitat and Salmon Models
Appendix B – Methow IMW Analytical Design
Appendix C – Beaver Creek Studies
Appendix D – Elbow Coulee Studies
Appendix E – Middle Methow M2 Studies

APPENDICES

APPENDIX A

Review of Habitat and Salmon Models

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A-1 **Models in Salmonid Habitat Management**

A-2 **Workshop on Habitat and Fish Modeling**

A-3 **A Prospective Examination of Ecological Modeling for the RPAs**

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Appendix A

Review of Habitat and Salmon Models

A-1. Models in Salmonid Habitat Management

Models have been used extensively in environmental planning (Busch and Trexler 2003). Reclamation dams were planned through the use of hydrological simulation models and laboratory hydraulic models. Action Agencies use water supply forecasting models and multi-purpose operational models to regulate water at dams based on forecasts. Action Agencies use a comprehensive fish passage model called COMPASS (Zabel 2008) to evaluate fish survival through Federal dams on the Columbia River. Models are used both to plan environmental monitoring (e. g., Ringold et al. 2003; Noon 2003) and to evaluate the results of monitoring (e.g., Ogden et al. 2003; Reynolds and Reeves 2003). Adaptive management decisions rely on decision analysis models. Sometimes conceptual models are used to develop the decision pathways. Often simulation studies are used to test and compare the significance of the pathways to the decision process (see e.g., Holling 1978).

The Action Agencies and NOAA Fisheries concluded that models are needed to develop and test hypotheses about the relationships between salmonid populations and their environment. RPA action 57 calls for the development and use of models to plan and evaluate habitat projects effects on salmonid populations. The fish and habitat relationships are very complicated with many relational pathways and often with synergistic effects among explanatory variables. Models will assist the Action Agencies and others in the prioritizing and monitoring projects.

This conclusion is supported by Pacific Northwest independent science reviews and generally in the science literature. The Independent Science Advisory Board (ISAB) reviewed models in Columbia River Basin Salmonid Management (ISAB 2001-1, ISAB Model Synthesis Report) and proposed uses of models in decision support. They reviewed several decision support systems, and included responses to ISAB modeling questions directed at the principal scientists doing analytical modeling in the Basin, including the Interior Columbia Basin Environmental Monitoring Program (ICBEMP), the Cumulative Risk Initiative (CRI), the Plan for Analyzing and Testing Hypotheses (PATH), the Ecosystems Diagnosis and Treatment (EDT) model, and the Columbia River Intertribal Fish Commission (CRITFC) Cohort Model.

The ISAB made a comprehensive review of the CRI project in 1999 (ISAB 99-7), praising the overall approach, but criticizing the Initiative for the use of mostly derived data; for lack of an explicit synthesis of its own analysis and conclusions; a lack of transparency with regard to the modeling steps; the use of an extinction model that does not take into account density dependence and variability in growth rates associated with environmental variability as mediated by life-history and metapopulation structure; implausibly low estimates of extinction risks; and most importantly for the Action Agency habitat and hatchery programs, a lack of a thorough analysis of the potential of program improvements to mitigate extinction risks. The CRI did suggest in a published paper (Kareiva et al. 2000) that small improvements in recruits per spawner from habitat quality improvements would make an important difference in population growth rate for select populations.

Particularly notable were the answers to the ISAB‟s 2001-1 assessment of the Cumulative Risk Initiative submitted to the ISAB by two of the Initiative‟s authors, Peter Kareiva and Chris Jordan. These authors concluded that a decision-theoretic approach is not possible because of the paucity of monitoring data, particularly for habitat and hatcheries, which is one of the conclusions noted earlier in ISRP/ISAB 2001-7. The authors felt that the CRI modeling gave the „illusion of science when there is really very little science to support particular choices‟ because of the lack of quality data, and where quality data does exist, a lack of original analysis. The CRI authors said that the ISAB should have at least included the few notable examples of original analysis in its review, including suggestions of how to incorporate these analyses in modeling.

We do not attempt to cover exhaustively the subject of salmonid population modeling here (see Hilborn and Mangell 1997 for a systematic treatment of data analysis in fisheries management; also see Knudsen and Michael, Jr. 2009; and Shenk and Franklin 2001, Walters and Korman 1999, and Walters et al. 2009, to name a few). Instead, we present a brief overview of a few outstanding modeling issues relevant to the Methow IMW.

Hilborn (2009) summarized the challenges in using life history models for analyzing salmon habitat. His habitat-related challenges included: 1) increasing the dynamic understanding of habitat use; and 2) acquiring real habitat and fish relational data to populate statistical models. The Columbia Habitat Monitoring Program (CHaMP - http://www.champmonitoring.org/) and the Integrated Status and Effectiveness Monitoring Program (ISEMP - http://www.nwfsc.noaa.gov/research/divisions/cbd/mathbio/isemp/index.cfm) are largely dealing with his challenge number 2 through a systematic sampling of habitat and fish data in an IMW framework. Hilborn reviewed two habitat and fish models, EDT and Shiraz, which attempt to address challenge number 1.

In its Review of the Biological Objectives of the 2000 Fish and Wildlife Program (ISAB 2001-6), the ISAB said that the EDT model was useful for generating hypotheses about species-specific survival improvements from restoration projects. However, the ISAB noted that EDT cannot be used to verify the predictions; as an equilibrium model, it is not designed to predict how long it will take to reach an equilibrium state, and it assumes that once the equilibrium state is reached, the response thereafter remains constant. Thus, the ISAB concluded that EDT is not useful in recovery planning.

The Beverton-Holt model or some similar logistic-like model is commonly used in fisheries to represent the number of individuals in a generation to the number of individuals in a previous generation, such as adult spawner recruits per previous generation spawner. An ordinal spawner-to-spawner or amolt to spawner curve is created for a period of record, and a function like the Beverton-Holt curve is fit to the data to estimate the parameters of the curve If the slope of the curve appears asymptotic, it is assumed that the asymptote defines the carrying capacity c for the population

Shiraz uses a two-parameter Beverton-Holt model to relate the number of individuals at some life-stage s+1 to the number of individuals at a previous life-stage.

$$N_{s+1} = \frac{N_s}{\frac{1}{p} + \frac{1}{c} N_s} \quad \text{where} \begin{cases} p = productivity \\ c = capacity \end{cases}$$

Scheuerell et al. (2006) used habitat functions and ocean productivity estimates to develop parameters for a full life-cycle, multi-stage Beverton-Holt model and applied it in Shiraz to the Snohomish River basin. Shiraz has been applied subsequently in the Columbia River Basin. The model is flexible in that the relationships describing the survival from one life-stage to the next can be theoretical or experimentally derived from site-specific field data.

McHugh et al. (2004) modeled the effects of habitat improvements on egg-smolt survival of Snake River spring-summer Chinook using a similar stage-to-stage modeling approach. The authors calculated egg-smolt survival as the product of (1) survival from egg-fry emergence as a function of average water temperature during the period; (2) survival during the summer, based on summer productive capacity as a surrogate for survival, as a function of percent cobble embeddedness for riffle-run habitats; (3) survival rate as a function of mean daily water temperature during the summer parr rearing period; (4) survival during the winter, based on overwintering survival capacity as a surrogate for survival, as a function of the cobble embeddedness in pool habitats; and (5) survival as a function of percent fines in spawning gravels.

These Beverton-Holt model approaches used empirical habitat and fish survival relationships from the literature. The relationship between survival and fines came from laboratory experiments conducted by Tappel and Bjornn (1983) and calibrated by Stowell et al. (1983). The incubation temperature function came from field and laboratory sources (Murray and McPhail 1988; Armou 1991; and McCullough et al. 2001). The riffle-run embeddedness function came from Stowell"s polynomial fit (1983) to data from a Bjornn et al. (1977) field study. The summer parr rearing temperature function data was derived from Brett (1952), McCormick et al. (1972), and Coutant (1973). The pool embeddedness function also came from Bjornn and Stowell.

Both the Scheuerell et al. (2006) and the McHugh et al. (2004) studies only addressed some aspects of the habitat effects on overall survival. The studies did not consider the second part of the production equation which is the effects of habitat on growth; they did not address biotic effects on production, and/or they assumed that current habitat and fish population relationships are stationary.

We assume that the historic freshwater salmonid populations, habitat carrying capacity, and habitat productivity are likely greatly reduced for a variety of reasons related to human activities. The objective of habitat improvement projects is to improve the p and c parameters as represented in the Beverton-Holt model. The assumptions in the Beverton-Holt model about initial population size, and potential carrying capacity (c) and productivity (p), interact to create different asymptotic population growth curves in the model. If the freshwater carrying capacity was historically much higher, then our ability to restore current populations with freshwater habitat restorations may require large changes to productivity. Figure 1 illustrates this concept for Beverton-Holt curves of varying initial conditions (N1,x), p, and c. If some life-stage is below freshwater carrying capacity for that stage, the population approaches capacity only at a very high productivity rate, and exceeds a one-to-one replacement rate only for a relatively high capacity, a large ratio of the initial population to the carrying capacity coupled with a high carrying capacity, or the case of a very high productivity.

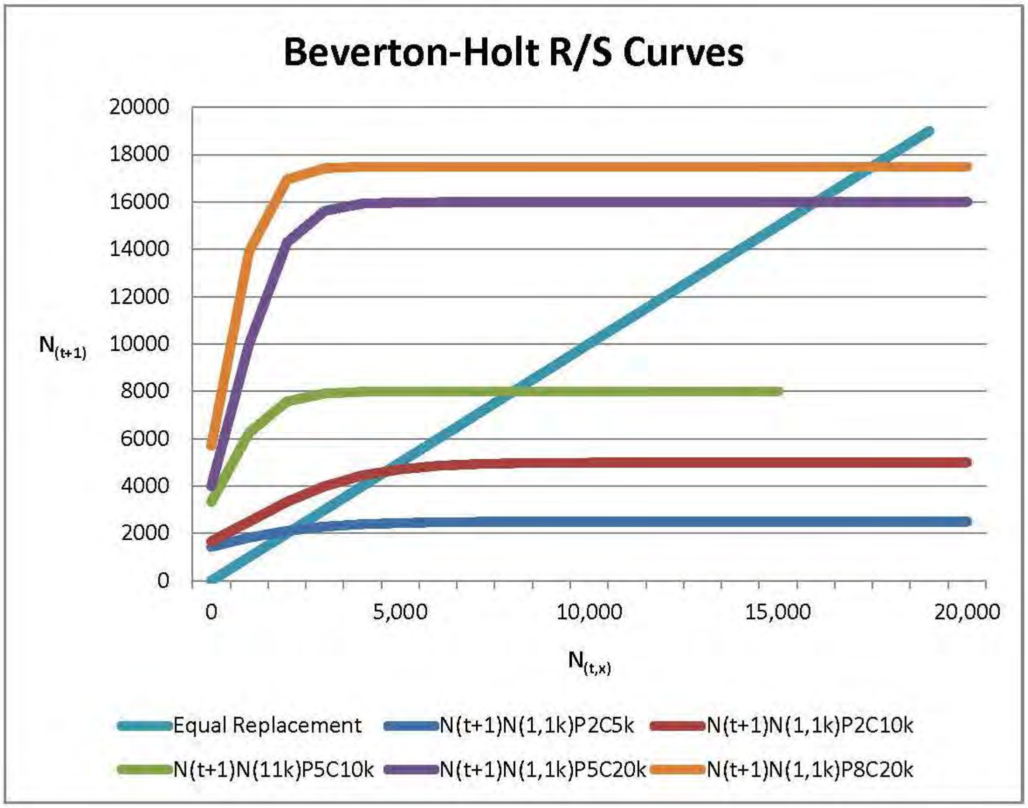

Figure 1. Beverton-Holt Spawner Recruit Curves; P=Productivity; C=Carrying Capacity; N(1,x)=Initial Spawning Population x

There are some recent notable examples of original model analysis. Ebersole et al. (2009) used “multiple regression and hierarchical mixed-effects models to examine spatial patterns of overwinter survival and size at smolting in juvenile coho salmon (*Oncorhynchus kisutch*) in relation to habitat attributes across an extensive stream network in southwestern Oregon over 3 years. Contributing basin area explained the majority of spatial variation (R21/40.57–0.63) in coho salmon overwinter survival (range1/4 0.02–0.63), with highest survival rates observed in smaller headwater and intermittent streams. Other habitat attributes, including proportional pool area, percent exposed bedrock substrate, percent broadleaf canopy cover, and adult salmon carcass density, were relatively poor predictors of survival. Indices of individual fish condition, including fall parr fork length, condition factor, and parasite infestation rates, were also relatively uninformative in coho salmon overwinter survival models. Coho salmon smolt length was primarily a function of length at the time of fall tagging, but stream type, contributing basin area (positive effect), thermal history (positive effect), and black spot infestation (i.e., trematode metacercariae; negative effect) were also important.”

Kocik and Ferreri (1998) studied the spatial structure of Atlantic salmon (*Salmo salar*) river habitat. They identified functional habitat units FHU based on maps, fish ecology, and habitat characteristics and showed how simulation models can test hypotheses about salmon population dynamics. They propose using the model to analyze the effects of habitat alterations and habitat ecology of salmonids at different time and space scales.

Some modeling approaches have tried to capture the dynamic aspects of fish and habitat relationships. Satterthwaite et al. (2009) used dynamic state-space modeling using data on optimal life-stage parameters to predict the resident life-history strategies and smolting size and age distributions. This model could be used in conjunction with habitat and fish growth models to optimize population smolt size and age.

Karlsson et al. (2005) took a more fundamental approach to understanding salmonid food supply by developing an ecological model of organic matter dynamics using a program called Stella©. The simulations allowed them to investigate the effect of land use practices (e. g., logging) and temperature fluctuations on the amount of dissolved organic matter available ultimately for fish production in a stream. Their model predicted that removal of streamside or riparian vegetation results in up to 80 percent reduction in dissolved organic matter.

Kiffney and Roni (2007) used eight ecological covariates and a version of Akaike‟s information criterion to choose models that predict the relationships between the ecological variables and distribution and abundance of stream organisms. "Our analyses provided quantitative evidence supporting a priori hypotheses that predation, physical habitat, basal productivity, and the interaction between productivity and physical habitat are important sources of variation explaining biomass, abundance, and diversity of invertebrate and vertebrate populations. In particular, we observed that current velocity and light input were important covariates positively associated with a number of biotic variables." Physical habitat variables included wood, average stream velocity and depth, stream slope, and stream fine sediment.

The biotic interactions of competitors and predators are expressed conceptually in food web and food chain models. Power et al. (1995) modeled food webs with food chains with three trophic levels and two energy sources, detritus and vegetation, in response to changes in river width, depth, and velocity. The models were used to guide field observations and measurements that linked the relatively well understood responses of river width, depth, and velocity to changes in discharge and the poorly understood responses of river biota to these hydraulic parameters.

Power (2001) summarized the importance to river ecology and river rehabilitation of understanding food web and food chain dynamics:

> "Managers are increasingly aware of the need for science to inform the stewardship of natural lands and resources. If ecologists are to address this need, we must increase the scope of our inferences, while maintaining sufficient resolution and realism to predict trajectories of specific populations or ecosystem variables. Food chain and

simple food web models, used either as core or component hypotheses, can help us to meet this challenge. The simple mass balance logic of dynamic food chain or food web models can organize our thinking about a range of applied problems, such as evaluating controls over populations of concern, or of biotic assemblages that affect important ecosystem properties. In other applications, a food chain or web may be incorporated as one element in models of regional mass balances affecting resources or environments…dynamic food chain or simple food web models, because of their compelling mass balance logic, are useful in framing management problems. These models can also serve as initial null hypotheses, guiding the investigation of key natural history and environmental variation that drive real management problems. Predictions of these models will often fail, but they will leave us with more focused and coherent sets of assumptions and alternate hypotheses to investigate, hastening our approach to more predictive understanding."

A-2. Workshop on Habitat and Fish Modeling

Where: University Place Hotel
Willamette Ballroom
310 SW Lincoln St.
Portland, Oregon 97201
503-221-0140
When: 9 AM February 8th to 3:30 PM February 9th

Objectives: This Workshop will summarize recent work on habitat and fish modeling. The proceedings of the Workshop will provide guidance to a Regional Technical Workgroup that has been organized to recommend modeling for the 2008 Federal Columbia River Power System Biological Opinion, Reasonable, and Prudent Alternatives (RPAs) 56, 57, and 65. **The RPAs call for modeling to (1) improve the development and parameterization of models used in planning and implementation of habitat projects, (2) further the testing and development of relationships and models used for estimating habitat benefits, and (3) develop conceptual study designs to analyze critical uncertainties associated with hatchery operations**.

Approach: Four sessions of invited papers on modeling will address: the effects on fish populations of large environmental perturbations; predicting fish population responses to habitat treatments; the physical and biological environment at the landscape level; and the use of decision support tools for resource planning. Presenters will participate in open discussions and provide extended abstracts of their work which will be published along with a meeting synopsis.

Special Guest Lectures: Tuesday, February 8th, 7:00-9:00pm

Host Presentation: "Climate Change Research at the Lab"
Steve Waste, U. S. Geological Survey, Columbia River Research Laboratory

Guest Presentation 1: "Effects of climate change on Columbia River salmon: is the past a guide to the future?"
Lisa Crozier, Northwest Fisheries Science Center

Guest Presentation 2: "Future climate and habitat scenarios for northwest salmon and some thoughts on how to use them in recovery planning"
Nate Mantua, University of Washington Climate Change Impacts Group, School of Aquatic and Fishery Sciences

Sponsors:
U. S. Geological Survey
Bonneville Power Administration
U. S. Bureau of Reclamation
Northwest Fisheries Science Center
Columbia River Inter-tribal Fish Commission

Tuesday February 8th

Michael Newsom (Welcome and Conference Introduction: 9:00-9:10)

Session A

Modeling the effects on fish populations of large environmental perturbations, such as climate change, hatchery production, loss of marine-derived nutrients, exotic species, and harvest practices

Lead – Mark Scheuerell (Opening Remarks 9:15-9:25)

1. Impacts of hatcheries on wild salmon productivity: lessons from long-term monitoring
Eric Buhle, Northwest Fisheries Science Center (NWFSC)
9:30-9:50

2. Predicting population response of O. mykiss to direct feeding on carcasses and eggs in the Methow River: simulations to represent historic conditions
Jason Romine, U.S. Geological Society, Western Fisheries Research Center, Columbia River Research Lab (USGS-CRRL)
9:55-10:15

3. Non-native predators in the Columbia and Snake Basin: hotspots of predation
Mike Carey, NWFSC
10:20-10:40

Break: 10:40-10:55

4. Replacement of a native salmonid by a nonnative salmonid: changes in trout production and consequences of stream-riparian food webs
Joe Benjamin, USGS-CRRL
11:00-11:20

5. What does fishing-induced evolution mean for sustainable salmon harvest?
Jeff Hard, NWFSC 11:25-11:45

Lunch: 11:45-12:45

Session B

Predicting fish population responses to habitat treatments

Lead: Rishi Sharma (Opening Remarks 12:50-1:00)

1. Role of Quantitative Models in Science with respect to RPA"s in the Hydro-BiOp
Rishi Sharma, Columbia River Inter-tribal Fish Commission
1:05-1:25

2. Using geomorphology to predict salmon habitat capacity and productivity potential at the watershed scale
Jody Lando, Stillwater Science
1:30:1:50

3. Estimating environmental effects on survival using a life-cycle approach
Bob Lessard, Columbia River Inter-tribal Fish Commission
1:55-2:15

4. Modeling fish movement, survival and smolt production in a Methow River O. mykiss population
Russ Perry, USGS-CRRL
2:20-2:40

Break: 2:40-2:55

5. Monitoring and modeling populations in multiple watersheds
Martin Liermann, NWFSC
3:00-3:20

6. Estimating increases in salmon population metrics from habitat actions: how much restoration and how much monitoring is needed to detect change?
George Pess, NWFSC
3:25-3:45

Question and Answer Session
Mark Scheuerell, NWFSC, Moderator: 3:50-4:45

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Evening No Host Restaurant Options – Information Provided at the Workshop

Evening Presentations and Discussion

Where: University Place Hotel and Conference Center
When: 7:00-9:00pm

Welcome and Introduction: 7:00-7:05
Michael Newsom, Bureau of Reclamation, PN Research Program Manager

Host Presentation: 7:05-7:20, "*Climate Change Research at the Lab*"
Steve Waste, Director, USGS Columbia River Research Lab

Guest Introduction: 7:25-7:30
Rishi Sharma, Columbia River Inter-tribal Fish Commission

Guest Presentations: 7:30-8:30

"*Effects of climate change on Columbia River salmon: is the past a guide to the future?*""
Lisa Crozier, Northwest Fisheries Science Center

"*Future climate and habitat scenarios for northwest salmon and some thoughts on how to use them in recovery planning*"
Nate Mantua, University of Washington Climate Change Impacts Group, School of Aquatic and Fishery Sciences

Question/Answer Session: 8:30-9:00

Alec Maule, USGS-CRRL, Moderator

Wednesday February 9th

Session C

Modeling the physical and biological environment at the landscape level

Lead - Chris Jordan (Opening Remarks 8:30-8:40)

1. Change Detection in Land Cover from TM imagery
Robert Kennedy, Oregon State University (OSU)
8:45-9:05

2. Spatially and temporally explicit, individual-based, life-history and productivity modeling: steelhead in the John Day
Kris McNyset, OSU
9:10-9:30

3. Landscape-scale classifications of Pacific Northwest watersheds based on natural features and human disturbance.
Thom Whittier, OSU
9:35-9:55

Break: 9:55-10:15

4. Channel typing and riparian vegetation modeling at the Columbia River Basin scale
Tim Beechie, NWFSC
10:20:10:40

5. Landscape modeling of habitat and fish monitoring data from the Oregon Plan monitoring program.
Kara Anlauf, Oregon Department of Fish and Wildlife
10:45-11:05

Lunch: 11:10-12:30

Session D

Decision Support Tools

Lead - Alec Maule (Opening Remarks 12:35-12:45)

1. The Okanagan Fish-Water Management Tools (FWMT) decision support system: balancing water regulation objectives to promote sockeye salmon production gains
Kim Hyatt, Fisheries and Oceans, Canada
12:50-1:10

2. Adapting a decision support system to forecast climate impacts on Yakima River salmonid habitat
James Hatten, USGS-CRRL
1:15-1:35

3. Developing integrated decision support tools for local and regional decision makers: a pilot study modeling the impacts of climate change on water management in the Methow River Basin
Karen Jenni, Insight Decisions
1:40-2:00

Break: 2:00-2:15

Workshop Panel Discussion

Leads - Mark, Rishi, Chris, Alec and Michael

2:20-3:30

The following workshop synopsis was written by Michael Newsom.

Introduction

The U.S. Geological Survey-Columbia River Research Laboratory, the Bonneville Power Administration, the U.S. Bureau of Reclamation, the Columbia River Inter-tribal Fish Commission, and the Northwest Fisheries Science Center hosted a Workshop on Habitat and Fish Modeling, February 8th-9th, in Portland Oregon. Alec Maule (USGS), Barbara Shields (BPA), Michael Newsom (Reclamation), Rishi Sharma (CRITFC), and Mark Scheuerell (NWFSC) planned and implemented the workshop. The Workshop objective was to present recent modeling work relevant to the 2008 Federal Columbia River Power System Biological Opinion, Reasonable, and Prudent Alternatives (RPAs) 56, 57, and 65. The RPAs call for modeling to (1) improve the development and parameterization of models used in planning and implementation of habitat projects, (2) further the testing and development of relationships and models used for estimating habitat benefits, and (3) develop conceptual study designs to analyze critical uncertainties associated with hatchery operations. The Workshop proceedings, to be published as extended abstracts, will provide guidance to a Regional Technical Workgroup that has been organized to recommend modeling for the RPAs.

Four sessions of invited papers on modeling addressed: the effects on fish populations of large environmental perturbations; predicting fish population responses to habitat treatments; the physical and biological environment at the landscape level; and the use of decision support tools for resource planning. Presenters participated in open discussions and provide extended abstracts of their work.

Our goal for the workshop was to recognize the contribution that modeling can make to the examination of fish populations for the RPAs, to demonstrate the breadth and depth of the contribution of existing modeling to the examination, to stimulate ongoing discussion of modeling, both theory and applications, to recognize gaps or potential shortcomings in past or current modeling, and to hopefully influence the direction of future modeling efforts. The papers are representative but certainly not exhaustive. For example, the modeling topic of hatchery critical uncertainties is covered by several ongoing or completed studies in the Pacific Northwest Region, in Canada, and for Atlantic salmon on the eastern coast of the United States. Because of time constraints, we limited the coverage to one outstanding piece of work for this RPA.

Our intent was to keep the discussion alive by creating an open web conversation which the RPA Regional Technical Group will review and summarize annually such that new ideas and results are incorporated in future modeling efforts.

Workshop Goals and Papers

The workshop planning team of Alec, Barbara, Michael, Rishi, and Mark chose authors and papers for the workshop that represent some of the brightest and most instructive research on the subject of habitat and fish population modeling in the Pacific Northwest. The papers were diverse and informative. Many presentations directly addressed modeling guidance relevant to the RPAs. Some speakers addressed general modeling concepts that were important to thinking about a future modeling framework. The following synopsis sorts the presentations with regard to the RPA questions and types the modeling work with respect to general modeling categories.

RPA 56: Monitor and evaluate tributary habitat conditions and limiting factors:

1) Does the work improve the development and parameterization of models to quantify the relationships between tributary habitat and fish productivity?

2) Were models developed and used successfully to evaluate tributary habitat conditions and limiting factors?

3) Did models contribute to the planning and implementation of tributary habitat projects?

Four presentations classified habitat at the landscape level relevant to known or perceived habitat and fish productivity factors. Tim Beechie developed models to predict channel type (mountain: cascade, plane-bed; step-pool; pool-riffle/floodplain: braided, island braided, meandering, straight); riparian potential; and salmon distribution and abundance as a function of channel type and riparian potential. The authors developed a physical model for channel type formation using physical channel variables and sediment variables, and used aerial imagery to train the model. Next they used historical land surveys to identify pre-contact riparian vegetation. The authors then developed potential riparian vegetation from the surveys and models with precipitation and temperature as primary control variables. The channel pattern model can be used for example, to understand channel restoration potential, predict spawning and rearing habitat capacity, and guide riparian restoration. Robert Kennedy evaluated linkages between land cover classes at spatial and temporal scales that are considered relevant to fish populations using aerial photos and satellite imagery. The work is designed to resolve land use changes in space and time with resolution appropriate to predicting changes in fish populations over broad scales. Tom Whittier used clustering and canonical correlation algorithms to map seven natural landscape features relevant to salmon populations for 438 standard hydrologic units. The model results have been used to compare natural features with some human disturbance features and with the coverage of intensively monitored watershed programs. Kara Anlauf used a regression approach to relate coho abundance to landscape-level characteristics using a long-term, dataset from Oregon coastal rivers and tributaries. Even with this rich dataset, the authors encountered statistical problems such as significant unexplained variance, because of key missing explanatory variables or due to patchy or rare data.

Two presentations modeled landscape processes at the basin or watershed scale. Jody Lando related geomorphic features of habitat to salmon productivity. The RIPPLE model consists of three modules: a spatially explicit physical model, a salmon habitat carry capacity model, and a population dynamics model. The model was applied to estimate spawning potential in model validation basins. Kris McNyset wowed us with simulations from a highly spatial and temporally discrete (ten day time steps and 200m hexagons) but dynamically continuous individually based model of the relationship between temperature, food and physical habitat to fish survival reproduction, movement, species interaction, and heritable traits.

Two authors explored fish population limiting factors using a bioenergetic model approach. Russell Perry coded a bioenergetic model coupled to a life-history decision model to estimate how various food resources effect growth and likelihood to smolt. The authors used the model to predict changes in the likelihood of an individual steelhead smolt as a result of its predation on coho eggs in the previous fall. The authors plan to couple the models to habitat and life-history models to examine other factors that possibly limit smolt production such as food web dynamics. Mike Carey used bioenergetics to show that an interaction of outmigration timing and water temperature shifts the diet of smallmouth bass from crayfish to salmonids. The percentage consumption of salmonids increases as temperatures exceed 15^{o} C, a temperature that likely will be more common under future climate change scenarios.

Jeff Hard modeled potential evolutionary effects of harvest on size and fecundity of spawners using a stochastic individually-based model through a regression of breeding values on phenotypes assuming a stationary phenotype variance-covariance matrix as a sum of a variance-covariance matrix of breeding values and a matrix of environmental plus non-additive genetic values. Simulations demonstrated substantial reductions in fecundity and age of fished populations compared to unfished populations. The harvest model is a subset of a larger full life-cycle modeling framework.

Joe Benjamin used an ANOVA approach to examine the consequences of the introduction of brook trout on riparian food webs and native cutthroat fish populations. The study compared the effects across a spectrum of population ratios of brook and cutthroat trout to tease out statistically the habitat and population dynamics. Modeling showed that early maturity, spawning, and emergence of brook trout allowed the species to exploit emerging riparian insects, reducing spider populations by 20 percent, and thus contributing to higher density and production of brook trout compared to cutthroat in the model.

Three authors used decision analysis models that contribute to habitat management for salmonid populations. Kim Hyatt used biophysical operation models in a mass balance approach to examine dam operation effects at Okanagan Lake on a suite of environmental factors with particular emphasis on mitigating operational losses of kokanee and sockeye egg and fry production. Jim Hatten used a 2-D hydrodynamic model to predict changes on existing physical habitat features under different future streamflow scenarios based on down-scaled climate change scenario data. Numerous simulations demonstrated reductions in salmonid abundance ameliorated somewhat by flow management through operations of dams upstream.

Karen Jenni developed an integrated physical, social, and biological decision analysis model with an emphasis on the use of models to develop planning scenarios including climate change. These decision support tools were used in the Methow River to examine alternative irrigation practices and the potential benefits to fish production.

RPA 57: Evaluate the effects of tributary actions on fish populations:

1) Does the modeling support effectiveness monitoring, i.e., the testing and further development of relationships and models used for estimating habitat benefits?

2) Did the work contribute to annual assessments by regional technical groups like the expert panel process in the Opinion?

Pat Connolly modeled cohort structure from mark-recapture data that was used to estimate survival from age one to smolt age for a population of *O. mykiss* in Beaver Creek, a tributary of the Methow River where anadromous fish passage was recently restored. The model compared the smolt contribution of fish that leave Beaver Creek in the fall versus fish that leave in the spring. Recapture data showed that counting smolts leaving in the spring misses the smolts that result from fall movers and thereby underestimates the benefit of the passage restoration.

George Pess used correlation models to regress fish population response to restoration actions using published empirical data. The authors then used Monte Carlo simulations to estimate a range of responses to typical (8 percent) versus full (100 percent) restoration of a validation watershed. The modeling demonstrated a huge variance in estimates of density and abundance, given the reliance on empirical data from the literature, such that a 100 percent restoration would be required to obtain a 95 percent confidence in achieving a 25 percent increase in smolt production.

Martin Liermann looked at optimal study designs for monitoring fish response to watershed habitat treatments. The modeling simulation demonstrated the decrease in effect size when trading space for time and the effect of scale on model performance.

Rishi Sharma summarized model selection issues such as sensitivity of the model to assumptions and initial conditions; the effect of spatial scale on the choice of model (lumped versus split); the tradeoffs between parsimony and complexity; and the potential compromises for predictive power when we assume that mechanisms explain the past are applicable to the future. He emphasized the need to define both a process control system composed of a research process (design, measure predict) and a communication process (reliability and adaptation).

RPA 65: Investigate Hatchery Critical Uncertainties:

> Does the presented work demonstrate conceptual modeling designs that aid the investigation of hatchery critical uncertainties?

Eric Buhle used a Leslie-Gower population model to predict total naturally derived recruitment from both wild and hatchery reared adult spawners in hatchery supplemented versus unsupplemented streams. Because some parameter estimates were poorly defined and exhibited unrealistic ranges, the authors constrained the ranges by informative prior distributions in a hierarchical Bayesian model to simulate hatchery effects on wild productivity and distinguish between these effects and overall density-dependent effect. The authors concluded that hatchery reared fish are less productive with less relative reproductive success at higher spawner densities. The results suggest that a trade-off between possible short-term population gains from hatchery supplementation versus long-term population declines due to lowered productivity in hatchery supplemented populations.

Modeling Workshop Retrospective

Models represent our understanding of a process. They explicitly communicate our ideas about the process through the relationships in the model. We use the relationships to understand, or explain, and predict an effect or a response so that we can recreate or avoid it. We may use the relationships to define the data collection process. Alternatively, we may construct the models from existing data. Because the world is complicated, we search for models that are both accurate and parsimonious. A parsimonious model needs less data because it has fewer relationships. We collect data to test and refine our relationships and build new models that predict more accurately or precisely. We use models to simulate conditions not found in the data. The process of building, testing and modifying models, and adjusting management responses accordingly is called adaptive management.

A model may define an experiment and its associated data (prescriptive or constructive) or represent existing data that was derived from one or more sources but was not derived as part of the model study design (retrospective). It may be mechanistic, conceptual, or statistical. Mechanistic models may be deterministic with non-varying or stochastic parameter values. Non-mechanistic models may be conceptual (sometimes called qualitative or approximate) or statistical (often curve fitting, but see Breiman 2001).

The workshop presentations are a representative sample of modeling fish populations in their freshwater environment relevant to the RPAs. *All but one presentation applied a retrospective model approach*. I classified presentations by Buhle, Perry, Carey, Hard, Lessard, McNyset, Beechie, Hatten, Hyatt, Jenni, Crozier, and Mantua as *retrospective mechanistic* approaches. Carey and Russell employed bioenergetic relationships to explain respectively predation consumption rates relative to temperature, and growth rates from different food sources relative to the likelihood of smolting. Buhle and Hard used a matrix model approach relating respectively spawner density by supplemented versus non-supplemented hatchery populations, and fecundity and age of recruits as affected by harvest. Lessard developed a Beverton-Holt population model using functional relationships between habitat variables and fish productivity. Hard and McNyset used individually based models to relate respectively life-stage-specific effects of harvest, and fish population response to numerous abiotic and biotic factors. Jeff Hard used stochastic simulations to generate data. Hatten used a 2D hydrodynamic model and GIS habitat data to develop mathematical relationships between flow and spawning and rearing habitat. Crozier used a stochastic life-cycle model parameterized with habitat and fish survival statistical relationships. Mantua used mathematical hydrologic and energy balance equations with downscaled climate data to develop regional climate change effects on water supply balance and flooding. Beechie used physical channel evolution models to predict spawning and rearing habitat potential based on known relationships between channel types and spawning and rearing densities. Additionally, the authors calculated riparian habitat potential using historic riparian vegetation survey data, with precipitation and temperature as the mechanistic drivers for riparian habitat in the model. Jenni and Hyatt used mass balance equations to analyze instream water supply effects on fish habitat or fish populations at certain life-stages.

The presentations by Pess, Anlauf, Kennedy, and Whittier described statistical model approaches to data analysis that I typed *retrospective statistical*. Pess correlated coho and steelhead populations with habitat restoration effort, then used Monte Carlo techniques to simulate full restoration scenarios and studied the variability in the estimated effects. Anlauf regressed coho spawning data on habitat variables that were collected in a random design. Kennedy developed statistical algorithms to analyze land use trends based on Landsat data. Whittier used statistical clustering and principal component analysis to identify and map natural landscape features that are significant to salmonid populations in the Pacific Northwest.

Connolly designed life-cycle cohort model to analyze fish movement and fish production as a result of the removal of a passage barrier in a prescriptive mechanistic approach.

A-3. A Prospective Examination of Ecological Modeling for the RPAs

The process of choosing a modeling approach – the structure of the models including the forcing functions, the mechanisms operated on by the forcing functions, the range of initial conditions under consideration, the choice of parameters and a parsimonious but sufficient parameter space, and the experiments designed to test the models – requires both a thorough knowledge of modeling and a command of the subject matter of interest.

The holy grail of modeling is the deterministic model with parameters that are fixed in space and time. Such a model is called a law (Feyman 1965). Newton‟s first and second laws of motion explaining inertia and forces are used in all models of motion including fluid flow in freshwater environments. Practical applications of Newton‟s laws were made possible through the more parsimonious Langrangian equations for the momentum and energy of a moving mass (Lanczos 1970). The macroscopic heat and energy equations of thermodynamics are even more parsimonious because the mechanics of energy flow can be stated without reference to particle mechanics. Statistical mechanics can explain these macroscopic properties of energy flow at the microscopic level again without reference to particle mechanics (Landau and Lifshitz 1980). Thermodynamic law is so parsimonious that the famous physicist Arnold Sommerfield mused, "The first time I studied thermodynamics, I thought I understood it except for a few minor points. The second time, I thought that I did not understand it except for a few minor points. The third time, I knew I did not understand it, but it did not really matter, since I could still use it effectively," quoted from Gyftopoulos (2001) who cautions us about the use of a law without qualification or a complete understanding of the nature that it models.

Universal ecological laws that are spatially and temporally invariant would greatly enhance our ability to predict and manage the effects of human activities in the freshwater environment. Ecologists have made numerous attempts to formulate laws for ecological systems. Lotka‟s *Element's of Physical Biology* (Lotka 1925) and Schrodinger‟s *What is Life* (Schrodinger 1944) applied thermodynamic principles to biology. Lotka viewed life processes as a giant heat engine. Schrodinger used a negative entropy principle to explain the molecular structure of organisms. This systems concept of the world as a heat engine opened the door for H. T. Odum‟s concept of the world as an electrical energy network where energy flows through trophic levels that represent different energy states of the system. Odum (1960) proposed the use of the ratio production: respiration (P:R) as a measure of a system balance between energy input and output. Later he proposed a thermodynamic power optimality law replacing the earlier Lindeman concept of a thermodynamic flux efficiency optimality law.

Real and Levin (1991) summarized the theoretical advances in ecological modeling in a review of the classical works by Preston, May, Hutchinson, Schoener and MacArthur, and Pianka. Preston (1962) used a logarithmic scale of relative abundance to derive the species area relationship $S=cA^z$ where z~1/4 characterizes many species. Both the canonical properties of the Preston‟s log-normal distribution, as well as the S-shaped properties of the continuous logistic distribution, a well known mathematical distribution in population biology, can be derived from theCentral Limit Theorem allowing the normal distribution can be substituted with all its inherent statistical advantages (May 1975; Feller 1940). Real and Levin examined the history of the niche concept. The concept was generalized by Hutchinson (1957). Sugihara (1980) proposed a hypervolume niche interpretation of Preston‟s canonical distribution. In Hutchinson‟s model, the competitive exclusion principle (Gause 1934) is formulated as the disjoint set of niche N1 of species S1 and N2 of species S2. Cole (1954) models the tradeoffs between fecundity and survivorship at different life stages. May (1974) shows that density-dependence generates chaotic population swings if the assumed model is the discrete logistic equation. Schoener (1971) demonstrates that the MacArthur and Pianka (1966) model of foraging effects on rates of energy conversion as a proxy for fitness involves two strategies: (1) maximizing total energy acquisition per unit of time, as MacArthur and Pianka modeled, plus (2) minimizing the time spent acquiring a given amount of energy.

The search for universal ecological laws is not without its detractors[1]. Simberloff (1983) warned that physics envy is misguided, "…ecologists‟ proper goal should be not the approbation from physical scientists but a firm understanding of natural processes and answer many of the specific ecological questions of direct application that currently besiege us." The author however does conclude that the multiple causality factors inherent in ecological processes can be studied by "the framing of unambiguous hypotheses." Hypotheses of course are the basis for model building.

In his classic article, Levins (1966) argued that "It is of course desirable to work with manageable models which maximize generality, realism, and precision toward the overlapping but not identical goals of understanding, predicting and modifying nature. But this cannot be done." He suggested three alternative strategies: 1) sacrifice generality to realism and precision (Type I model); 2) sacrifice realism to generality and precision (Type II model); and 3) his preferred approach, sacrifice precision to realism and generality (Type III model). Levins concluded with an argument for developing robust theorems that "treat the same problem with several alternative models each with different simplifications but with a common biological assumption. Then, if these models, despite their different assumptions, lead to similar results we have what we call a robust theorem, which is relatively free of details of the model. Hence our truth is the intersection of independent lies"[2]. More recently, Orzack and Sober (1993) question the value of Levins‟ model trichotomy and the use of the term robust to describe models that appear to be laws.

[1] Perhaps the most ambitious statement of the idea is found in Bejan and Lorente's paper (2010) on design laws in nature.
[2] I think Levins meant different model simplifications, since he stated they had a common assumption. It is different model structures leading to the same conclusions for a given assumption that makes a robust model.

The authors argue that "the robustness of a theorem reflects the fact that the assumption is convenient, not that it is true."

An example of Levin"s Type III models is the idea of forest succession and the theory of forest climax which states the principle of unidirectional temporal community evolution (Clements 1936). Gleason (1926) popularized the concept of community diversity in his individualistic concept of plant associations. These two ideas coupled with the concepts of energy flux opened up a field of modeling laws for community structure and evolution, speciation and diversity, and population dynamics especially centered on the concepts of density-independent versus density-dependent population regulation. For years, the principles of forest succession and climax were accepted without any attempt to examine the accuracy or the precision of field data supporting the concept.

Unlike molecules or particles moving in a medium like air or water that can be treated as identical individual constituents, the variability of members of a biological population are sufficiently different and the total population often small, at least compared to some 6 x 1023 molecules in a mole of a gas, that generalizations about changes to a population through time in response to environmental variation are very difficult. Moreover the traits of the individuals and the environment are difficult to measure precisely, and experiments to determine population changes in response to environmental change are difficult to conduct (Getz 1998). Ecologists attempt to capture individual responses to the environment in population models in what has been termed physiologically structured population (PSP) models (Metz and Dickman, 1986); de Roos 1997). PSP models combine three state variables: an i-state representing the individual by a collection of physiological traits; a p-state model that represents the frequency distribution of all possible i-states; and an e-state model that characterizes the biotic and abiotic factors in which an individual lives. Thus PSP models are individually-based models, or actor-based models in the case of grouped individuals, combined with environmental and population models. Typically individuals are grouped by age and size (de Roos and Persson 2001).

In Appendix A.1 we discussed the concept of food web and food chain models. A crucial but daunting task for PSP models is to understanding how the flow of energy that is exchanged from primary producers up the food chain to a community of competitors and predators translates e-states and i-states into population structure. The classic paper by Yodzis and Innes (1992) initiated the modern synthesis of energy flow through a community of organisms and the dynamics of the populations representing the community. The authors accomplished the synthesis through the abstraction relating production, metabolic rate and maximum consumption rates to a species" body mass (Williams et al. 2007). These advances have led to modern attempts to apply scaling and power laws to individuals and populations in ecological systems in so-called macroecological approaches (see e.g. the review by Marquet et al. 2005). McGarvey and Johnston (2011) used scaling laws and pattern data from the McKensie River to predict regional fish abundance and regional carrying capacity for juvenile salmonids. White et al. (2007) summarized three distinct theoretical relationships between body size and population abundance.

1. Global Size-Density Relationship (GSDR) and Local Size-Density Relationship (LSDR)

   GSDR uses average body size of a species and its average population density. Related to Damuth‟s rule, the relation is characterized by a power law with an exponent of -3/4. It is usually applied at the continental or global scale. GSDR led to the energy equivalent rule that states that population energy use is approximately invariant with respect to mass, implying that resources are divided equally across species populations, regardless of body size. LSDR acknowledges that locally some species may not coexist at these abundances; moreover, the GSDR exponent often applies only to maximum population densities. LSDR often have smaller negative exponents, reflecting a smaller range of body sizes; aquatic studies appear to capture a more complete range of body sizes and therefore, may satisfy GSDR power law relationships.

2. Individual size distributions or size spectra (ISD)

   ISD is mostly used in aquatic studies. ISD is the frequency distribution of individual body sizes in a community, irrespective of species. Three major classes or patterns observed (1) monotonically decreasing, with smallest classes containing most individuals, characterized by power functions; (2) unimodal, where some intermediate size class contains the most individuals; and (3) multimodal, where the distribution is characterized by multiple peaks. Typically aquatic studies use distributions of body mass across size classes instead of abundance. Across trophic levels, abundance generally is related to body size (volume). Often ISD is modeled using predator prey size ratios, constraints on trophic efficiency, and allometric relationships for physiological processes. Several approaches to handling abundance distributions include (1) binning (linear, logarithmic, normalized logarithmic); (2) maximum likelihood fits to data; and (3) fitting cumulative distribution functions.

3. Cross community scaling relationships (CCSR)

   This is often called the self-thinning concept. The number of individuals in an assemblage is equal to the resource utilized by that assemblage divided by the average resource use per individual. Average resource use is usually estimated by a nonlinear function relating size and resource use, and therefore total abundance becomes a function of average mass. However, the average value of a function

> relating size and resource use is not the same as the value of that function for the average size individual. White argues that it is "… more appropriate to plot abundance as a function of average estimated resource use."

Allometric relationships combined with foraging theory provide the tools to represent the flow of energy through food webs. Holling (1959) represented foraging theory as a Type I model linear model (note: not the same as Levin‟s Type I), a Type II hyberbolic-shaped function, or a Type III sigmoid-shaped function. The choice of the function depends on the relative predator and prey density, and the attack rate of the predator. The complex structure of food webs makes the representation of energy flow in multi-species communities mathematically intractable. Nonetheless some simplifying assumptions (simplified trophic pathways, lumping species in trophic levels, etc.) have led to considerable progress toward an analytical representation of food web dynamics (Yodzis 1998; Cury et al. 2008). These simpler rules have been used to describe bottom-up and top-down control in food webs (Wollrab et al. 2012).

Since movement is a significant factor in the life-history of organism, and the metabolic energy demand of an individual or group of individuals on a resource is not only a function of the availability of the resource but also a function of the time spent by the consumer in presence of the resource, Fretwell and Lucas (1970) developed a distribution law for individuals of a species, "By considering concepts related to over-crowding and evolutionary optima, we will develop a theory to describe a particular way in which bird populations might distribute themselves over the available living places. This distribution will be called the ideal free distribution". Fretwell (1972) elaborated on the subject in *Populations in a Seasonal Environment* (1972). Subsequently, Sutherland (1983) elaborated on the concept, "If one assumes that predators always respond so as to maximize food intake per unit of time, it is possible to predict the distribution of predators taking into account the opposing effects of food density and interference; the result has been called the „ideal free‟ distribution. Thus, if one can predict prey density, then one can predict predator distribution." DeAngelis and Petersen (2001) developed models of juvenile salmonids moving through predator fields in Columbia River reservoirs to demonstrate the importance of ecological neighborhood when interpreting such concepts as ideal free distribution.

We chose a two step modeling approach for the Methow IMW. Step 1 represents the individual, environmental and population states in a full life-cycle dynamic modeling approach using the software Stella© The software supports mapping and modeling, simulation and analysis, and communication tools including text, graphs, tables and reports. The approach is described in Appendix B4.2.

As we develop and test the dynamic model, we will search for and select those simplifying relationships that allow for general analytical solutions to the dynamic equations. We will use this approach to test hypotheses and develop field study designs for studying the effects of habitat treatments on listed fish populations. Physiologically structured models, allometric scaling and ideal-free distribution will be core concepts for the analysis.

In a comparison of the production of salmonid populations in streams worldwide, Bisson and Bilby (1998) asked: Why are some streams more productive than others? The answer to this question provides valuable insight for the planning of habitat projects. The authors state:

"Most streams are relatively unproductive for salmonids; only a few demonstrate high levels of productivity. What makes these streams productive, while so many others are not? One hypothesis is that they possess superior physical habitat but a careful examination of descriptions of study sites reveals that many of the unproductive streams contain abundant pools and cover, two features often emphasized in assessment of salmonid habitat quality…Physical characteristics such as cold water, channel morphology, and coarse substrates, so often identified as key limiting factors in lotic environments, do not appear to be primarily responsible for regulating the productivity. This is not to discount habitat, rather to point out that other factors have a powerful influence on productivity.

"The most productive streams appear to contain abundant food…Although there are exceptions, production of salmonids is often more strongly influenced by high growth rates than by dense populations…Growth rates are a function of food availability, metabolic costs of obtaining and processing food, and density-dependent interactions including competition and predation…Population density is mediated by habitat quality but growth rates can be low when densities are relatively high, even in high-quality habitat…For stream-dwelling salmonids, these observations suggest that food availability may be one of the most important factors controlling production"

We think it is imperative to answer through modeling and carefully designed experiments associated with habitat treatments the question that Bilby and Bisson posed. In the process we will answer two questions central to habitat management programs: 1) What are the salmonid production benefits of a habitat project?; and 2) Why are some habitat projects more effective than others? In essence we focus our modeling on how habitat produces food and how food is used by listed salmonids to grow and survive. In the process we explore how the functions that the habitat program can repair (floodplain and channel complexity, riparian structure, instream flows, temperature, sediment) affect both the production of salmonid food and the direct survival of salmonids.

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APPENDIX B

The Methow IMW Analytical Design

B-1 The Intensively Monitored Watershed Concept

B-2 The Methow IMW Framework

B-3 The Methow IMW Partnership

B-4 The Methow IMW Model: Background and Design

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Appendix B

The Methow IMW Analytical Design

Appendix B1: The Intensively Monitored Watershed Concept

Intensively Monitored Watersheds (IMWs) are key elements of the programmatic monitoring approach developed by the Pacific Northwest Aquatic Monitoring Partnership (http://www.pnamp.org/), the Federal Columbia River Power System Biological Opinion (FCRPS BiOp) Action Agencies (Bonneville Power Administration [BPA] and U.S. Bureau of Reclamation [Reclamation]), and NOAA‟s Northwest Fisheries Science Center (NWFSC) to evaluate management questions at the landscape and fish population level. The basic premise of the IMW is that the complex relationships controlling a fish population response to habitat conditions can only be understood and quantified by concentrating monitoring and research efforts at an appropriate spatial and temporal scale.

Generally, the Action Agencies have defined the watershed scale, for the purpose of implementing an IMW in the Columbia River Basin, as the area occupied by one population of an evolutionary significant unit, or of a distinct population segment. To tease out the effects of watershed improvement projects on target populations, the IMW project is conducted over multiple years, at multiple spatial scales, in response to multiple habitat treatments of ample size to affect a measurable response at multiple life-stages of the populations. Additionally, population and habitat models are used to plan and analyze data collected in field research experiments and monitoring.

The IMW approach has broad scientific support in the Pacific Northwest Region. The Independent Science Review Panel (ISRP) and the Independent Science Advisory Board (ISAB) recommended the use of IMWs for large monitoring programs over wide geographic areas like the Columbia River Basin, with inclusion of probabilistic habitat and fish sampling. The ISRP and ISAB also have recommended mathematical modeling and food web analyses in an IMW framework.

Like the ISAB/ISRP, Oregon‟s Independent Multidisciplinary Science Team recommended standardization of monitoring terms and data metrics; basic research to fill information gaps; landscape assessment tools and other tools for aggregating data from IMWs; statisticians to develop sound experimental designs, and centralized data management. Similar recommendations for an IMW approach have come from the Washington Independent Science Panel and the Pacific Northwest Aquatic Monitoring Partnership (PNAMP).[1]

[1] See PN FCRPS RME Program, unpublished report, USBR, PN Region, Columbia-Snake River Operations Office

Appendix B2: The Methow IMW Framework

1. Guiding Principles and Design Philosophy

Management Questions are best answered through Experiments.

Experiment suggests Theory.

Theory guides Experiment.

The Methow IMW design is based on three guiding scientific principles. The first principle states that theory guides the development of both qualitative and quantitative models of how systems function. The models then guide experimental design, monitoring, and data identification. The second principle says that complex resource management questions usually require well-designed field experiments to promote learning. The third principle is that the systematic knowledge that is derived from well-designed experiments often suggests new theory and revisions to the models.

Reclamation began the process of developing its modeling approach with a thorough review of the current state of Columbia River salmon population modeling. More recently (February 2011), Reclamation hosted a modeling workshop in Portland, which brought together leading salmon modelers. Finally, Reclamation actively participates as a steering committee member of the PNAMP in the planning and development of regional monitoring programs, including the development of IMWs.

These activities led Reclamation to the following propositions:

Proposition 1

A model must be capable of exploring a continuum of past, present, and future population and environmental states, including the effects of climate change states, by taking into account the fundamentals of the relevant evolutionary environment at each of those states.

Corollary 1

Modeling must take into account the evolutionary environments that listed salmon and steelhead populations experienced up to the time of large scale exploitation of the populations and their environments in order to understand how to fix the processes that supported those populations. The FCRPS Action Agencies do not have a mandate to restore listed populations to historic levels under the Endangered Species Act (ESA) (Figure 1- note that the Northwest Power and Conservation Council did set an objective to restore these populations to 50 percent of the historic levels through its Fish and Wildlife Program). However, even to restore populations to the modest levels required by the FCRPS BiOp, the model must be able to compare hypothetically the relative effects of habitat actions on the population processes that formed the major part of the evolutionary history of the listed species.

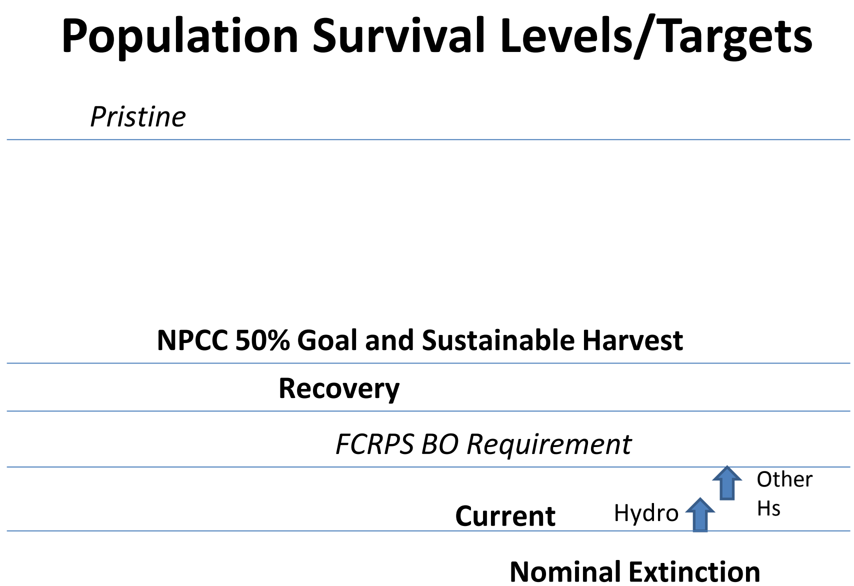

Figure 1. Some Population Survival Levels and Targets as Potential Modeling Scenarios

Corollary 2

A model that takes into account the fundamentals of the relevant evolutionary environment at each of those temporal states must be built on mechanistic first principles.

Proposition 2

The management and policy needs of funding and regulatory entities must be met by research, monitoring, and evaluation programs. Large perturbations of the current environment sufficient to understand and compare the effects of many habitat rehabilitation strategies generally occur over time scales that do not meet those needs in a timely manner. A model that can evaluate large perturbations of the environment and quickly generate and compare hypotheses is more likely to meet those management and policy needs.

Proposition 3

A model should be developed and validated independently. The Methow IMW aquatic production model has been developed and parameterized using an extensive survey of scientific literature and field studies. Regional salmon and steelhead experimental data obtained by rigorous sampling protocols is very limited. We intend to use existing and new regional data collected through protocols approved by the PNAMP (http://www.monitoringmethods.org/) as our validation datasets.

Proposition 4

Model development and validation must be adaptive. If a model is not validated by field data, an adaptive assessment of data and model integrity is completed. The assessment may warrant changes to the fundamental first principles of the model. This process is best described by the acronym MADMDA (see Figure 2) which stands for Model, Analysis (Data Synthesis and Evaluation), Design (Field and/or Laboratory Experiments), Monitor, Data process (Identification, Standardization, Retrieval), and Adaptive Management (Models and Habitat Projects). Each calendar year begins with a review of the field data from the past season, followed by a set of analyses based on the models leading to formal publications, a new research design, model refinement, and associated new or altered experiments with monitoring plans.

Corollary 1

Model development, validation, and deployment processes must be supported by a data management structure that meets management and policy needs. Data required for these processes must flow seamlessly from the field to the model. For this purpose, data harvester software is developed to ensure the seamless flow to the model and to reports that are needed by management and policymakers.

Corollary 2

The data management and modeling process are interactive. The data universe is largely determined by the inputs and outputs of the mechanistic models. However, the data harvest must anticipate, as possible, the data needs for the validation, adaptation, and use of the model.

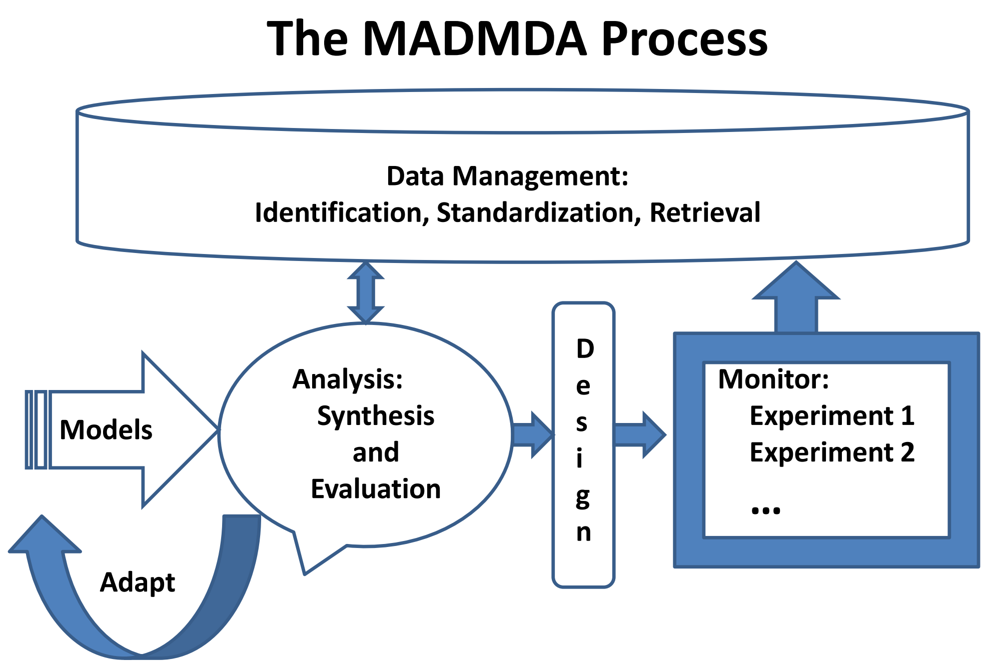

Figure 2. The Model, Analysis, Design, Monitor, Data and Adapt Process

Proposition 5

To the maximum extent possible, the development and validation of the model should be planned at the regional level such that there is a wide choice of validations datasets over a range of management perturbations. When this is not possible, the mechanistic relationships between fish populations and habitat processes determined through IMWs can be used with associative data in the non-IMW basins to predict population responses to habitat treatments. This is a two-step process of model verification and population predictions in non-IMW basins. This concept is illustrated in Figure 3 below.

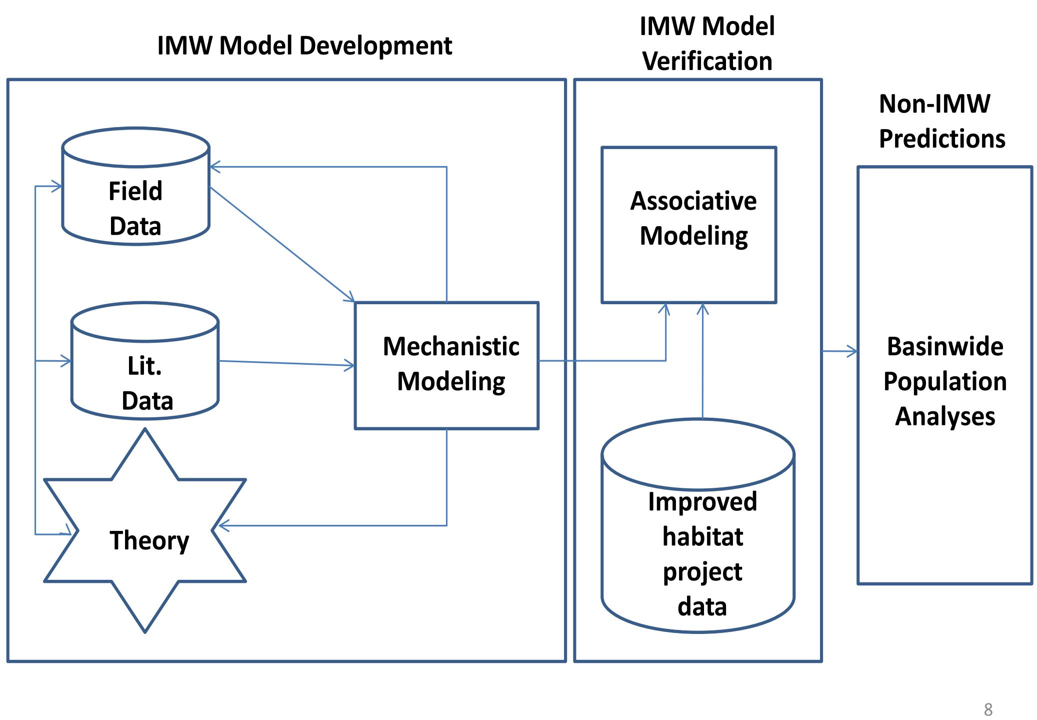

Figure 3. The IMW and non-IMW Basin Modeling Concept

2. Assessments through a Modeling Design Framework

Reclamation, USGS-CRRL, and U of I developed a Research, Monitoring, and Evaluation (RME) framework for the collaboration among the Methow monitoring entities (Figure 4). The Federal entities include Reclamation, BPA, the U.S. Fish and Wildlife Service (USFWS), and the NWFSC. Others include additional State and Tribal entities and non-governmental organizations. The annual schedule for the Methow IMW process is shown in Table 1 below.

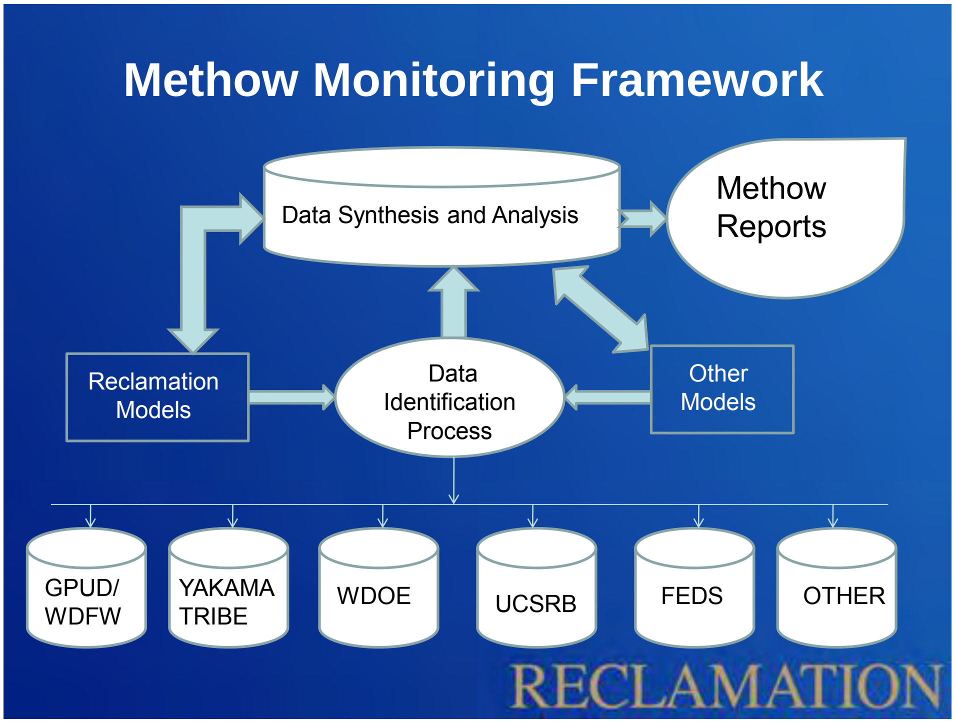

Figure 4. Methow IMW Monitoring Framework

Table 1. The Methow IMW Annual Schedule

		RME Annual Schedule				
	Jan-Feb	March	April-November	May	December	
Model and Data Evaluation	X					
Data Exploration	X					
Model Refinement	X					
RME Partners Review	X					
Submit Papers for Publication		X				
New Formal Model Evaluations		X				
Develop Adaptive RME Field Plan		X				
Write Evaluation Report		X				
Field Season			X			
Data Upload and Synthesis			X			
Write APR				X		
Write Field Reports					X	

Appendix B3: The Methow IMW Partnership

The Methow River IMW watershed is home to two ESA-listed populations of anadromous fish: endangered Upper Columbia River spring Chinook and threatened Upper Columbia River steelhead. The population of the Methow watershed is further divided into subpopulations in five distinct regions: the Upper Methow River above Winthrop, the Chewuch River at Winthrop, the middle Methow River between Winthrop and Twisp, the Twisp River, and the Lower Methow River below Twisp including three significant tributaries (Beaver Creek, Libby Creek, and Gold Creek).

The IMW partnership is a collaborative monitoring effort among the Upper Columbia River Salmon Recovery Board, the Washington Department of Fish and Wildlife (WDFW), the Douglas County Public Utility District (DCPUD), the Yakama Nation (YN), the USFWS, the NWFSC, and the U.S. Forest Service (USFS), through RME agreements with the U.S. Geological Service - Columbia River Research Laboratory (USGS-CRRL) and the Cooperative Ecosystem Study Unit – University of Idaho Fish and Wildlife, College of Natural Resources (U of I).

Reclamation personnel organize regular coordination meetings with its Methow monitoring partners, and through its agreements directs and funds data management and modeling services, and conducts reach-scale monitoring activities associated with Reclamation‟s habitat and hatchery funded programs. The WDFW, through funding from DCPUD, is collecting fish population data to assess improvements in State hatchery projects, including a relative reproductive success study of hatchery and wild steelhead in the Twisp River; the USFWS is working with the NWFSC, Reclamation, and USGS-CRRL to collect data on hatchery improvements at the Reclamation-funded Winthrop hatchery; the YN, through BPA funding, is collecting data on nutrient supplementation projects and coho reintroduction projects; Reclamation‟s Technical Service Center (TSC) received three years of funding to model Methow River physical processes such as flow and temperature with respect to climate change effects; the Washington Department of Ecology funded The Wild Fish Conservancy to conduct a long-term water quality study, including an intensive network of temperature data loggers; and the USGS is collecting social, physical, and biological data to evaluate a decision analysis model for natural resource decisions in the Methow River using down-scaled climate data.

The full extent of Methow monitoring programs has been documented in the Methow Subbasin Monitoring Inventory, prepared by John Crandall, Wild Fish Conservancy, for the Methow Restoration Council, published in Reclamation‟s Reach Based Indicators, Appendix B, Monitoring Inventory, 2009.

Appendix B4: The Methow IMW Model: Background and Design

1. Background

Regional planning efforts have identified lack of data priorities, insufficient data standards, and poor data integration as major impediments to management of federally-mandated programs for fish recovery. Data management, capture, and analysis intersect in the identification, collection, synthesis, storage, and transmission of data for stated data management purposes. Unfortunately, data management is usually not done at all and analysis is generally done ad hoc using inductive reasoning. Rarely are management, capture, and analysis done together as expected using a deductive or hypothesis-directed approach. We will use modeling to develop a deductive framework to guide data collection.

Reclamation funds modeling, data analysis, data management, and field work through Interagency Agreements (IAs) with the USGS-CRRL and a contract with the University of Idaho (U of I). These arrangements are used to plan data management, data capture, and data analysis activities together in a deductive approach through a demonstration, or proof of concept project such that the RPA requirements are met for tributary habitat and hatchery project implementation. The work will address program coordination needs at Reclamation as well as regional coordination priorities in the context of an IMW.

Reclamation initiated the Methow IMW to meet its requirements under RPA 56, 57, and 65. The Methow River basin offers a unique opportunity to evaluate fish life history and population models because of an extensive, long-term data collection effort by numerous agencies to assess fish habitat, hatchery practices, and climate change. Reclamation funds the USGS to conduct a long-term study of the fish response to Reclamation-funded habitat and hatchery improvement projects. The USGS data includes water temperature and flow, measures of lateral and longitudinal connectivity of habitat (e.g., side channels, springs), fish distribution and abundance, and stream productivity (nutrients, macroinvertebrate, and fish production). As part of this effort, the major species of fish have been PIT-tagged in order to track movements, estimate survival, and assess growth. Paired with this large PIT-tagging effort of wild fish (over 5,000 per year) was the establishment of an extensive network of fixed PIT-tag interrogation systems including a site in the lower Methow River, near its confluence with the Columbia River.

Other projects in the Methow River basin are collecting data that will facilitate Reclamation‟s ability to develop and evaluate models. The WDFW, through funding from DCPUD, is collecting fish population data to assess improvements in State hatchery projects, including a relative reproductive success study of hatchery and wild steelhead in the Twisp River; the USFWS is working with the NWFSC, Reclamation, and USGS to collect data on hatchery improvements at the Reclamation-funded Winthrop hatchery; the

YN, through BPA funding, is collecting data on nutrient supplementation projects and coho reintroduction projects; Reclamation‟s TSC received three years of funding to model Methow River physical processes such as flow and temperature with respect to climate change effects; the Washington Department of Ecology funded The Wild Fish Conservancy to conduct a long-term water quality study, including an intensive network of temperature data loggers; and the USGS is collecting social, physical, and biological data to evaluate a decision analysis model for natural resource decisions in the Methow River using down-scaled climate data.

The models under this IA will be broad conceptual models as well as detailed causal or inferential fish life-cycle models. The Reclamation-funded model development will link an aquatic production model, a fish bioenergetic model, and an ansdromous fish full life-cycle model to predict the effects of habitat and hatchery projects on natural fish production. The full range of models will be developed in manner to be transportable to other hydrological and ecological settings.

Four habitat treatment projects are being designed to improve fish production. The first project is the Twisp River nutrient treatment project. Naturally spawning historic populations provided crucial sources of marine-derived carbon, nitrogen, and phosphorus to otherwise highly nutrient poor (oligotrophic) Pacific Northwest streams. Reclamation is teaming with the YN nutrient supplementation study by providing planning and bioenergetic modeling capability to evaluate how this lost nutrient source contributed to historic production, and how to amend this lost ecological function through natural and artificial nutrient treatments.

The second treatment is a channel connectivity and channel complexity treatment in the middle Methow River. Reclamation funded a fluvial geomorphic study of the middle Methow River including the development and calibration of a two-dimensional (2D) hydraulic model by Reclamation‟s TSC. Reclamation also funded a fish food web and fish production pre-treatment study. All the models are being used with the pre-treatment data to understand how habitat and fish production are linked in the pre-treatment environment. The models will then be used to predict the fish production response to treatments. Post-treatment data will be used to evaluate the model performance. The biological models will be linked to the 2D hydraulic model and a USGS‟ decision analysis model to assess the potential effects of climate change on fish production.

The third habitat treatment, funded and carried out by YN, occurred at Hancock Springs. It is a small channel complexity before and after control and treatment design. Extensive physical and chemical pre-treatment data has been collected with some data on fish production that demonstrates very high fish production in the treated portion. Brook predation on listed salmonids appears to be significant. Reclamation and USGS-CRRL are working with the YN to install PIT-tag detectors and develop a survival analysis. The conceptual models will be used to predict fish production; the conceptual models will be tested using field data. If survival data confirm that brook trout predation is significant, a brook trout removal experiment will be done and further model validation completed.

Reclamation and USGS-CRRL have studied *O. mykiss* survival, production, and genetics in a five-year passage barrier removal experiment in Beaver Creek. The fourth planned treatment is a large channel complexity project in middle Beaver Creek. The treatment is in the early planning stage. As the planning proceeds toward a 2015 treatment, Reclamation and USGS-CRRL will develop a field monitoring design and model analysis for the treatment.

2. Model Design

The Methow River IMW is designed to analyze two major factors that affect the carrying capacity of the environment: 1) trophic transfers of energy in a food web in response to treatments, including the role that spawning salmon and steelhead play in subsidizing the freshwater food supply, and 2) how floodplain and channel complexity treatments, including the addition of LWD, affect salmon and steelhead juvenile production. An Aquatic Trophic Production (ATP) model will be calibrated and tested for each of the treatments. The ATP model will be connected to a full-life cycle model.

Reclamation funded the development of an aquatic trophic production (ATP) model for the Methow IMW. The model calculates energy transfers from primary and secondary production to stage-specific fish survival and production model. The model has been parameterized from literature values and from a recently completed Methow River trophic productivity study. The model will be used to predict fish production at several planned treatment sites. The monitoring partners are developing study designs for the treatment sites that will provide input data to the model. CHaMP surveys will be conducted at the treatment sites. Additional key model data inputs will be collected by ChaMP and other Methow monitoring partners. The model is approximately 50 percent complete at this date, August 2012. After a model assessment and recalibration period, the intent is to use CHaMP data and other project-level action effectiveness data to scale up production to the watershed level. A database project will manage the model data and generate reports. The aquatic productivity model will be connected to a full life-cycle model to predict population changes through time.

We use the system dynamics software Stella© to code the complex mechanistic interactions among habitat and fish populations in a full life-cycle model. Stella© is system dynamics modeling software http://www.iseesystems.com/ that supports mapping and modeling, simulation and analysis, and communication tools including text, graphs, tables and reports. The software is flexible and easy to learn. It supports full internal documentation in the stock and flow representations of the dynamical processes.

We will use the Stella© models to generate and compare hypotheses. We will then use field experiments to validate the models. The models are regenerated or reformed using the results from the validation process. We are developing the life-cycle mechanistic modules based on existing experimental data and theoretical concepts about habitat and fish population processes.

The mechanisms in the model will be driven by separate „actor" or treatment modules for each of the main Methow River habitat treatments (Figure 5 below). We will have actor modules for nutrient supplementation (carcass additions, analog carcass and egg additions, and dissolved nutrients); habitat restoration (riparian plantings, floodplain restorations, and large wood additions); hatchery supplementation; and species introductions/removals. Each actor module will connect to the life-cycle model at the mechanistic points that are affected by the treatment type. Actor modules will be run independently or simultaneously to reflect combinations of treatments.

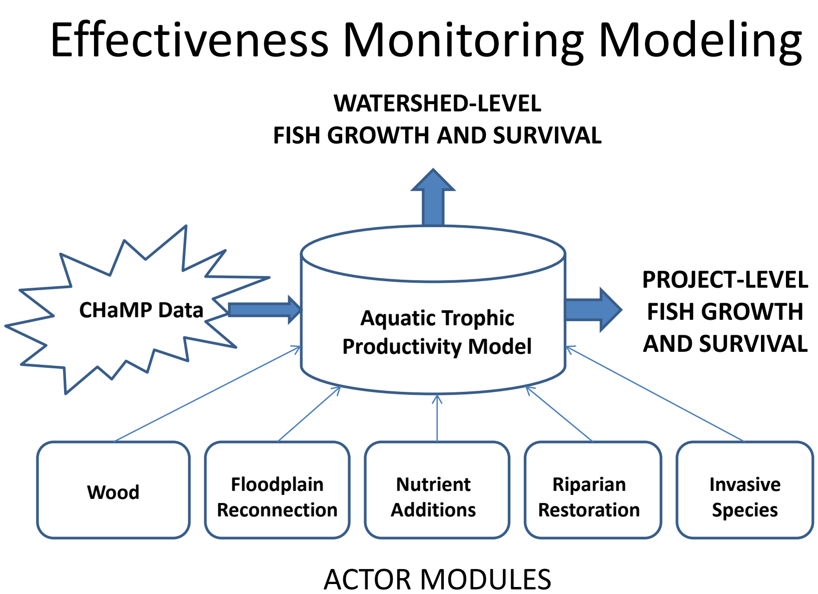

Figure 5. The model structure consists of actor modules (projects) connected to parameters of an aquatic trophic productivity model that distributes energy to a fish food web.

The system dynamics mechanistic model computes the effects of habitat projects on life-stage specific energy transfers in a fish community mediated by community relationships and habitat predictors. The model allows us to study the effects of salmon and steelhead on their environment as well the effects of the environment on their populations. The basic model environment is shown in Figure 6. The ATP model has been parameterized using values obtained from the literature and from Reclamation and USGS studies in the Middle Methow River. The model will be tested through a set of controlled habitat treatment experiments that perturb the energy flows in the environment. The productivity model is general enough to assess other treatment types in a variety of freshwater environments.

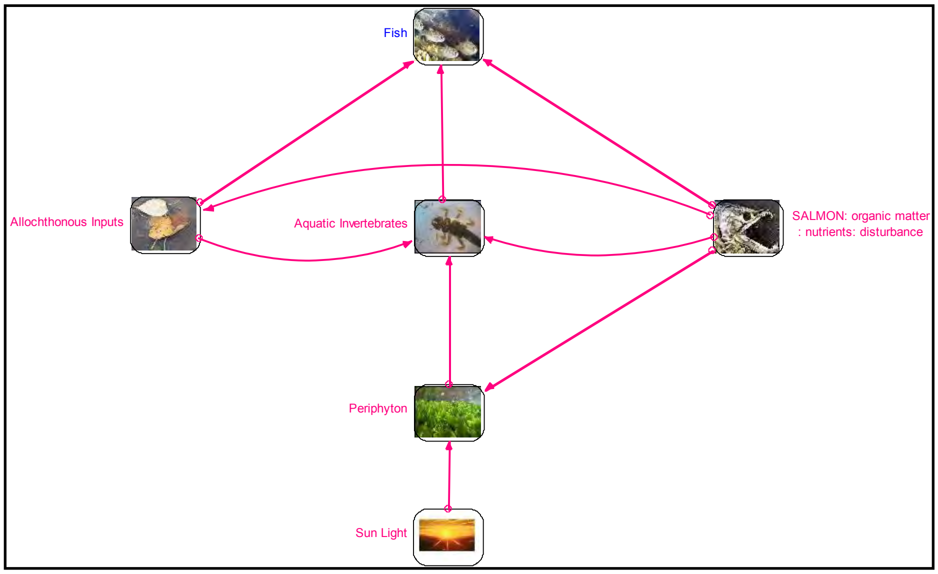

Figure 6. Aquatic food chain diagram, illustrating the direct and indirect pathways of organic matter flow that fuel fish production in the proposed Trophic Productivity Model.

The next steps are:

1. Validate the Model using field data from the Methow. Locations where appropriate multi-trophic level data have been collected, such as Hancock Springs and the Twisp River will be key locations for model parameterization.

2. Test alternative mitigation and restoration scenarios. Once the model is parameterized and validated, it will be utilized to test alternative mitigation scenarios, such as habitat restoration (e.g., large wood additions and channel reconnections), nutrient additions, and hatchery supplementation.

3. Make a spatially explicit landscape model. This will require developing and parameterizing models in adjacent river segments, and connecting these models via the transport and movement of nutrients, organic matter and organisms. This step will be crucial step in evaluating the impact of fish movement on landscape level food web dynamics. A full life-cycle model is being developed for the Methow IMW (Figure 7). For life stages outside of the Methow River, we will rely on empirical survival estimates that are being used for a Columbia River life-cycle model which is under development and managed through a separate process.

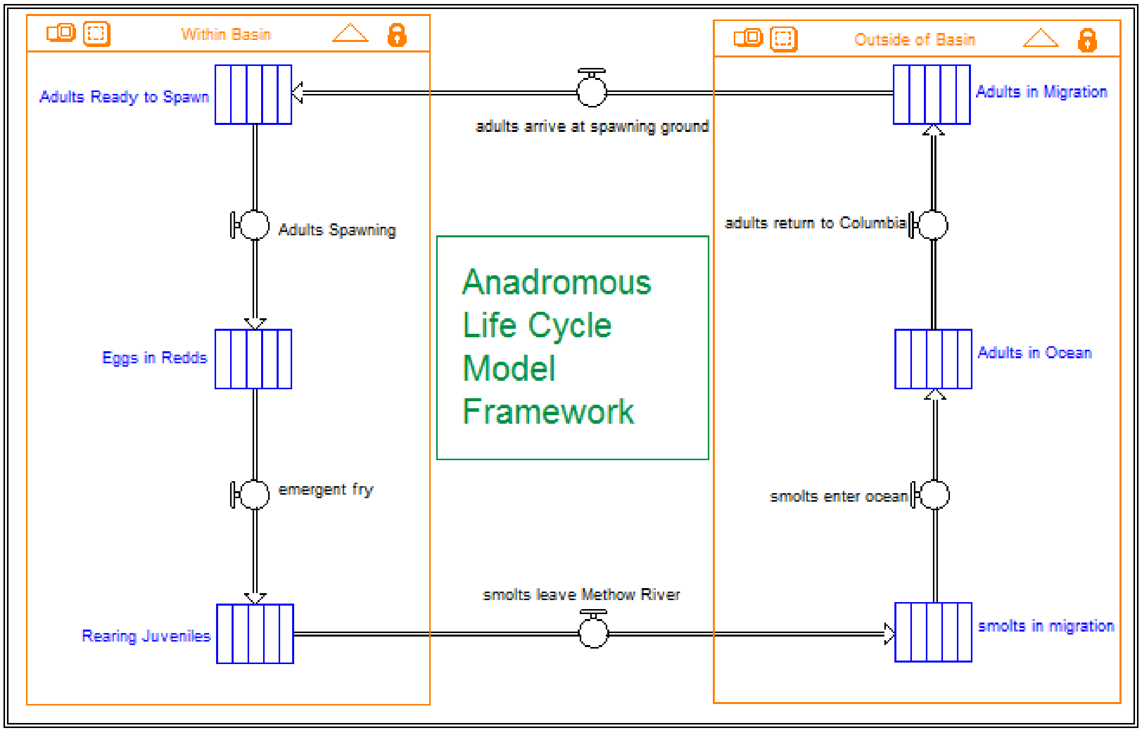

Figure 7. A basic salmon and steelhead life cycle, which illustrates the major life-stages and transitions. Redd boxes within figure separate within basin life-stages (spawner to rearing juveniles) from outside of basin life-stages (smolt to migrating adults).

Within the Methow, spawning success, egg survival, and juvenile growth and survival will be modeled using a series of linked modules (Figure 8). The current model design calls for five different modules, including: (1) a *Spawning Distribution Module*, (2) a *Trophic Productivity Module*, (3) a *Bioenergetics Module*, (4) a *Cohort Survival and Growth Module*, and (5) a *Life History Expression and Movement Module*. Although some modules will be designed to run independently, and alone, may reveal important characteristics and dynamics, the ultimate goal will be to create a comprehensive model, which links these modules.

The five modules and the linkages between them are briefly described here (see individual sections on each module below, for more details). The *Spawning Distribution Module* will predict the location and density of salmon and steelhead spawning within different segments of the Methow River, based on stream geomorphic and hydrologic condition. The *Trophic Productivity Model* will determine how much in-stream food production, including marine derived nutrients and organic matter, is available to fuel the production of fish, once they emerge from the gravel and begin feeding. The Bioenergetics model, will utilize a standard fish bioenergetic approach (Hansen 1997) to provide the critical connection between food availability, and fish growth and metabolism. The *Cohort Survival and Growth Module*, will synchronously calculate and track the survival and growth of co-existing cohorts of salmon and steelhead. Finally, the *Life History*

Expression and Movement Model will interact with the *Cohort Survival and Growth Module* to simulating juvenile salmon and steelhead life history decisions and movement choices, based on modeled fish growth and survival.

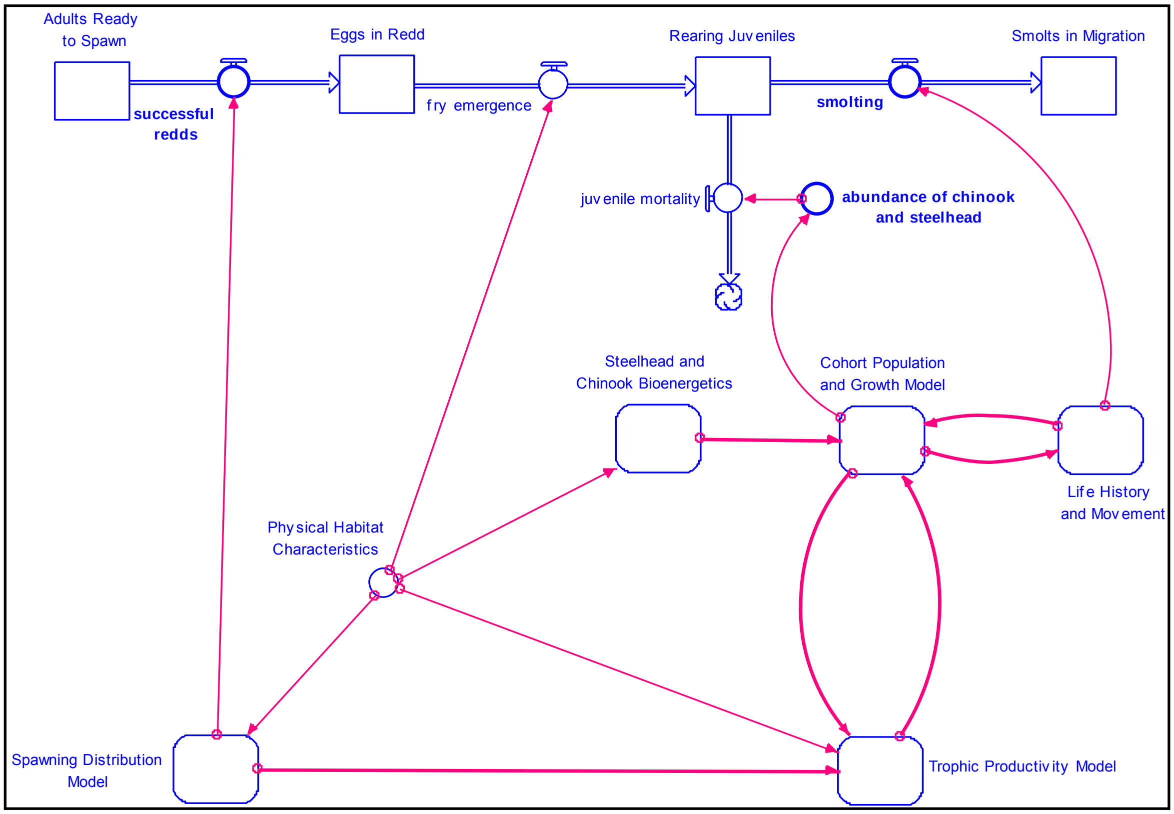

Figure 8. A conceptual representation of the linkages between different modules and associated freshwater life-stages.

Spawning Distribution Module

The goal of the spawning distribution module is to predict the number of redds within any given stream segment, based on stream geomorphic and hydrologic conditions, such as channel slope, substrate size, and water temperature. Although spawning surveys in the Methow provide an accurate picture of the spatial patterns in fish spawning under current conditions, as fish population grow, the spatial extent of fish spawning will is also likely to grow. Understanding where and how many fish are likely to spawn in a given stream segment will be very important for determining: (1) how many eggs are successfully deposited in the gravel, (2) how many redds and associated eggs are lost due to superimposition of redds, and (3) how much marine derived nutrients, carcasses and eggs are incorporated into stream and riparian food webs. The details of this model are still under development.

Trophic Productivity Model

The Trophic Productivity Module (TPM) outlined here utilizes a trophic food-chain approach (*sensu* Power et al. 1995), whereby fish production is explicitly tied to transfers of organic matter between different components of a simplified river food web (**Error! Reference source not found.**). In this framework, fish production is directly fueled by consumption of: (1) aquatic invertebrates, (2) terrestrial invertebrates (allochthonous inputs), and (3) salmon carcass and egg material. In-directly, the availability of food resources is a function of stream periphyton production (i.e., autochthonous production) and inputs of allochthonous organic matter (i.e., leaf litter).

The transfer and production of organic matter within and among different components of the food web is be mediated by both in-stream physical habitat conditions (i.e., water temperature, background nutrient load, substrate, large woody debris etc.), and the structure and composition of the adjacent riparian community (Figure 9). The model will be constructed to run on a daily time step and to simulate conditions on a per-meter-square basis.

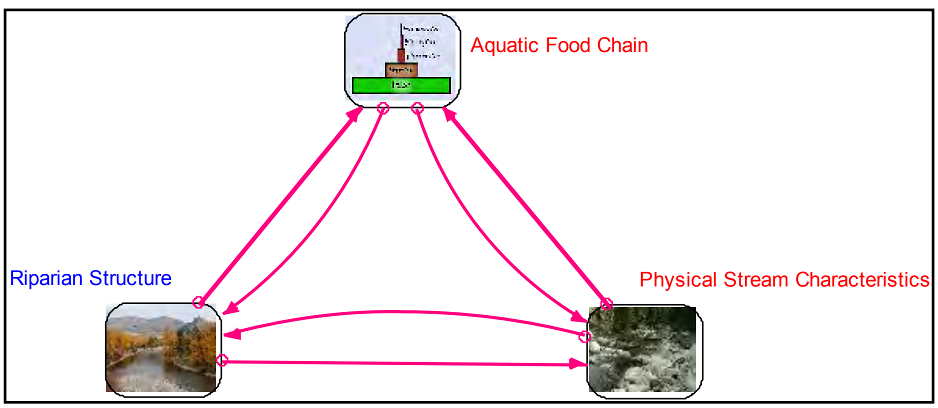

Figure 9. The aquatic food-chain portion of the model is linked with both stream physical habitat characteristics, and the structure and composition of the adjacent riparian habitat. Although not explicitly incorporated in the model, riparian structure and stream conditions are linked via inputs of channel forming woody debris and scouring over-bank flows.

Embedded within the module will be a series of sub-modules, which include: a benthic light module, a periphyton module, an allochthonous inputs module, and a salmon spawner and nutrients module, each of which are outlined in further detail below.

Benthic Light Sub-Module (BLAM)

Light is the energy that drives all in-stream primary production. Consequently, differences in light availability can strongly control how much production occurs in aquatic systems. The main goal of the BLAM sub-model (Julian et al 2008a and 2008b) is to estimate the amount of light available at a particular reach in the river. BLAM calculates the amount of photosynthetically active radiation (PAR) at the riverbed (Ebed) and incorporates terrestrial (shading) and aquatic controls (water depth and turbidity) on benthic light availability. The equation for this model is:

Ebed=(Ecan*S*R)e-Kd*Y

where Ecan is the above canopy PAR, S is the sum of all shading coefficients, R is the reflection coefficient, Kd is the diffuse attenuation coefficient for underwater PAR and Y is water depth. S includes shading from topography (e.g. canyons) and canopy cover. Parameters for the model will be obtained through remote sensing data (e.g. shading coefficients), already available data from Washington State University weather station (Ecan), USGS (discharge) or other agencies (turbidity) or will be measured in the field.

Periphyton Sub-Module

In montane gravel bed rivers, most in-stream autochthonous production occurs at the bed of the stream, in the form of attached algae, or periphyton. The periphyton sub-module will simulate the biomass of periphyton. In Stella, periphyton biomass will be modeled using a single stock (periphyton biomass). The addition of new periphyton biomass to the stock (i.e., net primary production) will be a function of the amount of PAR reaching the stream bed (output from the Benthic Light Sub-Module), water temperature, nutrient concentration, water velocity, and competition for light and nutrients. For a given time step, the removal of periphyton biomass will be the summation of four outflows: (1) respiration of periphyton, (2) detachment of periphyton, (3) detachment via bed mobilization, and (4) consumption by aquatic invertebrates. Respiration of periphyton will be a function of water temperature; periphyton detachment will be a function of shear stress on the bed; periphyton loss via bed scour will be a function of bed shear stress and critical bed shear stress (i.e., substrate size); and periphyton consumption by aquatic invertebrates will be a function of aquatic invertebrate biomass.

Allochthonous Inputs Sub-Module

Lotic systems receive subsidies from surrounding habitats. These allochthonous inputs can be important energy sources, fueling production at higher trophic levels in stream ecosystems. The main goal of this sub-module is to estimate the amount of leaf litter and terrestrial invertebrates contributed to stream from lateral riparian habitats. The allochthonous sub-module calculates contributions from areas covered by coniferous trees and deciduous trees as well as open areas. For the contributions of organic matter from riparian vegetation, the model incorporates two types of input: direct input into the stream which is likely to occur mostly in the autumn for deciduous trees and year-round for coniferous trees. Lateral inputs are assumed to occur during bankfull discharge events when the floodplain gets inundated (Naetrour et al 2004). Insect contributions incorporate the effects of air temperature on winged insect biomass by using water temperature as a proxy for air temperature (Edwards and Huryn 1995). Parameters for the model will be obtained through remote sensing data, already available data from USGS or other agencies or will be measured in the field.

Marine Derived Nutrients and Organic Matter Sub-Module

In many salmon spawning and rearing streams, nutrients and organic matter from salmon spawners are hypothesized to be an important subsidy to aquatic food webs (Gende et al. 2002). In our simplified food web, salmon “nutrients” contribute to periphyton growth, “carcasses” contribute to invertebrate and fish production, and “eggs” contribute directly to fish production. The Marine Derived Nutrients and Organic Matter Sub-Module will estimate the quantity of nutrients (nitrogen and phosphorus), salmon carcass material, and eggs that are available to be utilized by different components of the aquatic food chain. Nutrients delivered from spawners will be calculated using per biomass values of nutrient leaching from both live and dead salmon; the amount of salmon carcass material will be calculated based on average spawner size; and the availability of eggs will be estimated based on the occurrence and magnitude of redd superimposition. We assume that once a redd is superimposed by another spawner, the first redd"s eggs are lost, and are immediately available for consumption by fish. In addition to salmon carcass material being consumed by invertebrates and fish, salmon carcass material will also be lost to microbial respiration, at a rate set by stream temperature.

Bioenergetics Model

In conjunction with the overall model development, we have taken the Wisconsin bioenergetics model (Hanson et al. 1997) and placed it into the Stella modeling environment. This model provides a critical connection between food production and fish growth within the overall simulation process. The model is currently parameterized for juvenile steelhead (Oncorhynchus mykiss) using parameters developed by Railsback and Rose (1999) and follows the recommended equation sets (Hanson et al. 1997). The only data requirement is a water temperature profile which is easily linked to the user selected water temperature profile. The model allows the user to select a starting body weight, daily ration or percent of maximum consumption (P), and diet. Starting weight is set using a dial that ranges from 0 to 10 grams. Daily percentage of maximum consumption or P is set using a slider control that ranges from 0 to 1. Current literature suggests values in the range of 0.31 to 0.35, but P may be set to anywhere between 0 and 1. Currently diet is selected using slider bars. Diet will be determined by the production model once linked and the user defined diet will be removed. Once parameters are selected, fish growth is then simulated based on the input parameters and water temperature profile. The model has been corroborated with the Wisconsin model software Fish Bioenergetics 3.0 and is ready for use in the larger modeling framework. A juvenile Chinook model will also be developed for use by altering parameterizations.

Cohort Survival and Growth Module

The Cohort Survival and Growth Module will simply provide a framework for tracking different juvenile Chinook salmon and steelhead cohorts or age-classes. In particular, this Module will track the average growth of an individual fish in each cohort, and also how many fish are lost to predation or starvation. The growth and survival information from the Module, provides the basis for modeling fish movement and life history decisions (i.e., smotification, maturation).

Fish Movement and Life History Module

This module will represent a list of rules and distributions that determine the movement and life-history choices of juvenile Chinook salmon and steelhead. This module will interact with the Cohort Survival and Growth Module to determine when and what proportion of fish will either move, smolt, or sexually mature in freshwater, based on a cohort"s survival and growth experience. For example, if freshwater conditions are good (i.e., growth is high and survival is low), then only a small proportion of the population might move. Likewise, if freshwater conditions are extremely good, some proportion of fish may forgo smoltification and mature in freshwater (see Satterthwaite et al. 2009).

Next Steps

Once model development is complete, the next step will be to:

1. Parameterize the model for different river key locations within the Methow, such as the M2 segment, Beaver Creek, main-stem Twisp River, and Hancock Springs.

2. Validate the Model using field data from the Methow. Locations where appropriate multi-trophic level data have been collected, such as Hancock Springs and the Twisp River will be key locations for model parameterization

3. Test alternative mitigation and restoration scenarios. Once the model is parameterized and validated, it will be utilized to test alternative mitigation scenarios, such as habitat restoration (e.g., large wood additions and channel reconnections), nutrient additions, and hatchery supplementation.

4. Make a spatially explicit landscape model. This will require developing and parameterizing models in adjacent river segments, and connecting these models via the transport and movement of nutrients, organic matter and organisms. This step will be crucial step in evaluating the impact of fish movement on landscape level food web dynamics.

The Characterization of the Physical Habitat

CHaMP habitat surveys will be completed to provide habitat and fish data for use in the ATP model. The Methow IMW habitat treatments, the individualized CHaMP survey sites in the treatment areas, and the 40 plus CHaMP status and trend sites are linked to together as shown in the following conceptual schematic to expand reach scale production to watershed scale production (see Figure 10).

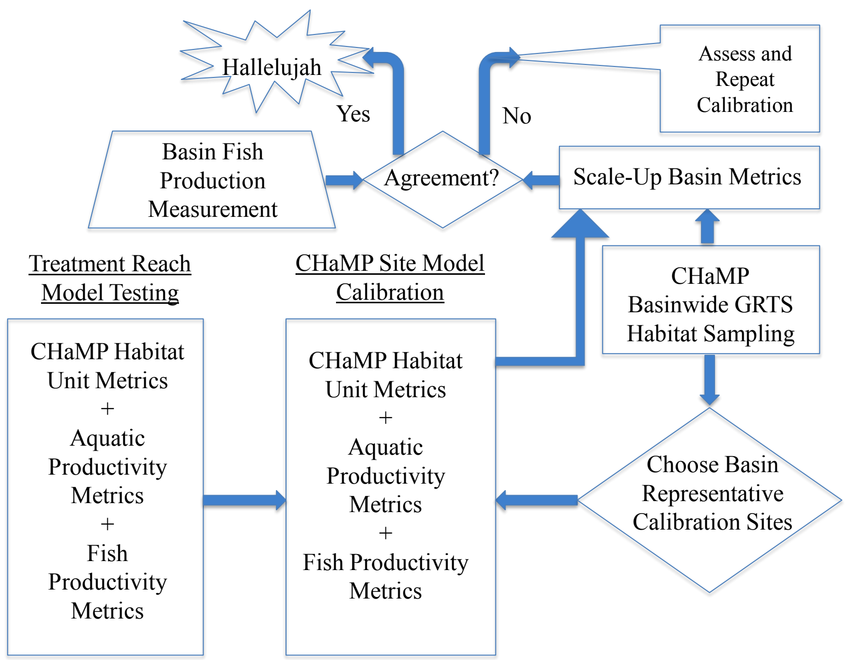

Figure 10. Use of CHaMP data to scale up juvenile production from treatment reach scales to the watershed scale

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APPENDIX C

Beaver Creek Studies

* Funded in part or in whole by Reclamation to help meet the FCRPS BiOp RME Strategies

C-1 Beaver Creek Passage Improvement Study

C-2 Effectiveness of Actions in Beaver Creek

C-3 Effectiveness of a Redesigned Water Diversion Using Rock Vortex Weirs to Enhance Longitudinal Connectivity for Small Salmonids

C-4 Lower Methow Tributaries Intensive Effectiveness Monitoring Study – Interim Report

C-5 An Evaluation of Fish Passage at Rock Vortex Weirs

C-6 Hydraulic Modeling and upstream fish passage effectiveness evaluation at rock vortex weirs based on field observations

C-7 Genetic Variation in Oncorhynchus mykiss in Tributaries to the Lower Methow Basin

C-8 Colonization of Steelhead (*Oncorhynchus mykiss*) in a Natal Stream After Barrier Removal

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Beaver Creek Passage Improvement Study[1]

Twisp, WA August 2012

Introduction

Many streams in the Pacific Northwest have had structures constructed on them to divert water for irrigation. These diversion structures may constitute complete or partial barriers to upstream migration of anadromous salmonids. Reduced access to historic spawning and rearing habitat has had an adverse impact on some salmonid populations. Beaver Creek, a tributary of the lower Methow River in north-central Washington that drains into the Methow River near Twisp, Washington, at rkm 57, has an area of 179 km^2 with numerous small tributaries. It was occupied historically by anadromous salmonids, particularly steelhead *Oncorhynchus mykiss* and perhaps Chinook salmon *O. tshawytscha* and coho salmon *O. kisutch*. The listed bull trout *Salvelinus confluentus* also occupied the stream. Some other resident salmonids such as resident *O. mykiss*, cutthroat trout *O. clarki* and the introduced brook trout *S. fontinalis* are also present. This report focuses primarily on anadromous *O. mykiss*.

Among anadromous salmonids *O. mykiss* have a complex life history. They are iteroparous (do not necessarily die after spawning and can spawn more than once); the juveniles have variable growth rates and life spans in freshwater rearing areas, dependant in part on water temperature and food availability, with outmigration ranging from one to four or more years; they spend a variable time rearing in the ocean before returning to freshwater spawning tributaries, resulting in various combinations of freshwater and ocean residency. *O. mykiss* also exhibit several life history polymorphisms, including resident and fluvial forms. Resident *O. mykiss* were abundant upstream from the diversion dams.

Water for irrigation has been diverted from Beaver Creek for over 100 years by barriers and diversions mostly impassable to migratory fish. This time span represents many generations of steelhead and other anadromous salmonids. The ESA-listed species are the target for habitat restoration. Improving access to suitable habitat and the quality of instream habitat are RPA action items in the 2008 NOAA Fisheries Biological Opinion on the Federal Columbia River Power System. Removing migration barriers or otherwise improving passage can provide access to previously blocked habitat, re-establish native fish populations, increase marine-derived nutrients to the aquatic and terrestrial ecosystem, improve spawning and rearing habitat and re-establish connectivity of disjunct fish populations (Martens and Connolly 2008). On the other hand, barrier removal or replacement could also allow introduction of non-native species, introduce disease by incoming fish, increase negative interactions among fish species, increase hybridization rates, and allow colonization by less successful stocks of fish. Besides diversion structures, some other activities in the watershed contributed to degraded salmonid habitat, such as sedimentation from roads, stream channelization, livestock grazing, timber harvest, large wildland fires, and landslides.

1 Steve Grabowski wrote this summary report. The intent was to summarize findings from the body of work on Beaver Creek funded by Reclamation. This paper is meant for a general audience. The individual science papers follow this report.

Beaver Creek Passage Improvement Study

The Beaver Creek Passage Improvement Study was an interagency and landowner effort initially undertaken beginning in 2002 to replace or modify four barriers to migration (push-up dams or small concrete dams to divert water for irrigation) and replace them with a series of rock vortex weirs (RVWs) that were expected to provide passage for adult and juvenile anadromous salmonids, particularly *O. mykiss*, while maintaining the ability to divert water for irrigation. Some other projects such as culvert removal and pump and headgate replacement were also implemented; some additional diversion replacement and water acquisition actions also occurred. A major objective of passage improvements on Beaver Creek was to reopen and reconnect historically utilized habitat for anadromous salmonids and assess recolonization of Beaver Creek by anadromous salmonids. Some seasonal passage based on seasonal stream flows might have been possible prior to replacement of barriers. Another objective was to evaluate upstream passage of smaller juvenile fish. Some novel aspects of the study included coupling new PIT-tag interrogation technology with genetic markers wherein PIT tags indicate movement of fish in the basin while genetics provides information about the reproductive contribution of individuals and the establishment of successful spawning. Table 1 lists the diversions, location in the stream, type of action taken and the date of completion. Figure 1 shows the location of the diversions replaced in Beaver Creek.

Project at a Glance

<table>
<tr><td colspan="2">Formal Project Name: Beaver Creek Passage Improvement Study</td></tr>
<tr><td colspan="2">Project Type: Re-opening Tributary Habitat for Use by Anadromous Salmonids</td></tr>
<tr><td colspan="2">Project Sponsor:</td></tr>
<tr><td colspan="2">Project Design: Bureau of Reclamation</td></tr>
<tr><td colspan="2">Landowner(s): Private, Washington Department of Fish and Wildlife, and US Forest Service</td></tr>
<tr><td>Partners: US Geological Survey, Washington Department of Fish and Wildlife, Columbia River Research Laboratory, University of Idaho Ecohydraulics Research Group (Boise, ID) Aquaculture Research Institute (Hagerman, ID and Bureau of Reclamation (Technical Assistance and Design)</td><td>Reclamation Development Costs:</td></tr>
<tr><td>Funding Source(s): BPA</td><td>Implementation Cost:</td></tr>
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Table 1. List of irrigation diversions in Beaver Creek, location, type of action taken to correct passage problem, and date of completion.			
Diversion	Distance from Mouth of Beaver Creek (km)	Type of Action	Date Diversion Completed
Fort-Thurlow	2.427	Replace existing diversion with rock vortex weir. Piped 2 years after RVW installed.	2004
Tice Diversion	2.484	Replaced diversion with pump and moved POD downstream to rkm 2.48.	2011
Lower Stokes	4.531	Replace existing diversion with rock vortex weir. Landowner piped diversion.	2003
Thurlow Transfer	6.342	Replace existing diversion with rock vortex weir. Not piped.	2003
Upper Stokes	7.063	Replace existing diversion with rock vortex weir. Some piping.	2003
Redshirt	8.065	Replace existing diversion structure with rock. Reconfigured head gate to provide water at low flow	2007
Batie	10.31	Partial or seasonal barrier, logs and plastic	On hold
Marracci	10.539	Replace existing diversion with rock vortex weir. Diversion piped by Reclamation at same time diversion was replaced. Water acquisition.	2005 2011
Fork in Upper Beaver Creek	14.974		

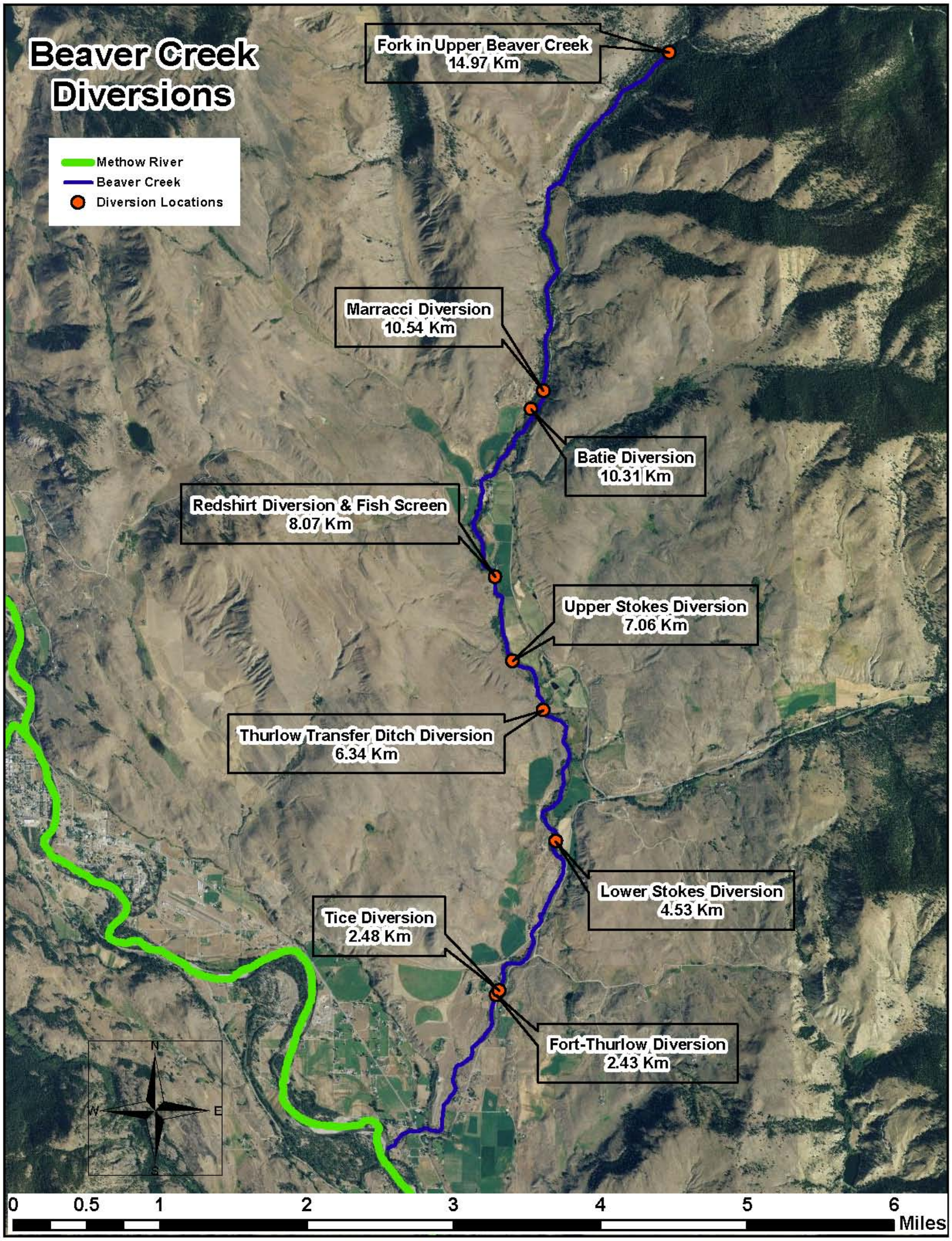

Figure 1. Location of diversion structures in Beaver Creek.

Rock Vortex Weirs

Rock vortex weirs are a relatively new methodology for providing fish passage. Little information was available as to their effectiveness at passing fish species of the Pacific Northwest (Connolly et al. 2010). Rock vortex weirs (RVWs) in Beaver Creek were designed to replace existing barriers to fish migration and constructed under supervision of the Bureau of Reclamation (Connolly et al. 2010). Large boulders were placed in a V-shaped configuration pointed upstream to provide hydraulic conditions that would aid upstream fish passage across a low rock weir (Photo 1). The "legs" angled downstream from 15° to 30° relative to the streambank. Boulders and rocks used in construction of RVWs were sized to remain in place and stable at a range of stream flows. RVWs are designed to create a scour pool just downstream of the weir, which may provide juvenile rearing or holding habitat and a jump pool. Two, three, or more such weirs were needed at each replaced irrigation diversion to reduce the gradient from the water surface elevation needed to divert water for irrigation and at the same time provide passage to all sizes and species of fish (Photo 2). A detailed account of hydraulic modeling of rock vortex weirs is presented by Ruttenberg et al. (2009).


1


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Photo 1. Lower Stokes rock vortex weir under construction. Large boulders are placed in a V-shaped configuration pointing upstream to provide hydraulic conditions that aid upstream fish passage. Boulders and rocks were sized to remain in place and stable at various stream flows.

Photo 2. Completed Fort-Thurlow rock vortex weir. Each weir consists of a low head structure that provides relatively easy passage for upstream migrating fish.

In Beaver Creek, replacement of barriers with RVWs began in 2002 at the fourth upstream barrier and progressed downstream. Three existing diversion dams on lower Beaver Creek were replaced in 2003 (Lower Stokes, Thurlow Transfer, and Upper Stokes) and one in 2004 (Fort-Thurlow) (Table 1) (Martens and Connolly 2008). Several other passage barriers further upstream were replaced or the point of diversion was moved and replaced with a pump (Tice Diversion, for example) (Table 1).

Effectiveness Monitoring

Effectiveness monitoring evaluates whether the management action achieved the desired effect or goal, including response of targeted fish species to the actions.

Methods for Monitoring and Evaluation

Monitoring and evaluation of both the replaced diversions dams and the use of the rock vortex weirs by adult and juvenile anadromous salmonids was important to measure the success of this project for re-opening historic tributary habitat for salmonids and the potential to use this methodology and structures to replace barriers to migration in other tributaries. Effectiveness is being measured by changes in physical stream characteristics upstream and downstream of the modified diversions, by

- monitoring upstream passage of fish,
- measuring changes in fish assemblage and distribution, population estimates and growth,
- colonization of newly re-opened habitat,
- assessing genetic structure of the colonizing population above the modified diversions,
- measuring nitrogen 15 (15N) and carbon 13 (13C) isotope levels in fish, vegetation and aquatic insects to detect change in anadromous fish use of the steam; and
- effectiveness of fish screens in diversion canals

Various studies were designed to evaluate the effectiveness of the new RVWs to pass upstream migrating fish. Study-specific sites were established in lower Beaver Creek to address effectiveness monitoring questions. Some sampling and surveys were conducted in nearby Libby and Gold creeks, which served as controls for the barrier replacement actions in Beaver Creek.

Fish assemblage and distribution

Electrofishing gear was used to collect fish throughout the three creeks. A fish weir located near rkm 1 in Beaver Creek was also used to collect upstream and downstream migrating fish. Fish collected were lightly anesthetized using MS-222 (tricaine methane sulfonate), identified, and measured to fork length in mm and weighed to the nearest 0.1 g. Captured juvenile fish were PIT tagged according to standard practices and guidelines.

Fish movement, population estimates, and growth

A study site was established at Lower Stokes Diversion RVW to assess upstream juvenile fish passage during 2004 – 2007 (Connolly et al. 2010). Adult and juvenile *O. mykiss* were trapped in a weir located about 1 km from the mouth of Beaver Creek and PIT-tagged. PIT-tagged fish and PIT tag interrogation systems were used to evaluate upstream passage of small salmonids through the Lower Stokes series of RVWs (Connolly et al. 2010). A large PIT tag interrogation system was installed above the Lower Stokes diversion and could be used to determine direction of fish movement. It consisted of six detection antennas. Small PIT tag interrogation systems were installed in Beaver Creek 3 km downstream from Lower Stokes, 20 m downstream from Lower Stokes, 100 m upstream from Lower Stokes and about 5 km upstream from Lower Stokes, to monitor movement of fish in 2004 and 2005 (Ruttenberg et al.

2009). Downstream passage of juvenile fish through the RVWs was not specifically evaluated since stream flows were expected to assist any downstream migrating fish.

Three 500-m-long sites were selected in Beaver Creek to estimate fish populations. Initial assessments began with a habitat survey, based on habitat type (pools, glides, riffles and side channels). Prior to sampling each site, the section was blocked with nets to retain fish. A backpack electrofishing unit was employed to capture fish.

Data from recaptured PIT-tagged juvenile fish were used to assess fish growth seasonally and annually.

Colonization

Annual counts of fish entering Beaver Creek and moving upstream were determined from PIT-tagged fish interrogated at PIT tag detectors or fish captured and tagged in the downstream weir.

Juvenile fish entrainment into irrigation canals

A fish screen was installed within the Lower Stokes irrigation canal. The effectiveness of the fish screens and bypasses were evaluated on three occasions during July and August 2005 by releasing 30 or more PIT-tagged juvenile rainbow trout/steelhead into the canal above the screen. Two PIT tag interrogations systems monitored movement of the fish released into the first 20 m of the canal.

Isotope Studies

Three sites at rkm 3, 12, and 15 in Beaver Creek and in two other nearby streams were selected for isotope analysis to determine the ratios of nitrogen 15 to nitrogen 14 and carbon 13 to carbon 12 (Connolly et al. 2010). The ratios of 15N to 14N and 13C to 12C can be used to provide an indication of the contribution of marine-derived nutrients to the system from returning adult anadromous salmonids. Adult salmon provide a subsidy of marine-derived nutrients to the ecosystem when they die and decompose after spawning. Nutrients are leached from the carcasses into the stream and contribute to primary production; juvenile fish and aquatic macroinvertebrates often feed directly on the carcasses, and mammalian predators can remove carcasses from the stream to the riparian areas where leached nutrients support growth of vegetation, as well as of terrestrial organisms. Samples of fish, vegetation and aquatic insects from Beaver Creek were collected at the sites, preserved, and analyzed in the laboratory.

Genetic Structure of the Population

Genetic data are sometimes used to monitor the effect of colonization to identify interbreeding groups and source populations. In some cases hatchery-origin fish provide an over-abundant source population to colonize unoccupied habitat. Hatchery-origin fish have been documented to have lower relative reproductive success compared to naturally produced fish. Hatchery fish may not be a desirable source population for colonization of newly accessible habitat. Genetic parameters were used to determine if anadromous *O. mykiss* successfully established in Beaver Creek after replacement of passage barriers with rock vortex weirs. The objectives of the study were to identify the source and abundance of colonizers after barrier removal, identify if and where detectable changes occurred to population metrics, and identify if a population of anadromous *O. mykiss* was successfully established in Beaver Creek. Pair-wise comparisons between the before-after samples were used to detect changes due to the barrier replacements with RVWs. Details of the genetic analysis are provided in Weigel et al. (2012 draft).

Results, Interpretations, and Trends

Replacement of four impassable irrigation diversions in lower Beaver Creek with rock vortex weirs was completed in 2004. Some other diversions were modified later. Adult anadromous *O. mykiss* entered the newly accessible habitat in Beaver Creek in 2005, the first year that upstream passage was provided. In 2005, two juvenile Chinook salmon were collected above the two RVWs. An adult Chinook salmon was seen near rkm 10 in 2006.

Adult anadromous *O. mykiss* entering Beaver Creek increased over the next several years (Connolly et al. 2010) (Table 2). Adult anadromous *O. mykiss* migrated into upper Beaver Creek in 2007 and 2008, 2 and 3 years after barrier reconstruction. Juvenile *O. mykiss* tagged in Beaver Creek returned as adults to the creek after two years, indicating the establishment of a full anadromous life cycle in the study area.

Table 2. Number of wild adult anadromous *O. mykiss* entering Beaver Creek (colonization or returning adults from smolts produced in Beaver Creek) 2005-2011. Data from USGS.

Year	Number of adults in weir and not detected at interrogator (total number at weir)	Number of tagged adults detected at Beaver Creek PIT tag interrogators	Total
2005	23 (25)	2	25
2006	20 (22)	2	22
2007	1 (4)	19	20
2008	5 (9)	16	21
2009	Weir was not operated	10	10
2010	Weir was not operated	6	6
2011	Weir was not operated	8	8

Fish Assemblage

At least 10 species of fish were collected throughout Beaver Creek in 2004-2005; the predominant species was juvenile rainbow trout/steelhead. About 3,300 were PIT tagged. Fewer brook trout, Chinook salmon, coho salmon, bull trout, and cutthroat trout were collected and tagged. Other fish species collected included smallmouth bass *Micropterus dolomieu*, bridgelip sucker *Catostomus columbianus*, longnose dace *Rhinichthys cataractae*, shorthead sculpin *Cottus confusus* and mountain whitefish *Prosopium williamsoni*. Except for the shorthead sculpin, most of these fish species were collected only in the lower 1 km of Beaver Creek. Figure 2 shows fish species and distribution in Beaver Creek.

Figure 2. The presence of fish species in selected sections of Beaver Creek before and after the replacement of the downstream-most water diversion. Grey highlighted boxes represent newly represented species after the barrier was modified. Figure reproduced from Connolly et al. (2010).

Fish movement, population estimates, and growth

Tagged juvenile *O. mykiss* moved upstream passed the rock vortex weirs mostly during the spring and summer months. Of the 3,699 juvenile *O. mykiss* tagged, 88 *O. mykiss*, 20 brook trout, and one coho salmon were recorded passing upstream (Martens and Connolly 2010). Some *O. mykiss* ascended the series of RVWs quickly, while others took up to 87 days to move upstream (Connolly et al. 2010). Some delay in movement was noted at flows of < 0.32 m/s (Martens and Connolly 2010). Delay may indicate that the juvenile fish were utilizing the habitat below the weir for rearing and resting during upstream movement. The smallest documented fish moving upstream was a 77 mm *O. mykiss*.

Juvenile *O. mykiss* outmigrated from Beaver Creek, but used two different migration and rearing strategies. Some juveniles overwintered in the stream itself and outmigrated as larger smolts the next spring, while some juveniles left Beaver Creek in the fall and apparently overwintered downstream in the mainstem Methow River or elsewhere. Those smolts that overwintered in Beaver Creek and migrated in the spring made a somewhat larger contribution to overall smolt production than did those that outmigrated in the fall and overwintered downstream before migrating to the ocean (Connolly et al. 2010). Some tagged juvenile *O. mykiss* that left Beaver Creek were detected either at the lower Methow River smolt trap or at one or more detection sites downstream in the Columbia River.

Several other species of native salmonids moved upstream through the Lower Stokes weir. These included Chinook salmon, coho salmon and mountain whitefish (Martens and Connolly 2008). Non-native brook trout already present in Beaver Creek also moved upstream through the weir. Bull trout are expected to utilize the RVWs to move throughout the basin. Low numbers of bull trout have been documented in some headwater tributaries and at the fish trap near the mouth of Beaver Creek.

Fish recaptured over time showed a seasonal growth pattern, with most growth occurring in the spring-summer time period, with less growth occurring during winter.

Juvenile fish entrainment into irrigation canals

Tagged juvenile trout released into an irrigation diversion upstream from the fish screen for the most part moved upstream and out of the canal (75%); some fish were later recaptured in the canal (16%) and a few fish were not detected (5%). Some fish appeared to be rearing in the canal. The fish screens and bypass successfully prevented juveniles from being entrained into irrigation canals.

Colonization

Anadromous *O. mykiss* successfully began colonizing Beaver Creek the first year after barriers to migration were replaced with rock vortex weirs (Table 2). Most of the fish were natural-origin; few fish were hatchery-produced, even though about 80% of the adult *O. mykiss* at Wells Dam are of hatchery-origin. Few hatchery-origin fish were documented entering the basin during the study, and did not contribute to production of juveniles; one of the adults was matched to parr, but none of the parr returned as adults. The number of colonizing adults fluctuated over the years 2005 to 2008, and followed trends in redd counts and adult counts at Wells Dam conducted by WDFW. This may simply reflect overall fluctuations in the returning adult *O. mykiss* population to the upper Columbia River during this period. Adult *O. mykiss* migrated higher into the Beaver Creek basin in 2007 and 2008. There were significant changes in genetic comparisons at lower monitoring sites comparing before and after treatments. The shift in genetics matches tag migration data supporting that adult fish were beginning to migrate into upper Beaver Creek about one generation after barrier removal. The process of colonization and full utilization of the re-opened habitat in Beaver Creek is likely to progress over several steelhead generations, as natural production becomes established and additional adults enter the basin. Steelhead generation time could be 4-8 years, depending on growth rate of juveniles to smolt outmigration and time spent rearing in the ocean. Chinook and coho salmon and mountain whitefish also moved upstream through the RVWs.

Isotope Studies

Results from the isotope studies should be considered preliminary at this time. The ratio of 15N to 14N were highest for the lower Beaver Creek site, while the ratio of 13C to 12C were similar between sites within the watershed. The higher nitrogen ratio in lower Beaver Creek may indicate some anadromous fish use of lower Beaver Creek prior to replacement of the Fort-Thurlow and Lower Stokes diversions with rock vortex weirs, or it may be the result of upstream land-use practices. Nitrogen ratios were highest for age-1 and age-0 fish (Martens and Connolly 2008). Vegetation samples generally exhibited a similar pattern of nitrogen ratios in lower Beaver Creek as did the juvenile fish. Nitrogen ratios for several insect groups were generally higher in lower Beaver Creek, but less consistent than observed for juvenile fish. These initial isotope data suggest that anadromous salmonids did not use or could not access the middle and upper reaches of Beaver Creek (Connolly et al. 2010). However, adult anadromous *O. mykiss* were documented migrating into upper Beaver Creek in 2007 and 2008, two and three years after barrier replacement, indicating that colonization of the stream was in progress. The higher ratio of 15N to 14N in lower Beaver Creek may indicate some input of marine-derived nutrients into the system from returning adult salmonids. Additional data collection and analyses are required over a long term to determine if adult salmonids returning to Beaver Creek provide a substantial nutrient subsidy in the form of marine derived nutrients that can be detected in stable isotope ratios for nitrogen and carbon in aquatic and terrestrial biota. Since steelhead are iteroparous and do not necessarily die after spawning as do salmon and may move down river, begin feeding again and return to spawn again in their natal stream, their overall contribution to the nutrient dynamics of Beaver Creek may be difficult to detect in the short term.

Genetic Structure of the Population

Genetic data were coupled with PIT tag movement data in Beaver Creek to understand the source and success of anadromous steelhead that were the primary target for stream restoration projects. This study used microsatellite data to track: 1) success of individual adults in Beaver Creek after barrier replacement; 2) spatial extent of population genetic changes coinciding with the movements of adult *O. mykiss* into Beaver Creek; and 3) assess the population genetic effect of small irrigation diversion barriers prior to replacement (the treatment).

Genetic data provide important information into population and species interactions that cannot be derived from movement and other tag-based observations. Barriers (primarily waterfalls) have been found to be related to genetic differentiation in stream species (particularly resident salmonids like bull trout). However, small diversion dams (<=2.0m) are not necessarily complete barriers to migration like large waterfalls. Hatchery salmon and steelhead have also been found to have reduced reproductive success in natural stream environments. The extensive hatchery programs in the upper Columbia Basin provide an abundant source of adult steelhead. Therefore, an understanding of the role and success of hatchery *O. mykiss* in this basin was critical to understanding the effectiveness of habitat restoration projects in the Methow and other local basins.

This study identified that adult *O. mykiss* entered Beaver Creek the first spawning season after barrier replacement. These individuals successfully reproduced in Beaver Creek and established anadromous progeny that returned to Beaver Creek as adults. Fluvial *O. mykiss* (riverine migrants) crossed with anadromous *O. mykiss* and contributed directly to the establishment of the population by matching to progeny that return to Beaver Creek as adults; few hatchery fish were encountered at the Beaver Creek weir during the parentage study (2005 and 2006) and only one of these adults matched to parr, but none of these parr returned as adults.

O. mykiss colonization occurred slower than expected in in Beaver Creek compared to other barrier removal projects. Only one site upstream from the fish barrier replacements showed significant change in population genetic parameters after 5 years. However, tag movement data indicated that adults were continuing to migrate into habitats further upstream. Adult *O. mykiss* counts into the stream did not increase during the first 5 years of the study, and could be a limiting factor in the extent and rate of colonization in Beaver Creek.

Genetic and isotope data were being used to determine if steelhead were able to migrate past the diversion dams in Beaver Creek prior to replacement with RVWs (the treatment). The genetic measurements (Fst, heterozygosity, allelic richness) were similar to other documented populations of *O. mykiss*. A standard genetic differentiation measure (Fst) was used as an indicator of isolation. There was a slightly higher range of Fst in Beaver Creek (0-0.019) versus Libby and Gold creeks (0-0.09), two nearby comparable tributaries. The higher Fst values in Beaver Creek are similar to those detected upstream of barriers in other *O. mykiss,* indicating more isolation and genetic drift in this basin prior to barrier removal. These findings suggest that barriers in Beaver Creek were limiting migration. In addition, tag data indicate lower levels of parr outmigration from sites upstream from the diversion barriers. Isotope data suggested that some passage might have been occurring, although these data have not been fully explored or reviewed.

Ongoing analysis is exploring the level of migration between sites in Beaver Creek in comparison to Libby and Gold creeks (non-treatment basins) and variables correlated with these migration rates, such as distance, barriers and other environmental variables.

Summary

Several barriers to upstream migration in Beaver Creek were replaced with a series of rock vortex weirs. Adult anadromous *O. mykiss* began occupying Beaver Creek soon after barriers to migration were replaced. Movement of adults to upper Beaver Creek occurred within a few years of barrier replacement. Several other salmonid species migrated upstream to newly accessible habitat. PIT-tagged outmigrating juvenile *O. mykiss* were detected at several downstream Methow and Columbia River detection sites, and some returned to the stream years later as adults, indicating that anadromy has been re-established in Beaver Creek with the replacement of impassable diversion with rock vortex weirs. Genetic studies indicated that populations of *O. mykiss* from tributaries in the lower Methow River are more diverse than previously thought, and anadromous salmonids may be contributing marine derived nutrients to the system.

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UCRTT Deliberations

"Do the apparently positive results of this study suggest that the UCRTT will be recommending installation of more small wood structures?," was the immediate feedback the UCRTT received from WATs and project sponsors. While the study was short term, only one year, and only looked at a small sample size of structures in a particular habitat type (the Lower Entiat), the study was intensive and well designed. Similarly, the Biological Strategy objective of "increasing stream habitat complexity" suggests that treatments ought to be developed over a wide range of shapes and sizes. Smaller pools, for example, may have biological benefits unrealized by large pools, and a range of habitat sizes can increase "instream habitat diversity." However, concerns about siting, scaling, and structure longevity will likely be amplified for small-scale projects. For instance, it may be counter productive to recovery objectives if the installation process damages riparian habitat, particularly if a small-scale project may not survive the next flood or have other long-term benefits. Furthermore, smaller-scale treatments may be less likely to effect the geomorphic changes on the river (like "thalweg development" and "channel forming processes") that is the second half of the two-pronged approach in the lower Entiat. Therefore, small-scale structures may be a part of meetinghabitat restoration objectives and will continue to be considered for future implementation, particularly if these types of structures are used where existing habitat values won't be diminished or used to augment channel forming processes and floodplain function.

tion treatments might be necessary to detect impacts to fish populations. Short-term data such as these help identify temporal variation in the use of treated vs. untreated habitat and whether there is a measurable change in density dependent life history traits such as growth and movement. Restoration treatments show some measurable positive impact on the species of concern but further analysis and more data are required to establish these conclusions more firmly.

Effectiveness of Actions in Beaver Creek

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Background

Actions were taken to replace four diversion dams in lower Beaver Creek with rock vortex weirs in order to enhance fish passage while maintaining the ability to divert water to gravity-fed irrigation ditches. Some of these diversion dams had been in place for over 100 years, and have impaired or completely blocked upstream migration of fish. Three diversion dams were replaced in 2003 (Lower Stokes, Thurlow Transfer, and Upper Stokes), and the forth and most-downstream (Rkm 2) diversion dam was replaced in 2004 (Fort-Thurlow). Four vortex weirs were designed and installed under the supervision of U.S. Bureau of Reclamation engineers and completed in accordance to National Marine Fisheries Service and Washington Department of Fisheries and Wildlife fish passage criteria. An effectiveness monitoring effort was warranted since installing rock vortex weirs represents a relatively new methodology and little information was available for their effectiveness of passing fish species of the Pacific Northwest.

Objectives

The primary objectives of the study were to: 1) assess effectiveness of the modified irrigation diversion structures for passage of fish, and 2) to document subsequent changes in fish populations in Beaver Creek.

Methods

An extensive PIT-tagging program with four PIT-tag detection antennas and a fish sampling weir was used to monitor the success of upstream passage of fish and to assess growth and survival within Beaver Creek (Figure 1). Electrofishing was used to survey and collect fish to measure change in fish assemblage, smolt production, and diversity of life history expression above the modified structures. Three sites in Beaver Creek were chosen for isotope analysis to represent the range of change in use by anadromous fish as the diversions were replaced with vortex weirs (Figures 2 and 3). For example, the lowest site (Rkm 3) was above two water diversions and we expected a large increase in

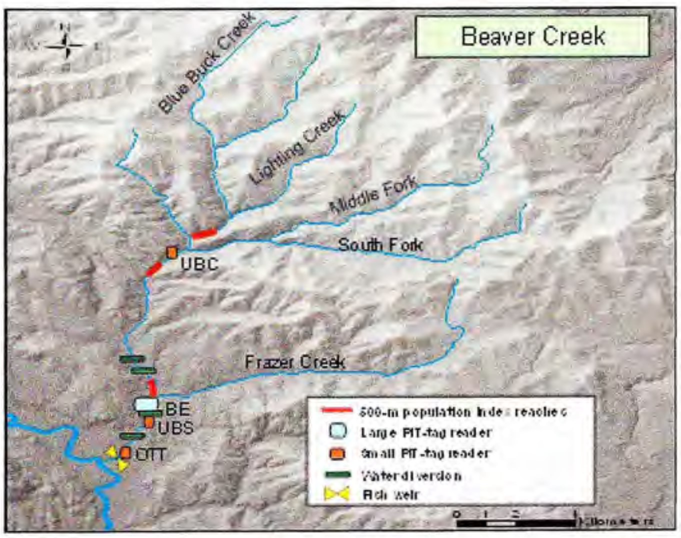

Figure 1. Sites for locations of PIT-tag interrogators, fish trap, and 500-m population electrofishing surveys in Beaver Creek. A2 = Upper Beaver Creek small interrogator, B0 = R1 large interrogator, A4 = R1 small interrogator, and A6 = Lower Beaver Creek small interrogator.

UCRTT Deliberations

- The monitoring program in Beaver Creek provides a unique and in-depth evaluation of the effectiveness of fish passage efforts in a small sub-watershed.
- This study also provides life history, phenotypic, and ecological information that could provide valuable insight for future evaluations following the re-colonization of Beaver Creek.
- The barrier passage efforts in Beaver Creek appear to have alleviated the primary limiting factor for this major spawning area of the Methow population.

anadromous fish in this reach after the diversions were replaced with vortex weirs. The middle site (Rkm 13) was selected because we expected to see some limited anadromous fish use after the water diversions were replaced with vortex weirs. Samples for isotope analysis were collected from fish, algae, leaves (cottonwood, red alder), and insects in fall 2004, and spring and fall 2005 and 2006, and the spring 2007.

Three 500m index sites (location of these sites was based largely on geomorphology and access) were sampled using electrofishing to obtain population and growth estimates (which were also obtained from the recapture of tagged fish at the fish sampling weir). Surveys were conducted during the spring, summer, and fall to collect previously PIT-tagged fish. Recapture data were analyzed by season of year. Recapture events were used when a fish was captured within the next season from its tagging or last recapture event. Since no sampling occurred during winter, we assessed growth for fish tagged (or recaptured) in the fall and recaptured in the spring. Recaptured fish were used only if they were recaptured after 10 days of their tagging or last recapture date. We defined seasons as: spring (March-May), summer (June-August), fall (September-November), and winter (December-February).

Results

After the lowermost remaining water diversion in Beaver Creek was replaced with a vortex weir, we collected or detected mountain whitefish, coho, and juvenile and adult Chinook at the R1 index site or large interrogator (Figure 4). Based on changes in fish assemblage, connectivity has been reestablished for a number of members of the fish community. Our PIT tag interrogator data indicate a four-fold increase from 2005-06 to 2007-08 in the number of potentially spawning adult steelhead getting past Rkm 4, with some getting past Rkm 12 by 2007 (Figure 5). Success of natural recolonization appears to be progressing, but it will likely take more time to realize full potential. In 2005, 2006 and 2008 the majority of recolonizing adults were wild.

The vortex weirs were demonstrated to be very effective in passing fish, including successful upstream passage of juvenile salmonids at all flow levels, even at flow levels as low as 2.3 cfs (0.07 m3/s; Figure 6). However, the rate at which rainbow trout/juvenile steelhead (Oncorhynchus mykiss) swam past the vortex weirs was significantly slower than the passage rate at the control reach ($X2 = 8.32$, $P = 0.004$).

In Beaver Creek, O. mykiss juveniles off all ages were most prevalent at the lowermost (R1) index site. The biomass of age-1 and older juvenile O. mykiss at the R1 index site was almost double the biomass of at other index sites sampled in the Methow watershed.

We found similar results of age-1 or older fish densities from 2004 to 2005 (Figure 7). The population of age-0 O. mykiss decreased in the R1 and R2 index sites in 2005, while the R4 index site's population increased. The biomass of O. mykiss in R1 and R2 decreased from 2004 to 2005, while the biomass increased

Figures 2 and 3. Before and after photographs of Beaver Creek. Left: Diversion dam in Beaver Creek that impaired or completely blocked fish passage upstream. Right: Diversion dam replaced with instream vortex weir allowing fish passage and maintaining ability to divert water for irrigation.

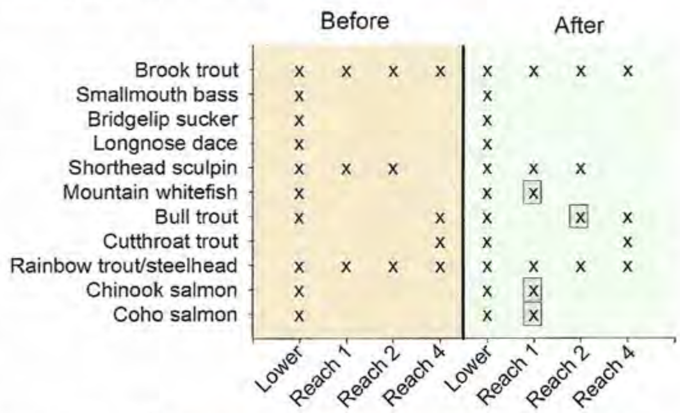

Figure 4. The presence of fish species in selected sections of Beaver Creek before and after the reconstruction of the lowest remaining water diversion.

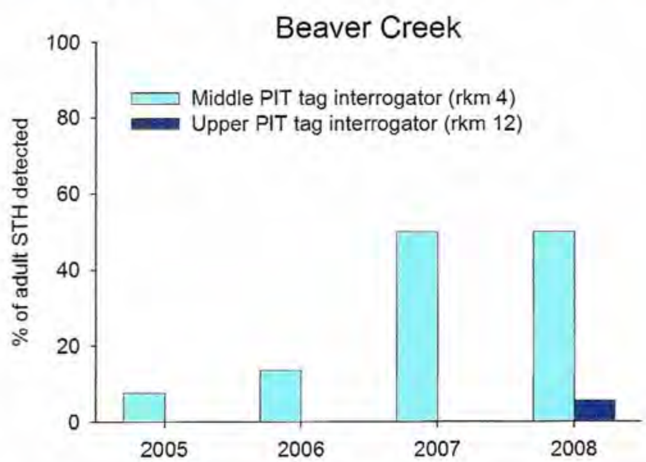

Figure 5. Percentage of adult steelhead caught at the weir and then detected upstream at the PIT tag detectors in Beaver Creek.

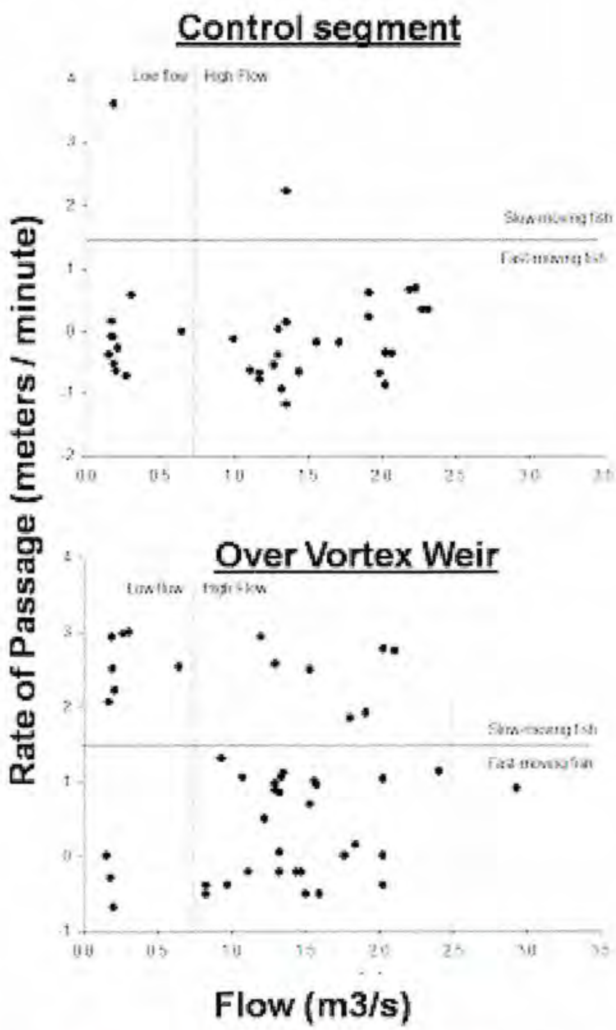

Figure 6. Rate of passage of juvenile steelhead across vortex weirs at various flows.

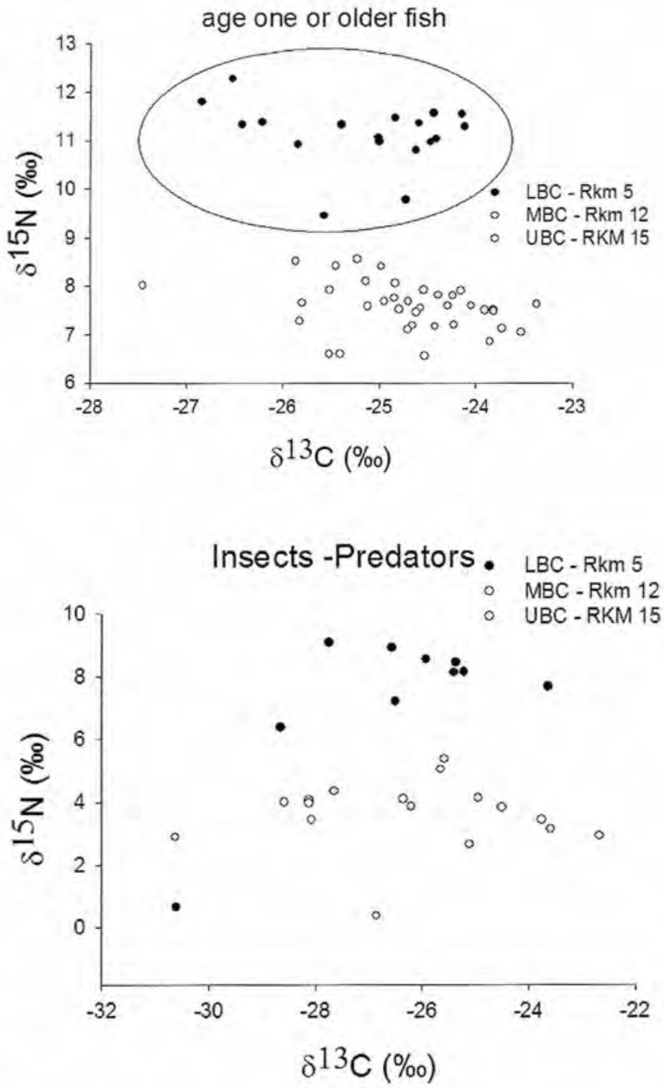

Figure 8. Isotope ratios (N, C) from 2004-2007.

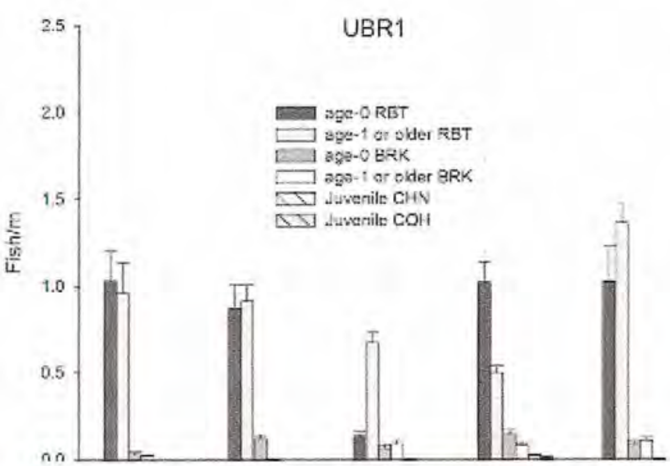

Figure 7. Salmonid abundance in upper Beaver Creek (Reach R1, Rkm 5) from 2004 to 2008.

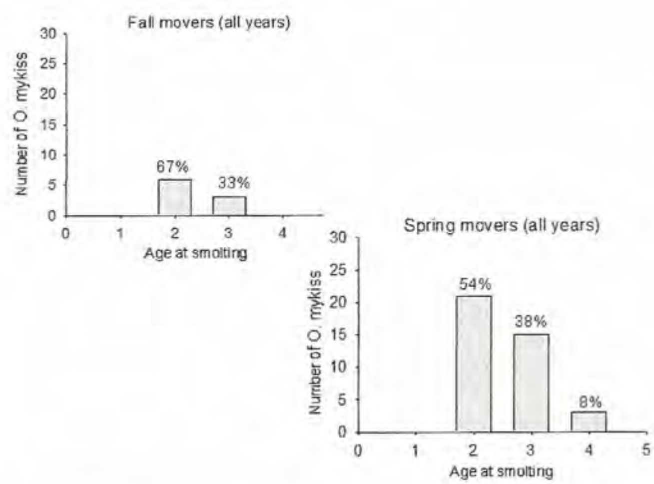

Figure 9. Lower Beaver Creek (R1) 2004-2007 age of smolts from two life history trajectorie, as detected in the Columbia River PIT tag interrogation network.

Year	Number PIT tagged	Number detected					
		2004	2005	2006	2007	2008	2009
2004	281	0	0	2	4	2	1
2005	169	--	0	0	1	3	1
2006	136	--	--	0	0	5	0
2007	113	--	--	--	0	1	1
2008	37	--	--	--	--	0	0

Table 1. Number of age 1 O. mykiss PIT tagged above Rkm 12, and then detected moving downstream past Rkm 4 (Stokes reader).

Year	Number PIT tagged	Number detected					
		2004	2005	2006	2007	2008	2009
2004	150	27	53	15	0	0	0
2005	140	--	31	30	1	0	0
2006	104	--	--	1	15	5	0
2007	50	--	--	--	13	8	1
2008	279	--	--	--	--	80	32

Table 2. Number of age 1 O. mykiss PIT tagged near Rkm 5, and then detected moving downstream past Rkm 4 (Stokes reader).

in R4. The population of age-0 and age-1 or older O. mykiss in Beaver Creek decreased at each upstream sampling site.

Because of the infancy of our analysis, we did not attempt a statistical analysis of the isotope data but present a brief qualitative analysis (Figure 8). The marine-derived isotopic signature indicates that anadromous fish currently use lower Beaver Creek (Rkm 5; solid circles in Figure 8) but also were present in lower Beaver Creek prior to the conversion of the Fort Thurlow and Lower Stokes water diversions to vortex weirs. Isotopic signatures suggest that the middle (rkm12) and upper (Rkm 15) reaches of Beaver Creek were not used by anadromous salmonids.

Juvenile O. mykiss that were tagged above Rkm 12 and that were subsequently detected moving downstream past the lower vortex weir at Rkm 4 were typically detected from 3 to 6 years after tagging and were detected at low levels (Table 1). Juvenile O. mykiss that were tagged above Rkm 5 and that were subsequently detected moving downstream past the lower vortex weir at Rkm 4 were typically detected from 1 to 3 years after tagging and were detected at higher levels (Table 2). A pattern of downstream movement was observed, with O. mykiss emigration prominent in April through June and in September through November.

We found differential smolting success of steelhead from the expressed life history strategies, where those juveniles that remain in the creek until smolting are contributing more to the smolt population than are fish which leave Beaver Creek in the fall at age-1 (Figure 9). Steelhead and other members of the fish community are actively recolonizing Beaver Creek but lower Beaver Creek is producing the majority of steelhead smolts.

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[Article]

Effectiveness of a Redesigned Water Diversion Using Rock Vortex Weirs to Enhance Longitudinal Connectivity for Small Salmonids

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Abstract.—For nearly 100 years, water diversions have affected fish passage in Beaver Creek, a tributary of the lower Methow River in north-central Washington State. From 2000 to 2004, four dam-style water diversions were replaced with a series of rock vortex weirs (RVWs). The weirs were designed to allow fish passage while maintaining the ability to divert water into irrigation canals. We observed the new appearance of three species (juvenile Chinook salmon *Oncorhynchus tshawytscha*, juvenile coho salmon *O. kisutch*, and mountain whitefish *Prosopium williamsoni*) upstream of the RVWs, indicating successful restoration of longitudinal connectivity. We used passive integrated transponder (PIT) tags and instream PIT tag interrogation systems during 2004–2007 to evaluate upstream passage of small salmonids (<240 mm fork length) through one series of RVWs. We documented 109 upstream passage events by small salmonids through the series of RVWs; most of the events (81%) involved passage of rainbow trout *O. mykiss* or juvenile steelhead (anadromous rainbow trout). Small rainbow trout or steelhead ranging from 86 to 238 mm (adjusted fork length) were able to pass upstream through the RVWs, although a delay in fish passage at discharges below 0.32 m^3/s was detected in comparison with nearby control sections.

The use of water diversions to irrigate crops and raise livestock continues to be a common practice for farmers and ranchers in the western United States. However, some of these diversions can act as barriers that limit the movement, distribution, and abundance of fish within and between watersheds (Bednarek 2001; Connolly and Sauter 2008). The diversions can also affect the composition of fish communities (Bednarek 2001) and reduce genetic variability of fish populations (Neville et al. 2006). The most recognized impact of instream barriers on fish movement in the Pacific Northwest is the blockage of adult salmonid access to historical spawning areas. However, even when adults can pass upstream, these structures can severely restrict upstream passage of juvenile salmonids (Curry et al. 1997; Erkinaro et al. 1998). This restriction can limit or block access to critical rearing areas (Scrivener et al. 1993), access to refugia from predation (Harvey 1991), and colonization of fish populations after disturbances (Detenbeck et al. 1992). Habitat fragmentation resulting from blocked passage can increase risk of extirpation of fish populations (Winston et al. 1991).

Direction and timing of fish movement can be difficult to assess by use of most common tagging methods (Bunt et al. 1999). Ficke and Myrick (2009) noted the limited number of techniques for effectively monitoring small-bodied fish in natural stream conditions. Typical tagging methods, such as Floy tags (Belford and Gould 1989), visible implant elastomer tags (Schmetterling et al. 2002; Ficke and Myrick 2009), acrylic paint injection (Warren and Pardew 1998), and radiotelemetry (Bunt et al. 1999; Ovidio and Philippart 2002), have serious limitations for determining fish direction and timing. Floy tags, visible implant elastomer tags, and acrylic injection techniques cannot provide information regarding specific travel times through a section of stream unless traps are continuously operated upstream and downstream of a specific section of interest. The use of radiotelemetry can provide travel time data; however, the number and size of tagged fish can be limited due to the size, cost, and life span of the tags. Passive integrated transponder (PIT) tags and fixed instream interrogation systems can be used to determine the direction and exact time of fish movement (Connolly et al. 2008), to relate the time of movement to near-instantaneous streamflow conditions (Bryant et al. 2009), and to tag large numbers of fish for a relatively low cost. For these reasons, the use of PIT tags has shown much potential for studies of fish movement.

Passive integrated transponder tags and instream interrogation systems have been successfully used to study large (>250 mm) migratory fish at natural-style passage structures (Aarestrup et al. 2003; Calles and Greenberg 2007), but few studies have examined small fish, which may or may not have migratory tendencies. Fish passage through rock vortex weirs (RVWs; Figure 1) has received little attention in laboratory and field studies (Ruttenberg 2007). Structures such as RVWs

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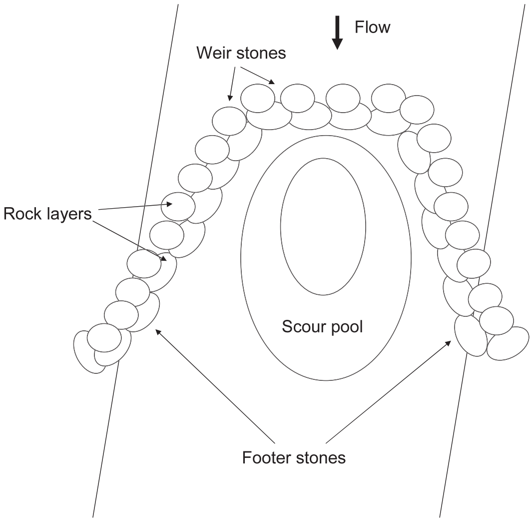

FIGURE 1.—Design of a typical rock vortex weir.

are built in a "close-to-natural" style that resembles natural river rapids (FAO/DVWK 2002). These types of structures offer an alternative to more traditional passage structures and can potentially create a more aesthetic look to the landscape (Jungwirth 1996). Some advantages of these natural-style structures include the variety of flows and depths for movement of different fish species and sizes and the creation of habitat (Aarestrup et al. 2003). Previous evaluations of natural-style structures have revealed mixed results (Aarestrup et al. 2003; Calles and Greenberg 2005, 2007), creating the need for more informative studies (Roni et al. 2002). Before the role of RVWs for instream restoration increases, their effectiveness should be assessed to justify large expenditures and to prevent the replication of flawed designs. The objectives of this study were to (1) assess the effectiveness of a series of RVWs in permitting upstream passage of small fish and (2) assess the effects of stream discharge and fish length on speed and timing of fish movement through the series of RVWs.

Study Area

Our study was conducted in Beaver Creek, a tributary of the lower Methow River in north-central Washington State (Figure 2). The Methow River is a fifth-order stream that drains into the Columbia River at river kilometer (rkm) 843. Beaver Creek is a third-order stream that drains westward into the Methow River at rkm 57 just south of Twisp, Washington. The watershed has an area of 179 km^2 (USFS 2004) and ranges in elevation from 463 to 1,890 m. Discharge in Beaver Creek is typically highest in May and June and then declines to base levels during August–October. From July 2004 to September 2007, the lowest daily median discharge was 0.05 m^3/s (September 2005), and the highest daily median discharge was 4.70 m^3/s (May 2006; Ruttenberg 2007).

Prior to restoration, various artificial and natural barriers existed in the Beaver Creek watershed for more than 100 years. One of these barriers was a small, concrete dam, while the other diversion barriers were structures made from a mixture of materials, such as wood, rocks, and plastic sheeting. The concrete diversion dam was modified in 2004, whereas three other upstream diversion dams were modified in 2003. At least two of these diversions were considered barriers to upstream fish passage before installation of the RVWs (USBOR 2004a, 2005). The RVWs in Beaver Creek were designed and installed under the supervision of the U.S. Bureau of Reclamation to meet fish passage standards established by the National Marine Fisheries Service (NMFS 2000) and the Washington Department of Fish and Wildlife (WDFW 2000).

Modifications to the water diversions in Beaver Creek included the installation of a series of RVWs at a given site (USBOR 2004a, 2004b, 2004c, 2005). These RVWs were made of large boulders to increase the stream elevation so that it matched the height of the original diversion. A typical RVW was pointed upstream with the "legs" angling downstream from 15° to 30° relative to the streambank (Figure 1). Footer stones were installed along rock layers, and weir stones were positioned above them. Rock vortex weirs were designed to allow passage of water and biota around and between the rocks at normal flows, creating a variety of flow velocities and depths to accommodate fish passage (SMRC 2008). The RVWs typically create scour pools downstream of the weirs, which have the potential to provide rearing habitat and a jump pool for fish. Although RVWs are not new (Roni et al. 2002), their effectiveness for allowing upstream passage of small fish is largely unknown and is likely to vary among sites.

Before the construction of the Lower Stokes Water Diversion (LSW) on Beaver Creek, rainbow trout *Oncorhynchus mykiss*, steelhead (anadromous rainbow trout), brook trout *Salvelinus fontinalis*, and shorthead sculpin *Cottus confusus* could be found just upstream of the LSW area. Downstream of the LSW, anadromous salmonids (primarily steelhead but also Chinook salmon *O. tshawytscha* and coho salmon *O. kisutch*), nonanadromous salmonids (rainbow trout, westslope cutthroat trout *O. clarkii lewisi*, bull trout *Salvelinus confluentus*, mountain whitefish *Prosopium williamsoni*, and brook trout), and nonsalmonids (shorthead sculpin, longnose dace *Rhinichthys cataractae*, bridge-

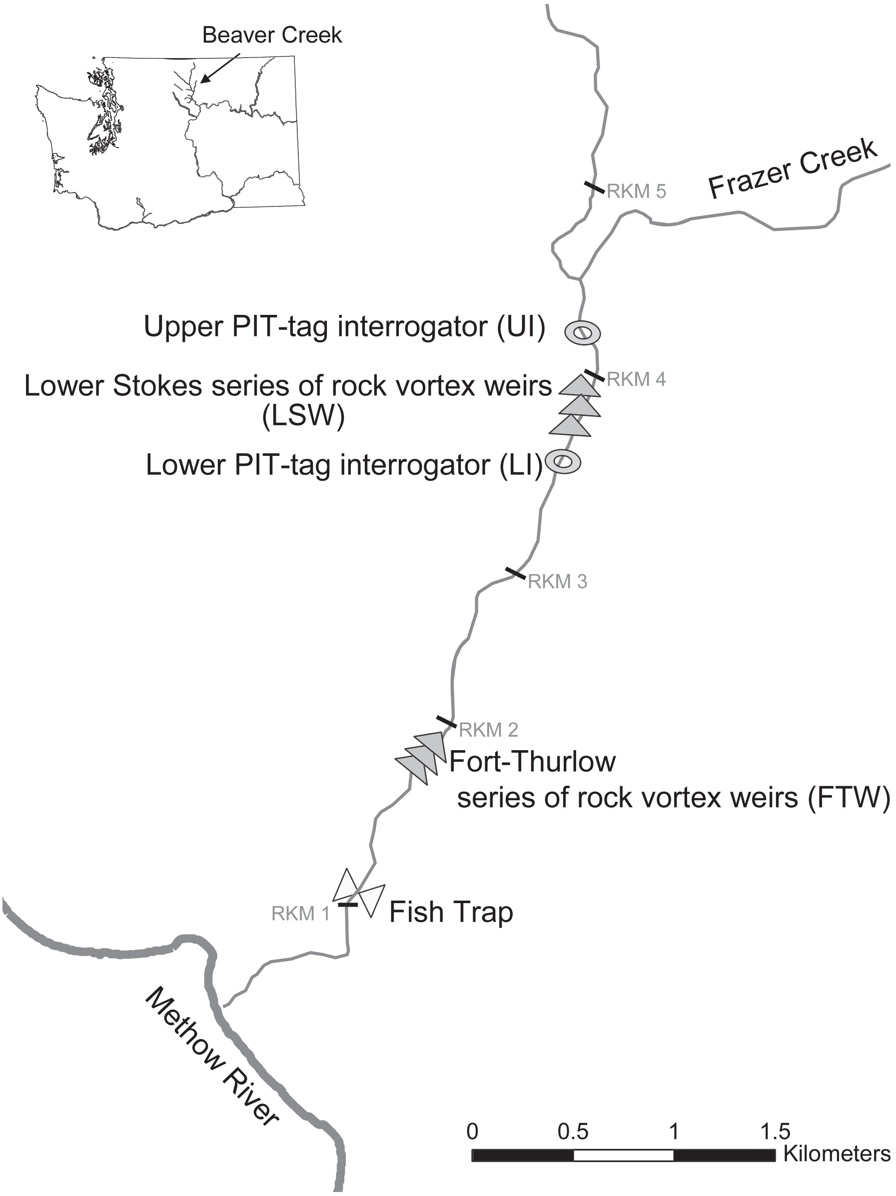

FIGURE 2.—Sites for locations of passive integrated transponder (PIT) tag interrogators, the fish trap, and the series of rock vortex weirs in Beaver Creek, Washington (RKM = river kilometer). The upper interrogator (UI) was a multiplexing system with six antennas, while the lower interrogator (LI) was a single-antenna system.

lip sucker *Catostomus columbianus*, and smallmouth bass *Micropterus dolomieu*) were present (Martens and Connolly 2008).

Methods

Fish were collected by use of a two-way fish trap at Beaver Creek (rkm 1; Figure 2) and backpack electrofishers. To track fish movements, a 12.5-mm PIT tag (full duplex, 134.2 kHz) was applied to most fish of 65 mm or greater lengths. Electrofishing was conducted at the lower sampling area (rkm 1), upstream and downstream of the LSW, and in the upper watershed. We intensively sampled a 600-m section of stream immediately upstream of the LSW multiple times during each year of the study (2004–2007) to PIT-tag fish, recapture previously PIT-tagged fish, and look for the presence of new species above the LSW. Surveys were conducted in the spring, summer, and fall.

A fish trap was deployed at rkm 1 and was used to collect and tag upstream-moving fish below the LSW. The two-way fish trap was operated during 22 October–22 December 2004 (60 d); 20 March–5 December 2005 (253 d); 13 February–27 April and 28 June–27 November 2006 (220 d); and 24 February–30 March and 25 May–30 September 2007 (219 d). The trap was checked a minimum of once per day. Trap operations were typically compromised by high flows during the fall and early spring. The trap was removed during winter due to ice accumulations. Fish trapping operations started in late-fall 2004 and extended through fall 2007.

We maintained and operated one multi-antenna, multiplexing PIT tag interrogation system and one single-antenna PIT tag interrogation system (Figure 2). The multi-antenna PIT tag interrogation system (hereafter, upper interrogator [UI]) was deployed 30 m upstream of the LSW. The UI consisted of one Digital Angel Model FS-1001M multiplexing PIT tag transceiver, six custom-made antennas, and a DC power source. The six antennas were arranged longitudinally in three arrays (2 antennas/array), which (1) allowed us to determine direction of fish movement, (2) enhanced the efficiency of detection, and (3) ensured coverage of the entire wetted width of the stream during the majority of summer flow levels. At the upstream-most array (array A), we installed a 1.8- $\times$ 0.9-m antenna (number 1) on river left and a 3.1- $\times$ 0.9-m antenna (number 2) on river right. At the middle array (array B), we installed two 3.1- $\times$ 0.9-m antennas (numbers 3 and 4). For the downstream array (array C), we installed two 1.8- $\times$ 0.9-m antennas (numbers 5 and 6). Arrays A and C were installed in a pass-by configuration, while array B was installed in a hybrid configuration as described by Connolly et al. (2008). Array A was 8.2 m upstream from array B, and array B was 14.6 m upstream from array C. The total distance from array A to array C was 22.8 m. The UI had detection efficiencies that exceeded 96% during high-flow periods and approached 100% during low-flow periods (Connolly et al. 2008). Downstream from the UI, the single-antenna PIT tag interrogator (hereafter, lower interrogator [LI]) was installed just downstream of the LSW at Beaver Creek rkm 4 during fall 2005 (Figure 2). The LI consisted of a Digital Angel Model 2001F-ISO PIT tag transceiver, a 12-V battery, and a small (1.2 $\times$ 0.6 m) antenna.

To assess discharge, a MiniTroll pressure transducer (In Situ Corporation, Fort Collins, Colorado) was deployed 5 m upstream of the LSW. The pressure transducer recorded water depths at 20-min intervals. These readings along with instream flow calculations were used to develop a rating curve to estimate stream discharge at the diversion weirs (Ruttenberg 2007). Water depths were collected by the University of Idaho during July 2004 through May 2006 (when high flows washed out the pressure transducer). The U.S. Geological Survey reinstalled the pressure transducer in March 2007 and recorded stream levels through December 2007.

Upstream movement at LSW was determined based on detections of fish at the UI, but for our analysis we limited the data to fish detected at both the LI and UI. The timing of upstream passage was matched with the discharge readings taken just upstream of the LSW. Due to limited presence and PIT tagging of other fish species in Beaver Creek, our analyses of length and movement were focused on steelhead and rainbow trout (hereafter referred to collectively as *O. mykiss*, as we did not distinguish between the two forms).

Because *O. mykiss* were not physically recaptured upstream of the LSW, individual fish lengths at the time of passage were not available. To evaluate the size of fish passing the LSW, we adjusted fish length based on each fish's length at tagging and the growth of recaptured fish. We used PIT tag recapture data collected during three common sampling periods (spring, summer, and fall) from two locations (fish trap or electrofishing near rkm 1; electrofishing near the LSW between rkm 3 and rkm 5). The number of days from tagging to a fish passage event was then separated into growth periods (March–May, June–August, and September–February). If a fish was detected in both the LSW and fish trap areas, we used the average daily growth for each area and each growth period to adjust the fork length (FL) at the time of passage. If a fish was tagged and thought to remain in the LSW area, we used the average daily growth for the LSW area to adjust FL. Finally, we multiplied the number of days in each growth period by the appropriate average daily growth rate and added the total growth to the original FL. We refer to this new length as the adjusted FL (AFL).

We compared *O. mykiss* that moved from the LI to the UI (treatment section) with *O. mykiss* that moved from one UI array to another (array C to B, B to A, or C to A; control sections). If a fish was detected at all three arrays, we only used the distance from array C to array A. We evaluated the distribution of *O. mykiss* passage time for normality and found it to be positively skewed; therefore, we $\log_{10}$ transformed the data. To account for differences in reach length between the treatment section (141 m) and control sections (distances were 14.6 m between arrays C and B, 8.2 m between arrays B and A, and 22.8 m between arrays

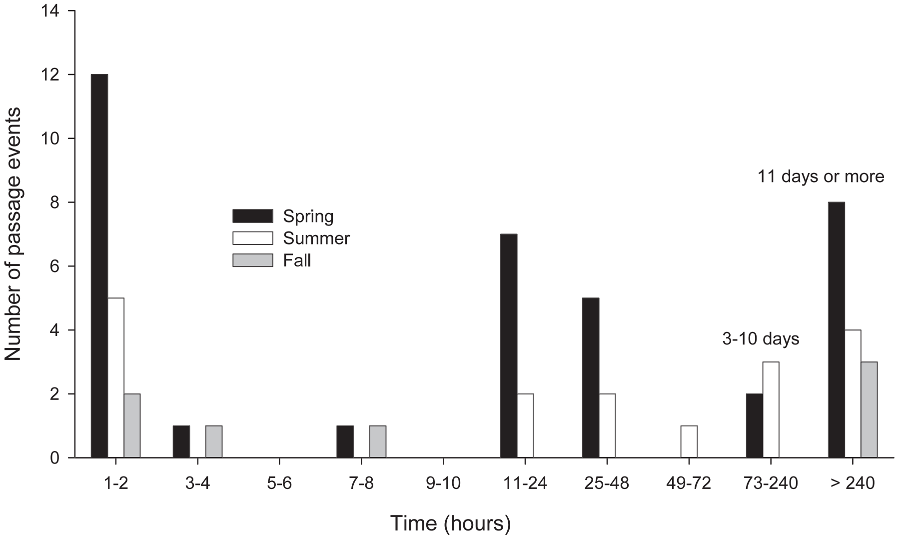

FIGURE 3.—Amount of time (h) taken by juvenile steelhead or rainbow trout (86–238 mm adjusted fork length) to move upstream through the series of rock vortex weirs at the Lower Stokes Water Diversion. No fish were observed to move through the rock vortex weirs in the winter.

C and A), we used the ratio of distance over time. We separated our fish passage data for treatment and control sections into four categories (low discharge and slow-moving fish, high discharge and slow-moving fish, low discharge and fast-moving fish, and high discharge and fast-moving fish). Discharge was separated into high and low categories on the first occasion that the discharge level doubled from the previous discharge rate (0.31–0.64 m^3/s) for fish passing the RVWs. Fast- and slow-moving fish were separated based on one SD over the mean movement rate (i.e., mean + SD = 2.2 m/min) of fish passing through the RVWs. The treatment and control data sets were then used to run a chi-square analysis to compare movement rates between the two discharge rates (low discharge = 0.15–0.31 m^3/s; high discharge = 0.64–2.93 m^3/s). Finally, we ran a linear regression to evaluate whether passage time was size dependent.

Results

We PIT-tagged a total of 6,596 *O. mykiss*, Chinook salmon, coho salmon, bull trout, brook trout, mountain whitefish, and bridgelip suckers. Of this total, 5,172 fish were small (<240 mm FL) *O. mykiss*, of which 3,699 were captured, tagged, and released downstream of the RVWs and LI. After the modification of the downstream-most water diversion (Fort Thurlow), new species collected by electrofishing or detected upstream of the LSW included juvenile Chinook salmon (n = 24), juvenile coho salmon (n = 2), and mountain whitefish (n = 1). Five small *O. mykiss* and one brook trout that were tagged and released below the LSW were recaptured through electrofishing just upstream of the UI. During 2005–2007, we recorded 109 events of upstream fish passage by small salmonids at the UI, including 88 *O. mykiss*, 20 brook trout, and 1 coho salmon. The smallest documented upstream mover (one *O. mykiss* that was 77 mm FL when tagged at the fish trap) was detected at the UI upstream of the RVWs less than 2 months after it was tagged.

Of the 88 upstream passage events of *O. mykiss*, 60 involved detection of fish at the LI and subsequent detection at the UI. The duration of these *O. mykiss* movements through the LSW ranged from 28 min to 85 d. Most of these fish moved through the LSW in the spring and summer, whereas little to no movement occurred during the fall and winter months (Figure 3). Small *O. mykiss* ranging from 86 to 238 mm AFL were detected as moving through the LSW (from LI to UI) within 1 h of first detection at the LI at discharges as low as 0.15 m^3/s. Since deployment of the LI in fall 2005, we did not record discharge levels less than 0.15 m^3/s. Corresponding flow records were available for 46 of the 60 *O. mykiss* that were detected at both the LI and UI. These 46 passage events with flow records were used in our comparison of treatment and control sections.

From October 2005 to September 2007, the LI detected 107 small *O. mykiss*, 98 of which had been tagged near (within 20 m of) the LI. Thirteen small *O.*

mykiss detected at the UI were originally tagged at the fish trap (rkm 1), which constituted an upstream movement of more than 3 km. Of these 13 *O. mykiss*, nine (70%) were previously detected at the LI; these nine fish ranged in size from 77 to 208 mm FL and took 28 min to 85 d to pass through the LSW.

At both high and low discharges, the number of slow-moving fish passing through the treatment section was greater than the number moving through the control sections (Figure 4). Fish passing the treatment section moved more slowly ($\chi^2 = 3.9781$, $P = 0.046$) at low discharge versus high discharge, but no such difference ($\chi^2 = 0.023$, $P = 0.880$) was found for fish moving through the control sections. There was no evidence for size dependence in movement rate through the LSW at either low discharge ($r^2 = 0.049$, $P = 0.564$) or high discharge ($r^2 = 0.003$, $P = 0.774$).

Discussion

We found three additional species of fish above the LSW after its modification: juvenile Chinook salmon, juvenile coho salmon, and mountain whitefish. Although the observed number of fish from formerly excluded species was relatively low (<30), the numbers are likely to increase in the future. Access to new rearing area for these juvenile salmonids will hopefully lead to a sustained process of colonization. Anderson et al. (2008) speculated that juvenile salmonids using nonnatal streams may increase colonization if they return as adults to their rearing sites rather than to their emergence sites. In addition, enhanced tributary access may provide additional benefits to juvenile salmonids in comparison with rearing that is confined to the main-stem river. Murray and Rosenau (1989) observed that juvenile Chinook salmon that moved into nonnatal tributaries experienced increased growth compared with fish rearing in a main-stem river, while Ebersole et al. (2006) reported that juvenile coho salmon had greater overwinter growth and survival in tributaries than in a main-stem river.

We successfully monitored over 100 small fish moving upstream and past a series of RVWs at our LSW site. Small *O. mykiss* ranging from 86 to 238 mm AFL were able to move through the LSW within 1 h, but some took much longer (up to 98 d). The increase in the number of species and the recorded movements of small *O. mykiss* through the LSW indicated that the RVWs were effective at passing small fish upstream. However, the modification appeared just as effective in allowing small-sized fish of an introduced salmonid species, brook trout, to pass upstream.

Small fish were able to move through the RVWs at low discharge levels as documented by the passage of *O. mykiss* as small as 77 mm through the LSW when discharge was at the lowest recorded level. Fish passing upstream through the treatment section at low discharge took a longer time than fish passing upstream through a control section. The treatment and control sections did differ in character. The control sections were more representative of a low-gradient pool–riffle complex, while the treatment section was more representative of a high-gradient pool–riffle complex. Ovidio and Philippart (2002) found that areas downstream of blockages provided good habitat for several species of fish, and Jungwirth (1996) observed that fish in pools created by natural-style passage structures were found in the same pool for months after initial sampling. The range in travel time (from 28 min to over 98 d) through the LSW may be related to the pools created downstream of each RVW, which could provide good habitat for the fish and less motivation for instream movement.

We could not identify the number of fish that made unsuccessful attempts to pass upstream and over the LSW. However, all nine *O. mykiss* (77–208 mm FL) that expressed definitive upstream movement (fish that moved distances >3 km) from the fish trap to the LI were also detected at the UI, upstream of the LSW. In addition, we found no evidence that fish were unsuccessful in their attempts to pass upstream and over the LSW (i.e., fish moving upstream from the fish trap and detected at the LI but not at the UI). Because the proportion of fish detected as moving upstream was reasonably high (70%) at the LI, we would expect that if fish were unsuccessful in their attempts to pass the RVWs, some individuals would have been detected at the LI as moving back downstream. No fish were observed to move back downstream. Nonetheless, our design was probably better at recording success rather than failure of passage through the series of RVWs.

It is difficult to decipher failure because small *O. mykiss* in our study could not be assumed to have a definitive motivation for moving upstream, unlike the upstream movement of adult steelhead near spawning time or the downstream movement of steelhead smolts. Cargill (1980) reported that wild rainbow trout in small streams exhibited no significant upstream or downstream movement after 2.5 years. Furthermore, Helfrich and Kendall (1982) found that hatchery-released rainbow trout in a mountain stream showed mostly local movements within 1 km of their stocking locations and that most of the fish moved downstream. Although Leider et al. (1986) provided some evidence of upstream movement (up to 2 km) by presmolt steelhead, most parr emigrated downstream. McMichael and Pearsons (2001) reported that residual hatchery steelhead moved over 12 km upstream. The relatively low portion of *O. mykiss* that were tagged at

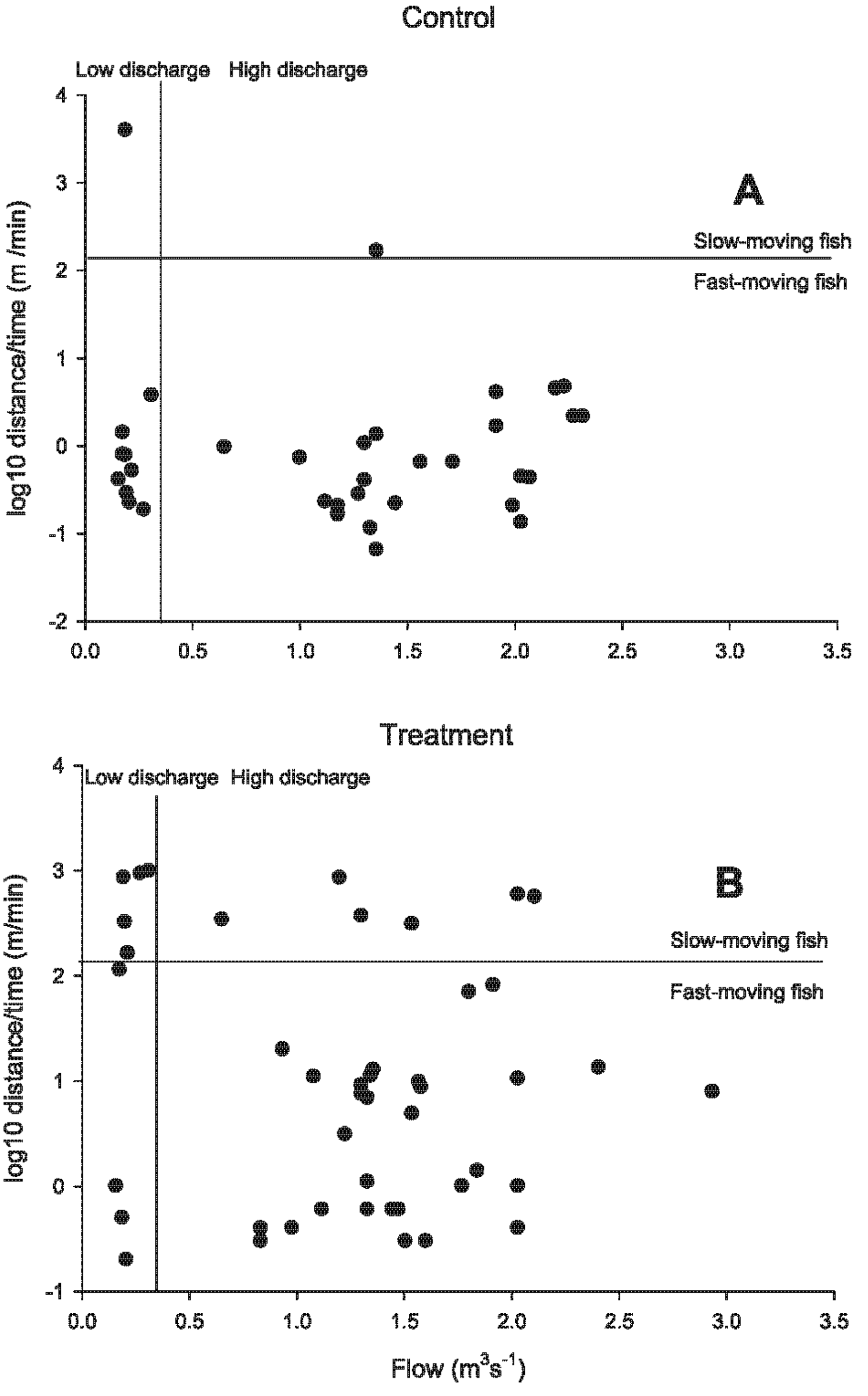

FIGURE 4.—Upstream fish passage events for fast- and slow-moving ($\log_{10}$[distance/time]) juvenile steelhead or rainbow trout during low and high flows at **(A)** a set of passive integrated transponder (PIT) tag antennas (control sections) and **(B)** a series of rock vortex weirs (treatment section).

the fish trap (>3 km downstream) and detected (13 fish) or recaptured (5 fish) at or above the RVWs indicates that small *O. mykiss* lacked motivation to move large distances upstream in Beaver Creek.

Water use in eastern Oregon and Washington has increased as irrigation has made large areas of land more useful for agriculture (Wissmar et al. 1994). Farmers and ranchers have come to rely on this water to grow crops and raise cattle. Unfortunately, the increase in irrigation via water diversions has often been at the expense of threatened and endangered aquatic species. Habitat enhancement measures, such as installation of RVWs, have been widely implemented to reduce human impacts, but the effectiveness of RVWs for fish had not been well documented (Roni et al. 2002) due to the lack of funding and appropriate methodologies to conduct definitive studies. Our work demonstrates an effective method for testing these enhancement measures and shows that RVWs are effective at passing small fish upstream. Modification of a century-old barrier helped to restore longitudinal connectivity of depressed native salmonid populations, but it also facilitated movement by brook trout, an introduced species.

Acknowledgments

Much of the PIT tagging field work and day-to-day maintenance of the interrogation systems was conducted by Brian Fisher and Wesley Tibbits (U.S. Geological Survey). The interrogator sites were located on private land, and we greatly appreciate the access granted by landowners Vic Stokes and Gary Ott. Development, installation, and maintenance of the multi-antenna PIT tag detection system were due in large part to the expertise of and collaboration with Earl Prentice (National Oceanic and Atmospheric Administration Fisheries). We acknowledge collaborators Steve Clayton and Denis Ruttenberg (University of Idaho) for their help in understanding the dynamics of RVWs and for providing flow records from 2005 to spring 2006. The Beaver Creek work was supported from a larger effort that was funded by the U.S. Bureau of Reclamation and administered by Dana Weigel and Michael Newsom. In addition, we thank Dana Weigel for her review of this document. We are also grateful to two anonymous reviewers for their review of an earlier draft of this manuscript. Any use of trade names is for descriptive purposes only and does not imply endorsement of the U.S. Government.

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Lower Methow Tributaries Intensive Effectiveness Monitoring Study

Interim Report

For the period: July 2004-November 2006

January 2008

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Introduction

Actions have been taken to replace diversion dams in lower Beaver Creek with a series of rock vortex weirs. Some of these diversion dams have been in place for over 100 years, and they have impaired or completely blocked upstream migration of fish. Three diversion dams were replaced in 2003 (Lower Stokes, Thurlow Transfer, and Upper Stokes), and a forth diversion dam was replaced in 2004 (Fort-Thurlow). These vortex weirs were designed and installed under the supervision of U.S. Bureau of Reclamation (BOR) engineers and completed in accordance to National Marine Fisheries Service (NMFS) and Washington Department of Fisheries and Wildlife (WDFW) fish passage criteria. The projects were designed to meet fish species recovery needs described by the Endangered Species Act (ESA) and the “BiOp” issued by NMFS (2000a). Since no specific guidelines have been identified to date specifically addressing diversion dams, WDFW and NMFS guidelines are being considered as the target design and performance criteria for the sites monitored as part of this project. Where used, the vortex weirs were designed to maintain irrigation diversion capabilities while improving fish passage.

Because installing rock vortex weirs represents a relatively new methodology and little information was available for their effectiveness of passing fish species of the Pacific Northwest, an effectiveness monitoring effort was warranted. Effectiveness monitoring evaluates whether the management action achieved the desired effect or goal. Success is measured against a pre-determined performance standard or a desired future condition. The change (or effect of a project) is measured against controls or pre-treatment conditions, and aims to develop a mechanistic understanding of the relationships between fish population response and various habitat management actions (Hillman and Giorgi 2002). The habitat improvement actions in the study area were not coupled with a fisheries management action, such as stocking. Therefore, recolonization of newly opened habitat by fish, especially salmon, steelhead, and bull trout, will rely on adult straying or juvenile migration into treatment basins.

The U.S. Geological Survey’s Columbia River Research Laboratory was contracted to assess the effectiveness of the vortex weirs for providing the desired fish passage. The specific objectives of the study were to: 1) Assess current and potential anadromous fish and bull trout production in Gold, Libby, and Beaver creeks associated with presence or removal of irrigation diversion passage barriers, 2) Assess effectiveness of modified irrigation diversion structures for passage of fish and subsequent changes in fish populations in Beaver Creek, 3) Relate hydraulic and sediment transport responses to and effectiveness of the installation of new irrigation diversion structures at 3-4 locations on Beaver, Libby, and/or Gold creeks [This objective was conducted through a CESU agreement with the Ecohydraulics Research Group at University of Idaho-Boise, the results of which are contained within a Master’s thesis (Ruttenberg 2007).], and 4) Work with cooperating agencies and established interagency groups to develop and implement a basin-wide research and monitoring plan for the Methow River and supplement project activities to further Objectives 1-3.

Important fish species that stand to benefit from these actions include ESA-listed species of steelhead *Oncorhynchus mykiss* (endangered), Chinook salmon *O. tshawytscha* (endangered), and bull trout *Salvelinus confluentus* (threatened). Effectiveness is being measured by changes in physical stream characteristics upstream and downstream of the structures, by monitoring upstream passage of fish, and by measuring change in fish assemblage, productivity, and genetics above the modified structures. To complement the fish productivity measures, the study includes extensive sampling to understand the relationships between stream habitat, life history aspects of various fish species, and genetic diversity, which will help to explain potential success or limitation to the fish community response in the treatment and non-treatment streams. The effectiveness of the modification of existing irrigation diversion structures is being measured by changes in fish assemblage and fish production. Isotope ratios in plants and aquatic life are being measured to detect change in anadromous fish use of the tributary systems. In a separate study, genetics of fish are being monitored to help us determine which of the many possible fish venturing into the newly opened tributaries were the most successful in producing offspring.

The study documents the physical and biological responses to the modifications of diversion dams that were implemented by the BOR at four sites on Beaver Creek: Lower Stokes (BOR 2004a), Thurlow Transfer (BOR 2004b), Upper Stokes (BOR 2004c), and Fort-Thurlow. A series of other barrier removal projects, such as culvert removals by the U.S. Forest Service (USFS), have been coincident with modifying these diversion dams. This study was designed to specifically measure important parameters listed in the Research, Monitoring, and Evaluation (RME) Plan (Jordan et al. 2003): size and age structure of fish populations, freshwater productivity, proportions of hatchery and wild spawners, biological and physical condition of spawning and rearing habitat, and habitat conditions and fish passage at the diversion structures.

Similar data are being gathered in the Libby Creek and Gold Creek watersheds. These two watersheds were sampled to serve as controls to help us judge the fish response to actions taken in Beaver Creek. However, the suitability of Libby and Gold creeks to serve as true controls were diminished when existing push-up dams were not maintained. Without these control streams, the project's focus is more concentrated on the specific performance of rock vortex weirs and the biological response in Beaver Creek. Tracking what transpires in Libby and Gold creeks was still considered important to increase our understanding of the variability in the recolonization process.

Fish passage through rock vortex weirs, such as those used in Beaver Creek of this project, have received little attention in lab and field studies. This may be due to their relatively recent use for fish passage compared to traditional approaches. Previous research has documented burst and sustained swimming speeds of salmonids and their ability to navigate through turbulence (Nikora et al. 2003). Similarly, jumping abilities of salmonids are well documented (WDFW 1999), including differences in species and life stages (Katopodis 1992, NMFS 2000b, Holthe et al. 2005). Results from these studies have been applied to the design of traditional fish passage structures (Katopodis 1992). Rock vortex weirs are likely to have complex hydraulics with more variables than some traditional fish passage structures controlling geometry, energy dissipation, and discharge.

Small diversion dams can limit the movement, distribution, and abundance of fish in a watershed. They can affect the composition of the fish community and the genetic interactions within and between fish species. In addition, diversion dams can have physical effects on local hydraulics, sediment composition, sediment transport, and quality of spawning and rearing habitat (Ruttenberg 2007). Removal of these diversion dams could have various positive and negative effects on fish populations. Positive effects of barrier removal could include access to previously blocked habitat, re-establishment of native fish populations, increased marine derived nutrients in the ecosystem, improved spawning and rearing habitat, and re-established connectivity of disjunct fish populations. Potential negative effects of barrier removal include colonization of less successful stocks of fish (such as hatchery strays), introduction of non-native species, introduction of disease by incoming fish, increased negative interactions among fish species, and increased intraspecific and interspecific hybridization rates. In addition to these biological constraints to success of the vortex weirs as a replacement, the modifications themselves may not succeed as promised. The current performance standard for diversion passage is to pass all fish at all flows (Hillman and Giorgi 2002), although some agency guidelines (e.g., NMFS 2000b) are slightly less restrictive. To assure that the standard is reached requires rigorous monitoring, especially for innovative designs that are not common to the landscape. Before designs are perpetuated across the landscape, their effectiveness needs to be assessed before large expenditures are made and potentially replicating flawed design elsewhere.

This interim report documents sampling efforts and preliminary findings from work conducted directly by USGS during summer 2004 through spring 2006. Collaborative work with personnel from UI (physical measures of hydrodynamics associated with the rock vortex weirs, fish passage past rock vortex weirs) and BOR (genetic analysis) that is ongoing or completed is largely not covered in this interim report.

Study Area

The Methow River is a fifth order stream in north central Washington State that drains into the Columbia River at river kilometer (rkm) 843 in the Upper Columbia River Basin. This study is focused on Beaver, Libby, and Gold creeks, three tributaries of the Lower Methow River subbasin (Figure 1). Beaver Creek is a third order stream that drains westward into the Methow River just south of Twisp, WA. Libby Creek is a third order stream that drains eastward into the Methow River at rkm 42, while Gold Creek is a forth order stream that drains eastward to the Methow River at rkm 35. Libby and Gold creeks drain off the east side of the Cascade Mountains, while Beaver Creek drains off a largely separated range to the east. Beaver, Libby and Gold creeks have much increased flows in early summer caused by snow melt, which is followed by low summer flows that are further decreased by numerous water diversions.

Various artificial and natural barriers exist in Beaver, Libby, and Gold watersheds (Table 1). Some of the artificial barriers were relatively permanent concrete dams, while others are, or were, “push-up” type structures. The degree of passage impediment that these concrete and push-up structures represent has likely varied much within and between years.

Upstream and downstream migrating fish need to travel through nine Columbia River dams to reach the Pacific Ocean. Out-migrating fish tagged with passive integrated transponders (PIT tags) have the potential to be detected on PIT-tag interrogators located at Rocky Reach, McNary, John Day, and Bonneville dams. Upstream-moving PIT-tagged fish have the potential to be detected on PIT-tag interrogators at Wells, Rock Island, Priest Rapids, McNary, and Bonneville dams.

Methods

Fish assemblage: electrofishing and trapping

Electrofishing: We used electrofishers to survey and collect fish throughout Beaver, Libby and Gold creeks. Getting fish to the hand allowed us to gain positive identification of species, to take basic fish metrics (length, weight), and to PIT tag fish for assessing fish movement within and among reaches and streams.

All electrofishing was conducted with a Smith-Root LR-24 backpack electrofisher with a setting of 90 Hz and 1-ms duty cycle. The voltage was largely determined by the suggested setting from the manufacturer’s calibration setting.

Weir: A fish trap was installed in fall 2004 near rkm 1 in Beaver Creek, which was below all fish diversions (Figure 2). The trap consisted of four wings of 0.25-in aluminum conduit spaced 0.25 in apart that directed fish to the upstream or downstream trap (Figure 3). The trap had an upstream and downstream box that was located in the deepest part of the stream. In spring 2005, the trap was modified to prevent fish from escaping the downstream trap. The modification consisted of moving the two upstream wings above a riffle, just upstream of the trap, and attaching them to an aluminum plate with a large hole in the bottom. We then inserted a large PVC pipe that connected the aluminum plate to the downstream trap. After modification, the water would fall from the pipe into the trap preventing fish from swimming back up the pipe. In fall 2006, we attached an additional one-directional box trap, without the wire-mesh back, in front of the upstream two-directional trap. This resulted in a two-staged trap design, which was devised to catch adult fish in the downstream section of the trap and juvenile fish in the upstream section of the trap (Figure 3).

The USGS field crew checked the trap at least once a day to collect fish and remove debris. During the fall, when leaves and other debris were more abundant in the stream, the trap was cleaned twice a day. To clean the trap, the conduit pieces were pulled up from the weir frame to wash the debris past the trap and relieve pressure that could result in trap blowout. Most fish collected at the trap were fin clipped for genetic samples and tagged with passive integrated transponder (PIT) tags.

<u>Fish handling:</u> Fish collected by electrofishing or in the trap were anesthetized with a light dose of MS-222 before handling. All fish captured were measured for fork length to the nearest mm, weighed to the nearest 0.1 g, and inspected for external signs of disease. A small number of scales were taken from larger fish (>250 mm), from fish that appeared to be between age-0 and age-1 or older, and from recaptured fish. Tissue for genetic analysis were clipped from the caudal fin of salmonids collected at the trap (with few exceptions) and from some salmonids at selected reaches. They were then stored in small plastic vials of 100% non-denatured ethyl alcohol. When possible, fish that died during sampling or abnormal looking fish were frozen and sent to U.S. Fish and Wildlife Service's Lower Columbia River Fish Health Center (USFWS-LCRFHC) for disease analysis. In order to track movements, growth, and survival of juvenile steelhead trout, we PIT-tagged fish that were 65-mm fork length or longer. After handling, fish were held in fresh ambient-temperature stream water and released near their point of capture after regaining equilibrium.

Fish movement: tagging and detecting

<u>PIT-tagging:</u> All PIT tagging followed the procedures and guidelines outlined by Columbia Basin Fish and Wildlife Authority (1999). Most fish were PIT tagged using a thin-walled, 12-gauge needle to insert a 134.2 kHz, 12-mm tag, but 27 fish were tagged with similar but larger, 23-mm tags, which required a scalpel to make a small slit for manual insertion of the tag. For small juvenile fish (65-200 mm), the PIT tag was inserted just beneath the pectoral fin and into the fish's abdomen. With large juvenile (>200 mm) or adult fish, we inserted the tag into the dorsal sinus to prevent tag loss that could occur with abdomen-inserted tags during spawning events. Because PIT tags have an effective life of over 10 years (Prentice et al. 1990), salmonids implanted with PIT tags provide the opportunity for recapture and data collection throughout the life of a fish. All PIT-tag and recapture data were submitted to the PTAGIS database administered by Pacific States Marine Fisheries Commission (PSMFC).

<u>PIT-tag interrogator systems:</u> Interrogation systems were installed in three lower Methow subbasin tributaries at ten sites from September 2004 to November 2005. We maintained and operated two large PIT-tag interrogation systems that could detect directional fish movement and eight small single-antenna PIT-tag interrogation systems to help determine fish presence and determine fish movement (Figures 2, 4, and 5).

The two large PIT-tag interrogation systems were installed in Beaver and Gold creeks. One system was placed in Beaver Creek above the second lowest water diversion (Figure 2), and the second system was installed in Gold Creek about 100-m upstream from the confluence with the Methow River (Figure 5). These large systems consisted of a FS 1001M Digital Angel multiplexing PIT-tag transceiver, six custom-made antennas, and a DC power source. These systems were built and installed by a crew from NOAA Fisheries led by Earl Prentice. A crew from USGS helped with site selection and installation of the systems. The six antennas were arranged in three arrays, with two antennas in each array. This was done to assess direction of moving fish and to cover most, if not all of the stream. The antennas were installed using two configurations. The first and most common configuration was where all four corners were tied to the stream bed creating a "pass-by" configuration. In the second configuration, the upstream side of the antenna was attached to the stream bed. This configuration allowed the downstream side of the antenna to rise and fall in the current, which would potentially increase read range, but also left the antenna more vulnerable to debris and high water. The Beaver Creek interrogator, and a similar unit deployed in Rattlesnake Creek in southern Washington, have been shown to have detection efficiencies that exceed 96% during high flow periods and approach 100% during low flow periods (Connolly et al. *In press*).

Eight small interrogators were distributed throughout Beaver, Libby, and Gold creeks. The small PIT-tag interrogators consisted of a 2001F-ISO Digital Angel PIT-tag transceiver, a 12-volt battery, and a single antenna. Initially we used rectangular antennas manufactured by Biomark (0.8-m length by 0.3-m width), but by the second year of the study, we were using our own custom-made rectangular antennas. These antennas allowed increased flexibility in the size of the antenna, so that an antenna could be custom-fit to a specific site. Maximum size was limited to 1.8-m in length and 0.3-m in width to insure desired electronic properties. Three of these small systems were deployed in each of Beaver and Gold creeks, and two systems were deployed in Libby Creek. In Beaver Creek, one system was installed just upstream of the fish trap, which was below all water diversions. A second system was installed just below a water diversion that was near our lowermost index site (R1), and a third system was installed in the upper watershed below the confluence with South Fork Beaver Creek (Figure 2). One of the Libby Creek systems was deployed near the Highway 153 Bridge, below the lowermost water diversion, and the other was deployed above the lowermost diversion (Figure 4). The small systems deployed in Gold Creek were located just above the confluence with Foggy Dew Creek, in Foggy Dew Creek just above its mouth, and in South Fork Gold Creek above the last parcel of private land (Figure 5). Batteries were swapped at the small interrogators twice a week.

Fish population estimates

Six sites dispersed among the three watersheds were sampled to obtain population estimates. The location of these sites within watersheds was based largely on geomorphology. University of Idaho personnel provided us the information on geomorphic reach breaks. One site was located in each of the lowermost reach of each watershed, and no reach contained more than one site. Final location of sites was largely determined by access, which required gaining written landowner permission in some cases. Three 500-m sites were selected in Beaver Creek (Figure 2), one 1000-m site in Libby Creek (Figure 4), and three 500-m sites in the Gold Creek (Figure 5). An additional 500-m site was added to Libby Creek in 2005.

Population assessments began with a habitat survey, which was used to stratify the fish sampling effort based on habitat unit types (e.g., pools, glides, riffles, and side channels). In cases where a habitat unit was unable to be sampled, the next unit within the same stratum was sampled. Habitat units chosen for electrofishing were blocked off with nets to insure no immigration or emigration of fish. A backpack electrofisher was used to conduct two or more passes using the removal-depletion methodology (Zippin 1956; Bohlin et al. 1982; White et al. 1982). The field guides of Connolly (1996) were used to determine the number of passes necessary to insure that a controlled level of precision in the population estimate was achieved (CV < 25% for age-0 salmonids and CV < 12.5% for age-1 or older salmonids) within each sampling unit for each salmonid species (steelhead/rainbow trout, brook trout, bull trout, cutthroat trout, and Chinook salmon) and age group (age-0 and age-1 or older). These methods were chosen to minimize the number of units sampled and the number of passes per unit. This approach lessened the chance that individual fish would be exposed to the effects of electrofishing while it insured a high degree of precision in our estimates. When not obvious in the field, we used a fork length of 80 mm as a separation point between age-0 from age-1 or older fish.

Fish growth

Surveys were conducted during the spring, summer, and fall to collect previously PIT-tagged fish to determine growth of individual fish. Electrofishing was used to collect fish from our three Beaver Creek, two Libby Creek, and three Gold Creek index sites. In addition, we were able to collect growth data from fish collected at the Beaver Creek fish weir. Recapture data were collected and sorted into the season of year they were collected. Recapture events were used when a fish was captured within the next season from its tagging or last recapture event. Since no sampling occurred during winter, we assessed growth for fish tagged (or recaptured) in the fall and recaptured in the spring. Recaptured fish were used only if they were recaptured after 10 days of their tagging or last recapture date. We defined seasons as: spring (March-May), summer (June-August), fall (September-November), and winter (December-February).

Isotope study

We chose three sites in Beaver Creek and two sites in Gold Creek for isotope analysis (Figures 6 and 7). The lowest Beaver Creek site (rkm 3) was picked because it was above two water diversions, and we expected to see a large increase in anadromous fish in this reach after the diversions were reconstructed. The middle Beaver Creek site (rkm 13) was selected because we expected to see some but limited anadromous fish use after the water diversions had been reconstructed. The upper most site, located in South Fork Beaver Creek (rkm 3), was selected because we did not expect to see an influence from anadromous fish, and thus, it would serve as a control. The lowest Gold Creek (rkm 5) site was selected because we expected to have anadromous fish present when no downstream barriers were present. An upper Gold Creek site (rkm 11) was selected as a control site because it was expected to remain inaccessible to anadromous fish.

Samples for isotope analysis were collected from fish, algae, leaves (cottonwood, red alder), and insects during fall 2004, spring 2005, and fall 2005. At each site, we collected six fish from the dominate fish species at each site, including three age-0 fish and three age-1 or older fish. We attempted to collect three samples from other fish species present if they could be collected in a reasonable amount of time. Algal samples were collected at each site by scraping rocks and picking filamentous algae. Samples of decomposing leaves were collected from red alder and cottonwood foliage found within the bankfull width of the stream. We disturbed the substrate from the stream bed to disperse insects into a D-net to collect insect samples. All samples were taken back to the field station and placed in a small freezer until the samples could be further prepared for analysis.

In the laboratory, the insect samples were allowed to thaw before they were processed. The insects were separated into three feeding groups (predators, shredders, and collector/gathers). We then selected samples that were found at multiple sites for further processing. In cases where we did not have enough of a sample from one species of insect, we used a combination of different species from the same feeding group to get a larger sample. All fish, algae, leaves, and insects were dried in an oven at 60 C for at least 48 hours. A mortal and pestle were used to crush the samples into a fine power. The samples were weighed to 0.002 – 0.003 g for plant tissue or 0.0008 – 0.0012 g for animal tissue, and sealed in aluminum capsules for analysis. The samples were then sent to the University of California – Davis, Department of Plant Sciences, for dual isotope analysis of Carbon 13 and Nitrogen 15 levels.

Diversion study

During summer 2005, we tested the effectiveness of a fish screen within a diversion canal designed to return fish to the stream after being in the first 20 m of the canal. We installed two small PIT-tag interrogation systems in the diversion canal, which was co-located above the uppermost rock vortex weir in Beaver Creek at rkm 5. The upper interrogator was located at the downstream end of the inlet pipe. A second interrogator was installed downstream of the fish screen and bypass pipe of the diversion canal. These interrogation systems ran from 28 July 2005 until 31 August 2005.

To collect test fish, we used a backpack electrofisher in the section of stream adjacent to the water diversion. We tagged and released a minimum of 30 fish on three occasions. Releases were approximately one week apart. The first release was on 28 July 2005, and the final release was on 12 August 2005. Data from the interrogators were downloaded every third day. On 31 August 2005, the fish remaining in the canal were removed with a backpack electrofisher. When we were reasonably confident that no fish remained in the diversion, we removed the small interrogation systems from the diversion canal. We used the number of fish returned to the stream and those recaptured in the upper diversion canal to assess the number of fish that were not diverted back to the stream by the screen as desired.

Results

The results we present below are intended to characterize the kinds, breadth, and variability of data collected to date. In general, it was considered too early in the study to present an analysis of the data to directly assess the effectiveness of the restoration action being tested, i.e., replacement of diversion dams with rock vortex weirs. This planned analysis will be the subject of a final report, which will include the data presented here plus data collected during additional years, 2007-2008.

Fish assemblage: electrofishing and trapping

We encountered at least ten species of fish in 2004-2005 (Table 2). Rainbow trout/juvenile steelhead was the most common fish species collected (Table 3), followed by brook trout and sculpin (which may have been represented by one or more species). From 2004 to 2006, the percentage of mortalities from the weir ranged from 0 to 2.0 percent per year, while the percent of mortalities from electrofishing ranged from 1.2 to 4.9 percent per year.

Beaver Creek: From 2004 to 2005, we tagged 3,300 rainbow trout/steelhead, 312 brook trout, 265 Chinook salmon, 16 coho salmon, 13 bull trout, and 5 cutthroat trout in Beaver Creek (Table 3). Juvenile Chinook salmon were encountered below the first diversion in 2004 and 2005. In 2005, two juvenile Chinook were collected near the R1 index site, above the two rock vortex weir structures. One adult Chinook was spotted in a water diversion (rkm 10) above all reconstructed water diversions during the summer 2006. Bull trout were found in Beaver Creek above the confluence with South Fork Beaver Creek, and they were collected in the fish trap. The largest number of bull trout (10) was found in Blue Buck Creek. Bull trout (>176 mm) were collected at the fish trap, located 1 km from the mouth of Beaver Creek. Westslope cutthroat trout were collected in Lightning Creek and the upper reaches of Beaver Creek. Sculpin were found in Beaver Creek from the mouth up to rkm 15, but were not found in any of the Beaver Creek tributaries. All other species were encountered within 1 rkm of the confluence with the Methow River.

Libby Creek: We found rainbow trout/juvenile steelhead in every reach and tributary sampled in the Libby Creek watershed (Table 2). From 2004 to 2005, we tagged 1,217 rainbow trout/steelhead, 2 Chinook, 1 bull trout, 82 westslope cutthroat trout, and 10 brook trout (Table 3). In 2004, one juvenile Chinook was collected above the water diversion in the R1 index section. In 2005, we collected one juvenile bull trout in R4 index site of Libby Creek. Westslope cutthroat trout were found in South Fork Libby Creek, North Fork Libby Creek and smaller numbers existed in the upper reaches of Libby Creek. Brook trout were present in low numbers, most found near the connection with Mission Pond. No sculpin were collected or observed in Libby Creek.

Gold Creek: Rainbow trout/steelhead were found at every site sampled in the Gold Creek Watershed (Table 2). From 2004-2005, we tagged 1,359 rainbow trout/steelhead, 4 Chinook, 64 bull trout, 70 westslope cutthroat trout, and 9 brook trout (Table 3). Juvenile Chinook were collected above the water diversion at rkm 4.4 in 2005. Bull trout and westslope cutthroat trout were encountered above rkm 7.4 in Gold Creek and in Foggy Dew and Crater creeks. Brook trout were limited to the Middle Fork Gold Creek.

Fish movement: tagging and detecting

Beaver Creek weir: We collected 133, 1,965, and 980 fish from at least ten species at the weir in Beaver Creek during 2004, 2005, and 2006 respectively (Table 4). Rainbow trout/juvenile steelhead made up 66% of the fish collected at the trap from 2004 to 2006. In 2006, we collected increased numbers of brook trout and longnose dace with the trap, and we collected a cutthroat trout for the first time.

Rainbow trout/juvenile steelhead emigration was prominent in April through June and in September through November (Figure 8). A large emigration of rainbow trout/juvenile steelhead and juvenile Chinook occurred during fall 2005. Most juvenile fish immigration started in early spring and lasted into early summer.

In 2005, downstream-moving adult steelhead started showing up at the Beaver Creek weir near the end of March, and they were detected through May (Figure 9). It was apparent that adult steelhead had already moved upstream before the trap was put in place in mid-March. In 2006, adult steelhead were trapped starting in mid-March and lasting into April. All fish except one was collected in the upstream trap. The low catch of downstream moving fish was likely due to high flows that washed out the trap for parts of April and the last half of May, but was reinstalled by end of June. In July 2006, we collected the first adult Chinook in the upstream trap. We later collected three adult Chinook in the downstream section of the trap. We could have missed some or most of the upstream migration for adult Chinook, and possible a few adult steelhead, while the trap was inoperable during high flows.

<u>Beaver Creek watershed:</u> In Beaver Creek, a total of 3,702 PIT-tagged rainbow trout/juvenile steelhead were available for our analysis of movement, which included fish tagged through spring 2006 (Figure 10). As of spring 2006, 93 rainbow trout/juvenile steelhead had been detected outside of Beaver Creek watershed: at the Lower Methow River smolt trap or at one or more of the detection sites in the Columbia River. In May 2006, only one rainbow trout/juvenile steelhead tagged above rkm 6 was detected, at Bonneville Dam, outside of Beaver Creek watershed. Over 30% of the emigrating fish were released at our R1, 500-m index site located at rkm 5.

Upstream migrating adult steelhead moved from Bonneville Dam to the lower Methow River tributaries between 122 to 334 days. The median number of days spent above Wells Dam, the last Columbia River dam before its confluence with the Methow River, ranged from 177 to 209 days (Table 5). Beaver Creek juvenile steelhead had the largest number of emigrants in the spring and fall (Figure 11). Spring movers made up 48% of the total emigrants, while fall movers made up 46% of the total emigrants. The spring emigrants traveled past John Day Dam in a median of 19 days, while fall emigrants traveled in a median of 200 days (Table 6). Most juvenile Chinook emigration in Beaver Creek occurred in the fall and winter (Table 7). Gold Creek juvenile steelhead had similar patterns as those in Beaver Creek, although spring migrating fish from Gold Creek moved into the Columbia River quicker. The large PIT-tag interrogator in Gold Creek was installed in late fall 2005 (10 November 2005), possibly missing most if not all of the fall emigration that occurred in Beaver Creek (Table 8).

The number of fish in Beaver Creek moving between PIT-tag interrogators increased in the spring and fall. During the winter months, there was little or no movement, with interrogations showing mostly local movement. In summer 2005, from July to mid-August, we observed a small number of fish emigrating. While most downstream movement occurred in April through May, we detected a second round of movement starting in mid to late September and lasting into early December (Figure 12). In early spring 2005, juvenile steelhead and Chinook emigrants from Beaver Creek started showing up downstream at detectors in Columbia River dams. The majority of these fish were detected at McNary and John Day dams in May (Figure 13).

We detected 10 hatchery steelhead in Beaver Creek, 3 as adult strays and 7 as juveniles, moving upstream from the Methow River (Table 9). All hatchery strays were either raised in Wells Hatchery (5 fish) or at the Winthrop Hatchery (5 fish). Fish from the Winthrop Hatchery were all released at the hatchery. Stray fish from Wells Hatchery had been released in the Twisp River, except one of these stray fish had been released in the Chewuch River.

After the reconstruction of the lowermost remaining water diversion in Beaver Creek, we collected or detected mountain whitefish, coho, and juvenile and adult Chinook at the R1 index site or large interrogator (Figure 14). As of 2005, five tagged fish had made multiple trips between rkm 5 and rkm 1, bracketing two reconstructed water diversions (Figure 15). Of the five fish, only one fish (brook trout) traveled down to rkm 1 and then moved back upstream to rkm 5, the rest moved upstream and then moved back down. Two fish (1 adult steelhead, 1 rainbow trout/juvenile steelhead) moved upstream to at least rkm 5 and then moved back down to the trap site in less than two months. Two rainbow trout/juvenile steelhead moved independently upstream past rkm 5 from June-July and held above the interrogator until October-November when they moved back downstream past the trap site.

Of those detected, most rainbow trout/juvenile steelhead traveled from the trap site (rkm 1) upstream to the detector site above the Fort-Thurlow (rkm 2) and Lower Stokes rock vortex (rkm 3) weirs in the first 20 days after handling at the trap. The fastest moving juvenile fish traveled upstream through the two rock vortex weir structures in two days. Four fish took 101 to 300 days to move upstream past the R1 index site (Figure 2). Most upstream movement of rainbow trout/juvenile steelhead occurred from June to July (22 of 27 fish), with two or fewer fish moving in April, May, September, and November. Of the 18 juvenile rainbow trout/steelhead that were observed to move upstream through the rock vortex weir structures, from the small PIT-tag interrogator (just below the Lower Stokes diversion) to the large PIT-tag interrogator (just above the Lower Stokes diversion), five did so within 10 hours. Half of the upstream moving juvenile fish moved above the diversion within 40 hours. The rest of the juvenile steelhead that definitively passed the diversion took over 50 hours (up to 2,400 hours). Rainbow trout/ juvenile steelhead moved upstream past one diversion with flows as low as 2.3 cfs (Figure 16). Most of the upstream movement from rainbow trout/juvenile steelhead occurred in June and July.

Two adult steelhead moved up within two days of being released from the trap, while most held between the trap and our first index site (R1) from 17-50 days before moving past the two rock vortex weir structures (Figure 17). All adult steelhead detected at the interrogator just below Lower Stokes moved upstream through the Lower Stokes rock vortex weir structure in less than one hour (Figure 18).

Libby Creek watershed: Juvenile steelhead emigrants were tagged up to rkm 5 in Libby Creek (Figure 19). One adult steelhead was spotted at rkm 10 while shocking in spring 2005. Less than 1% of fish tagged near rkm 1.0, above the first water diversion barrier, were detected outside of Libby Creek. Eight percent of the fish tagged below this barrier were detected outside of Libby Creek.

Interrogators in Libby Creek detected seven hatchery steelhead (6 adults, 1 juvenile) migrating into Libby Creek. Two of the adult hatchery fish detected in Libby Creek were originally released as juveniles in Nason Creek of Wenatchee River Watershed (Table 9). Only one of the seven hatchery strays moved in Libby Creek as a juvenile. Four of the hatchery fish were raised at the Wells Creek Hatchery, while one fish was raised at the Winthrop Hatchery. We did not detect any fish that were PIT tagged above rkm 3 at any of the instream interrogators, or at any of the Columbia River dams. A field crew spotted an adult steelhead near rkm 10 during spring 2005.

Gold Creek watershed: Juvenile steelhead emigrants were interrogated at Columbia River dams from fish released in North Fork Gold Creek, Foggy Dew Creek, and South Fork Gold Creek (Figure 20). We detected 14 hatchery steelhead (12 adults, 2 juvenile) in Gold Creek; all but 1, detected at the South Fork Gold Creek interrogator, after installation of the large PIT-tag interrogator was installed in late fall 2005 (Table 9). Ten hatchery fish were raised at Wells Hatchery and released in various locations in the Methow River watershed or the Wells Hatchery. One fish was raised and released at the Winthrop Hatchery. Three hatchery fish were detected from outside the Methow River watershed: two fish were released in the Wenatchee River watershed, and one fish was raised and released at the Ringold Hatchery. Two adult hatchery fish have been detected by the South Fork Gold PIT-tag interrogating system.

Population estimates

Beaver Creek: In Beaver Creek, age-0 and age-1 or older rainbow trout/juvenile steelhead were most prevalent at the lowermost (R1) index site (Figure 21). The age-1 and older rainbow trout/steelhead biomass at the R1 index site had almost double the biomass of the other index sites sampled in the Methow watershed. We found similar results of age-1 or older fish/m from 2004 to 2005. The population of age-0 rainbow trout/juvenile steelhead decreased in the R1 and R2 index sites in 2005, while the R4 index site's population increased (Figure 21). The biomass of rainbow trout/juvenile steelhead in R1 and R2 decreased from 2004 to 2005, while the biomass increased in R4 (Figure 22). The population of age-0 and age-1 or older rainbow trout/juvenile steelhead in Beaver Creek decreased at each upstream sampling site (Figure 23).

Brook trout were commonly found at all of our Beaver Creek index sites (Figure 22). The largest concentration of brook trout was found at the R4 index site (0.21 age-0 fish/m and 0.13 age-1 or older fish/m) in 2005. This was an increase from the 0.04 age-0 fish/m and 0.04 age-1 or older fish/m in 2004. Age-0 brook trout increased four fold in R1, from 0.03 fish/m in 2004 to 0.12 fish/m in 2005.

<u>Libby Creek:</u> The lower Libby Creek (R1) index site population of age-0 and age-1 or older rainbow trout/juvenile steelhead increased over 30% in 2005. This R1 index site was the only index site in the Methow River watershed to show an increase in both age-0 and age-1 or older steelhead from 2004 to 2005. In 2005, we added a new site in upper Libby Creek (R4), which contained 0.37 fish/m of age-0 rainbow trout/juvenile steelhead compared to 1.04 fish/m age-0 rainbow trout/juvenile steelhead in R1. The population of age-1 or older rainbow trout/juvenile steelhead were similar between the two Libby Creek sites (0.85 fish/m in R4 and 0.99 fish/m in R1). Rainbow trout/juvenile steelhead collected in R4 (4.06 g/m^2) had higher biomass estimates than fish in R1 (3.6263 g/m^2) even though R1 contained more fish (Figure 24). No other fish species had a population over 10 fish at the R1, 1,000-m site or the R4 500-m site.

<u>Gold Creek:</u> In 2004, North Fork Gold Creek index site (NF) had more age-0 rainbow trout/juvenile steelhead (1.66 fish/m) than any other index site in the Methow River watershed. The Foggy Dew (FG) and South Fork Gold (SF) index sites had similar numbers of age-0 and age-1 and older rainbow trout/juvenile steelhead for 2004 and 2005. The 2004 population estimates for age-1 or older rainbow trout/juvenile steelhead in the NF, FG, and SF sites ranged between 0.57-0.60 fish/m. In 2005, the NF index site's age-1 and older population increased, while the FG and SF populations were similar to the 2004 estimates (Figure 21).

Bull trout have been collected at NF and FG index sites in the Gold Creek watershed. The population of age-0 of bull trout in the FG index site decreased in 2005. We did not collect any age-1 or older bull trout in 2004, but several were collected in 2005. In 2004, no bull trout were detected in the NF site, but we had a population of 0.02 fish/m in 2005 (Figure 25).

Fish growth
Recapturing PIT-tagged fish allowed measuring growth over time for individual fish (Figure 26). Growth of rainbow trout/juvenile steelhead expressed a highly seasonal pattern, with most growth occurring during the spring-summer time period and the least growth during winter (Figures 27 and 28; Appendix Tables 1-9).

Isotope analysis
Because of the infancy of our analysis, we did not attempt a statistical analysis of the isotope data. Rather, we present a brief qualitative analysis. Five sites (three in Beaver Creek, two in Gold Creek) were sampled on three occasions, in fall 2004, spring 2005, and fall 2005. The ratio of Nitrogen 15 to Nitrogen 14 were highest for the lower Beaver Creek site, while the ratio of Carbon 13 to Carbon 12 were similar between sites within a watershed, but generally higher in Beaver Creek than in Gold Creek. For the dominate age-1 fish, marine derived 15N ratios were highest at the lowest site on Beaver Creek, with an average delta 15N just under 11‰. All other sites including the lower Gold site had levels <9‰ (Figure 29). The isotope levels remained relatively consistent during all three sampling periods. Age-0 fish had similar patterns to the age-1 fish with high levels of 15N in the lowest Beaver Creek site (Figure 29). In sites where sculpin were present, they had similar results to the age-1 and age-0 fish (Figure 29). Marine-derived 13C

ratios had relatively similar levels at three sites in Beaver Creek with a lower level in the two Gold Creek sites. The levels appear to be consistent during all three sampling occasions (Figure 30).

Vegetation samples showed a similar pattern of Nitrogen ratios in fish, but a different pattern for Carbon. Algae samples had a consistently higher nitrogen level at the lower Beaver Creek site through all three sampling occasions (Figure 31). Cottonwood leaves collected at the sites were inconsistent at several sites due to trouble finding enough samples at each site (Figure 31). The ratio of Carbon 13 was higher in all Beaver Creek sites than the Gold Creek sites (Figure 32). The ratios of N15 in algae were higher in the two Gold Creek sites during the fall than in spring, while the highest levels were found in R1 of Beaver Creek.

The predator insect group had a high nitrogen ratio in fall 2005, slightly higher than the ratio in spring 2005 (Figure 33). The collector-gather group had the highest nitrogen ratios for all three sampling occasions at the lowest Beaver Creek site. We had one sample of collector-gathers at the upper Beaver Creek site in fall 2004 that had a ratio similar to the samples at the lower Beaver Creek site (Figure 33). The fall 2005 sample of scrapers, from the lowest Beaver Creek site, had a wide range of nitrogen with one sample having higher 15N ratio typical of other samples at this site (Figure 33). The insect samples collected in Gold Creek had lower levels of Carbon 13 than the samples collected at Beaver Creek (Figure 34).

Diversion study

Three trials of 33, 30 and 30 fish were planted in the middle of the water diversion canal. Most fish planted in the water bypass section of the water diversion, left the diversion by moving upstream and exiting through the upper section of the diversion. In 2005, 75% of all fish released in the diversion were detected leaving the diversion, 16% of the fish were later recaptured in the water diversion, and 5% of the fish were never detected again (Figure 35). Of the 91% of fish with known origins, the majority of fish left the diversion with-in the first day of being released and 70% of the fish left the diversion within five day of being released (Figure 36). In all three of the trials, there were times when the reader was not operating, which could possibly account for all or some of the fish never detected.

Discussion

Much of data presented in this interim report will be used as baseline information to assess effectiveness of replacing diversion dams with vortex weirs to enable or enhance fish passage. Although this assessment did not have the luxury of pre-treatment years, the recolonization process is expected to take years to mature. The slow pace of the process in the initial years should allow an analysis of change over time. The role of monitoring Libby and Gold creeks, which were originally to be control streams with diversion dams in place, changed to “treatment-like” streams themselves when diversion dams eroded naturally (as in Libby Creek) or with human assistance (as in Gold Creek).

The primary goal of this report was to describe the methodologies, describe the types of data being collected, and summarize some initial findings so that the reader can gain a sense for the potential that this effort has to meet the objective of assessing effectiveness. Limited analyses beyond the observational and a summary treatment of data are offered at this time. We feel it much too preliminary of data to allow in-depth interpretation, and to do otherwise could result in spurious results.

Beaver, Libby, and Gold creeks were dominated by rainbow trout/juvenile steelhead. Brook trout were found in the upper reaches of Beaver Creek, and they dominate the South Fork Beaver and Middle Fork Beaver creeks. Brook trout were more limited in distribution in Libby Creek, with the only two individuals found around its confluence with Mission pond, and in Gold Creek, with all fish found in the Middle Fork of Gold Creek. We found bull trout in all three watersheds. In Beaver Creek, bull trout were found in Blue Buck Creek and the upper reaches of the mainstem Beaver Creek, as well as a total of four bull trout collected at the trap. Bull trout collected and PIT tagged at the trap were not subsequently detected in the upper section of the Beaver Creek watershed. One juvenile bull trout was collected in the upper Libby Creek index site. No other bull trout have been found in Libby Creek after several years of sampling suggesting limited use of Libby Creek. We found bull trout in all sections and tributaries of Gold Creek watershed above rkm 8. We have generally avoided sampling in areas with known populations of bull trout.

Juvenile Chinook were found above the water diversions in both Libby and Gold creeks. This suggests that the diversions are either seasonal or not barriers at all to adult Chinook or juvenile Chinook upstream migrants. Heavy winter run-off and unknown maintenance of these diversions has likely led to an improved condition of these water diversions for fish passage.

Modifications to the fish trap between fall 2004 and spring 2006 are believed to have increased our efficiency for fish collection. The large number of fish collected in 2005 (1,965) compared to 2006 (980) is likely due the trap being run for 253 days compared to 220 days in 2006. In spring 2006, we missed a critical period of time for fish immigration and emigration due to a long sustained spring run-off that prevented us from using the trap.

Downstream fish movement data along with isotope data suggest that steelhead were present in R1 of Beaver Creek prior to reconstruction of the water diversions. Little to no evidence of anadromy has been found above R1. This may be due to a large beaver dam at the upstream end of our lowest index site creating a temporary or seasonal barrier. This dam was removed by high flows during spring run-off in 2006, and an adult Chinook was subsequently spotted in an upper water diversion several kilometers above the beaver dam after it had washed out.

Rainbow trout/juvenile steelhead emigration occurred in the spring and fall. Most spring emigrants would immediately move downstream toward the Pacific Ocean, while fall migrants would hold over 100 days between rkm 1 of Beaver Creek and WDFW's smolt trap in the Methow River (rkm 30, which is 27 rkm downstream of the mouth of Beaver Creek). Juvenile Chinook emigration would occur in the spring and early winter. Most juvenile Chinook would leave Beaver Creek in the winter and would most likely hold in the mainstem Methow River until spring before they would emigrate to the ocean.

Juvenile steelhead outmigrants have been detected from all index sites in the Gold Creek watershed. However, we have not detected a strong anadromous signature in our isotope samples. This may be due to the location of the sites, but we would not expect to see a signature in our upper site, and the middle site may be more of a migration corridor than a spawning area. This idea is reinforced by juvenile outmigration data, where we found outmigrants from Foggy Dew and South Fork Gold creeks, but none from the mainstem Gold Creek between these streams. The lowest Gold Creek PIT-tag interrogator was installed in late fall 2005, which may have missed the fall migration from Gold Creek. More emigration data will help assess the life history strategies expressed in Gold Creek.

We found juvenile steelhead outmigrants in Libby Creek up to rkm 5. Although we did not find any juvenile fish outmigrants that originated above rkm 5, a crew observed an adult steelhead at rkm 10 in 2005.

From PIT-tag detections, most adult steelhead that entered Beaver, Libby, and Gold creeks migrated past Wells Dam from September to October and then would hold somewhere between Wells Dam and tributaries during fall to early spring. In the spring, the adults moved into the tributaries and spawned. Rainbow trout/juvenile steelhead PIT tagging started in the summer of 2004. We expect to see our first fish PIT-tagged as a juvenile steelhead to be detected at the Columbia River dams in fall 2007 and at the tributary interrogation sites in spring 2008.

The rock vortex weir structures have successfully allowed upstream passage of adult and juvenile steelhead, adult and juvenile Chinook, juvenile coho, and mountain whitefish. Adult fish have moved from just below the diversion to over the diversion in less than an hour. Similarly, juvenile fish have moved past the diversion in less than ten hours at flows as low as 2.3 cfs. Much more data should be available for this analysis after the spring and early summer fish migration period.

Most fish diverted into the water canal should successfully pass through the water diversion. The five percent of unknown fish could have been due to predation in the diversion or from periods when interrogator malfunction created lost of operation during short time periods. Unfortunately, all three trials in 2005 had small gaps in the detection data. Additional trials were planned in 2006.

Future Research Efforts

While this report covers sampling efforts through spring 2006, additional and essentially replicate efforts will continue at least through fall 2007. These additional efforts will allow tracking the fish recolonization processes, which will be used to judge the effectiveness of and value of the modification of fish passage barriers.

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Table 1. Passage barriers to upstream migration of fish in mainstem Beaver, Libby, and Gold creeks and their larger tributaries. The artificial barriers listed may or may not have been complete barriers. The list does not contain natural barriers upstream of the first one to be encountered by upstream migrating fish from the mouth, and it does not contain artificial barriers, such as culverts, that are upstream of natural barriers. Based on best available information at time of report.

Watershed Tributary	River mile	Barrier type[a]	Name of barrier	Height of barrier (ft)	Date removed	Nonadromous fish above barriers prior to 2000[b]
Beaver Creek	0.4	Culvert	Hwy 53	Unknown	Fall 2000	RBT, BLT, CTT, BRK, SCP, WHT, LND
	1.6	Concrete	Fort-Thurlow	6	Nov 2004	RBT, BLT, CTT, BRK, SCP, WHT
	2.8	Push-up	Lower Stokes	3	Sep 2003	RBT, BLT, CTT, BRK, SCP, WHT
	4.7	Push-up	Thurlow Transfer	3.5	Fall 2003	RBT, BLT, CTT, BRK, SCP
	5.3	Push-up	Upper Stokes	3	Fall 2003	RBT, BLT, CTT, BRK, SCP
	8.0	Push-up	Mirracci	1.5	Fall 2005	RBT, BLT, CTT, BRK, SCP
	8.0	Push-up	Baetty	3	Still there	RBT, BLT, CTT, BRK, SCP
	8.4	Push-up	Redshirt	4	Still there	RBT, BLT, CTT, BRK, SCP
	9.0	Culvert	FR 4225	2	Aug 2006	RBT, BLT, CTT, BRK, SCP
	13.7	Natural falls	(Unknown)	35	Still there	BRK
Blue Buck Cr.		(None)				BLT
Lightning Cr.	0.3	Natural falls	(Unknown)	(Unknown)	Still there	CTT, BRK
Middle Fork	1.0	Natural falls	(Unknown)	(Unknown)	Still there	BRK
South Fork		(None)				RBT, BRK
Frazer Creek		(None)				RBT, BRK
Libby Creek	0.8	Push-up	Libby-Peterson	3	Jun 2005	RBT, CTT (rarely BLT, BRK)
South Fork	4.0	Natural falls	(Unknown)	75	Still there	CTT
South Fork	1.0	Natural falls	(Unknown)	6	Still there	RBT
Gold Creek	0.8	Push-up	Campbell	(variable)	Jun 2005	RBT, BLT, CCT, SCP
	7.4	Gradient	(Unknown)	100	Still there	no fish
Crater Cr.	0.1	Natural falls	(Unknown)	70	Still there	RBT
Foggy Dew Cr.	4.3	Natural falls	(Unknown)	60	Still there	CTT
South Fork	3.8	Culvert	FR4330	4	Still there	RBT
	7.4	Natural falls	(Unknown)	20	Still there	(unknown)

[a] Push-up barriers may or may not be there year-round nor every year depending on landowner or water user efforts.
[b] RBT=rainbow trout, BLT=bull trout, CTT=cutthroat trout BRK=brook trout, SCP=sculpin, WHT=mountain whitefish, LND=longnose dace.

Table 2. Presence and absence of fish species sampled in the lower Methow tributaries by the U. S. Geological Survey during the 2004 and 2005 field season. Watersheds and streams are listed in an upstream to downstream pattern within a watershed. P = present, A = absent.

Watershed Reach or section	Distance upstream from mouth (km)	**Rainbow trout/ steelhead** *Oncorhynchus mykiss*	**Brook trout** *Salvelinus fontinalis*	**Cutthroat trout** *Oncorhynchus clarkii*	**Chinook salmon** *Oncorhynchus tschawytscha*	**Bull trout** *Salvelinus confluentus*	**Sculpin** *Cottus spp.*	Other species observed
Beaver Creek								
Blue Buck Creek		A	A	A	A	P	A	A
Beaver Creek - Reach 5	17.5	P	P	P	A	A	A	A
Lightning Creek		P	P	P	A	A	A	A
Beaver Creek - Reach 4	15.6	P	P	P[a]		P[a]		A
Middle Fork Beaver Creek		A	P	A	A	A	A	A
South Fork Beaver Creek		P	P	A	A	A	A	A
Beaver Creek - Reach 2b	12.8	P	P	A	A	A	P	A
Beaver Creek - Reach 2a	5.7	P	P	A	A	A P	P	A
Frazer Creek		P	P	A A	A	A	A	A
Beaver Creek - ab Diversion	4.6	P	P	A	P	A	P	A
Beaver Creek - bl. Diversion	1.3	P	P	A	P	P	P	P[b]
Libby Creek								
North Fork Libby Creek		P	P	P	A	A	A	A
South Fork Libby Creek		P	A	P	A	A	A	A
Libby Creek - Reach 5	10.0	P	P[a]	P	A	P[a]	A	A
Libby Creek - Reach 3	7.2	P	A	P[a]	A	A	A	A
Libby Creek - Reach 1 ab. Diversion	2.6	P	A	P	P[a]	A	A	A
Gold Creek								
Crater Creek		P	A	P	A	P	A	A
Gold Creek - Reach 4-5	8.9	P	A	P	A	P	P	A
Foggy Dew		P	A	P	A	P	P	A
Gold Creek - Reach 3	7.4	P	A	A	A	P	P	A
Middle Fork Gold Creek		P	P	A	A	A	A	A
Gold Creek - Reach 2	4.4	P	A	A	P	A	P	A
South Fork Gold Creek		P	A	A	A	A	P	A
Gold Creek - Reach 1	0.2	P	A	A	A	A	P	A

[a] Only one individual was observed during surveys at this site.
[b] Coho salmon, longnose dace, mountain whitefish, bridgelip sucker.

Table 3. Total number of salmonids that were captured and PIT-tagged in the Methow River subbasin 2004-2005. Watersheds and streams are listed in an upstream to downstream pattern within a watershed. RBT/STH=Rainbow trout/juvenile steelhead, CHN=Chinook, BRK=Brook trout, BLT= bull trout, CTT= westslope cutthroat trout, and COH=coho.

Watershed Stream reach or section	River Kilometer	RBT/STH 2004	RBT/STH 2005	CHN 2004	CHN 2005	BRK 2004	BRK 2005	BLT 2004	BLT 2005	CTT 2004	CTT 2005	COH 2004	COH 2005
Beaver Creek													
Blue Buck Creek	3.3	0	0	0	0	0	0	0	9	0	0	0	0
Beaver Creek - Reach 5	17.5	0	49	0	0	0	13	0	0	0	0	0	0
Lightning Creek	0.2	0	2	0	0	13	21	0	0	1	3	0	0
Beaver Creek - Reach 4	15.6	103	88	0	0	17	22	0	1	0	1	0	0
Beaver Creek - Reach 3	14.1	263	89	0	0	10	8	0	0	0	0	0	0
South Fork Beaver - Reach 2	8.7	0	3	0	0	0	28	0	0	0	0	0	0
Middle Fork Beaver Creek	4.9	0	0	0	0	18	13	0	0	0	0	0	0
South Fork Beaver - Reach 1	0.9	56	15	0	0	12	8	0	0	0	0	0	0
Beaver Creek - Reach 2	12.8	254	197	0	0	11	15	0	0	0	0	0	0
Frazer Creek	4.5	0	18	0	0	0	14	0	0	0	0	0	0
Beaver Creek - Reach 1 ab. Diversion	4.6	265	387	0	0	10	26	0	0	0	0	0	0
Beaver Creek - Reach 1 bl. Diversion	1.3	105	37	42	0	1	0	0	0	0	0	0	0
Beaver Creek Weir	1.3	94	1,275[a]	31	192	1	27	1	2	0	0	0	16
Beaver Creek Subtotal		**1,140**	**2,160**	**73**	**192**	**112**	**200**	**1**	**12**	**1**	**4**	**0**	**16**
Libby Creek													
South Fork Libby Creek	2.1	0	43	0	0	0	0	0	0	0	33	0	0
North Fork Libby Creek	0.8	3	6	0	0	9	1	0	0	17	23	0	0
Libby Creek - Reach 5	10.0	56	212	0	0	0	0	0	1	0	5	0	0
Libby Creek - Reach 3	7.2	84	53	0	0	0	0	0	0	1	1	0	0
Libby Creek - Reach 1 av. Diversion	2.6	408	328	1	0	0	0	0	0	0	2	0	0
Libby Creek - Reach 1 bl. Diversion	0.2	24	0	1	0	0	0	0	0	0	0	0	0
Libby Creek Subtotal			**642**	**2**	**0**	**9**	**1**	**0**	**1**	**18**	**64**	**0**	**0**
Gold Creek													
Gold Creek - Reach 5	10.9	0	14	0	0	0	0	0	0	0	0	0	0
Crater Creek	3.0 **575**	5	52	0	0	0	0	0	11	0	18	0	0
Gold Creek - Reach 4	8.4	148	180	0	0	0	0	1	4	3	0	0	0
Foggy Dew Creek	0.7	149	147	0	0	0	0	7	39	13	36	0	0
Gold Creek - Reach 3	7.4	0	55	0	0	0	0	0	2	0	0	0	0
Middle Fork Gold Creek	1.8	0	29	0	0	0	9	0	0	0	0	0	0
Gold Creek - Reach 2	4.4	0	84	0	2	0	0	0	0	0	0	0	0
South Fork Gold - Reach 2	9.3	132	58	0	0	0	0	0	0	0	0	0	0
South Fork Gold - Reach 1	4.2	101	156	0	0	0	0	0	0	0	0	0	0
Gold Creek - Reach 1 bl. Diversion	0.2	20	29	2	0	0	0	0	0	0	0	0	0
Gold Creek Subtotal		**555**	**804**	**2**	**2**	**0**	**9**	**8**	**56**	**16**	**54**	**0**	**0**
Grand Total		2,270	3,606	77	194	121	210	9	69	35	122	0	16

[a] Includes 27 adult steelhead.

Table 4. Species and number of fish collected at a two-way fish trapping weir located at rkm 1 in Beaver Creek, September 2004 to November 2006.

	Total number of individual fish captured		
Beaver Creek trap	2004	2005	2006
Number of days operated:	60	253	220
Rainbow trout/juvenile steelhead	46	1,423	567
Trout –juvenile, <80 mm	52	199	2
Steelhead - adult	0	31	26
Cutthroat trout	0	0	4
Chinook - juvenile	32	222	188
Chinook - adult	0	0	4
Coho - juvenile	0	18	26
Bull trout	1	2	3
Brook trout	1	42	118
Sculpin	1	13	0
Bridgelip sucker	0	10	16
Longnosed dace	0	4	25
Mountain whitefish	0	1	1
Total	133	1,965	980

Table 5. The number of days between interrogation for upstream moving adult steelhead at one or more Columbia River dams before their first interrogation in a tributary of the Lower Methow River subwatershed. The dam codes are: BON = Bonneville Dam, MCN = McNary Dam, PRA = Priest Rapids Dam, RIS = Rock Island Dam, RRE = Rocky Reach Dam, WEL = Wells Dam.

		Detection at dams (rkm)					
Tributary	Type of information	BON (234)	MCN (470)	PRA (639)	RIS (730)	RRE (763)	WEL (830)
Beaver Creek							
	No. of fish	4	3	4	4	0	3
	Mean (d)	231	201	184	180	--	174
	Median (d)	236	196	188	184	--	177
	Range (d)	205-246	190-218	148-213	145-208	--	139-206
Libby Creek							
	No. of fish	9	9	8	6	0	9
	Mean (d)	276	261	252	238	--	204
	Median (d)	270	253	246	235	--	209
	Range (d)	236-334	229-327	223-318	216-262	--	4-273
Gold Creek							
	No. of fish	18	18	16	14	1	17
	Mean (d)	259	237	228	214	104	193
	Median (d)	262	240	234	220	--	203
	Range (d)	122-303	116-295	108-288	105-282	--	36-277

Table 6. Number of days for juvenile steelhead emigrating from Beaver Creek to be recaptured or interrogated at one or more sites in the Methow and Columbia rivers as of 22 January 2007. The detections site codes are: MR = Methow River screw trap, RRE = Rocky Reach Dam, RIS = Rock Island Dam, MCN = McNary Dam, JDA = John Day Dam, BON = Bonneville Dam, TWX = Estuary Trawl.

			Detection Sites (Rkm)						
Season	Months		MR (843.003)	RRE (763)	RIS (730)	MCN (470)	JDA (347)	BON (234)	TWX (40)
Spring	March-May	No. of fish	4	3	4	30	20	5	2
		Mean (d)	15	139	131	45	61	94	191
		Median (d)	4	62	55	21	19	23	--
		Range (d)	1-51	3-353	24-390	9-352	12-402	17-362	18-363
Summer	June-August	No. of fish	0	0	2	1	1	1	0
		Mean (d)	--	--	333	319	345	336	--
		Median (d)	--	--		--	--	--	--
		Range (d)	--	--	317-350	--	--	--	--
Fall	September-November	No. of fish	2	1 --	4	7	23	11	0
		Mean (d)	169	189	205	208	211	205	--
		Median (d)	--	--	203	213	200	202	--
		Range (d)	160-178	--	188-225	184-243	177-251	182-236	--
Winter	December-February	No. of fish	0	1	0	2	1	0	0
		Mean (d)	--	174	--	142	524	--	--
		Median (d)	--	--		--	--	--	--
		Range (d)	--	--	--	135-149	--	--	--

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Table 7. Number of days for juvenile Chinook emigrating from Beaver Creek to be recaptured or interrogated at one or more sites in the Methow and Columbia rivers as of 22 January 2007. The detections site codes are: MR = Methow River screw trap, RRE = Rocky Reach Dam, RIS = Rock Island Dam, MCN = McNary Dam, JDA = John Day Dam, BON = Bonneville Dam, TWX = Estuary Trawl.

			Detection Sites (rkm)						
Season	Months		MR (843.003)	RRE (763)	RIS (730)	MCN (470)	JDA (347)	BON (234)	TWX (40)
Spring	March-May	No. of fish	0	0	0	2	0	0	0
		Mean (d)	--	--	--	26	--	--	--
		Median (d)	--	--		--	--	--	--
		Range (d)	--	--	--	19-36	--	--	--
Summer	June-August	No. of fish	0	0--	0	0	0	1	0
		Mean (d)	--	--	--	--	--	299	--
		Median (d)	--	--		--	--	--	--
		Range (d)	--	--	--	--	--	--	--
Fall	September-November	No. of fish	0	2--	1	10	6	8	1
		Mean (d)	--	175	171	197	195	192	190
		Median (d)	--	--	--	194	189	189	--
		Range (d)	--	155-196	--	168-231	167-247	176-221	--
Winter	December-February	No. of fish	1	2	1	2	2	2	2
		Mean (d)	132	155	162	168	163	165	168
		Median (d)	--	--		--	--	--	--
		Range (d)	--	146-165	--	156-180	160-165	163-167	165-171

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Table 8. Number of days for juvenile steelhead emigrating from Gold Creek to be recaptured or interrogated at one or more sites in the Methow and Columbia rivers as of 22 January 2007. The detections site codes are: MR = Methow River screw trap, RRE = Rocky Reach Dam, RIS = Rock Island Dam, MCN = McNary Dam, JDA = John Day Dam, BON = Bonneville Dam, TWX = Estuary Trawl. Caution Large PIT-tag detector was installed in the winter of 2005, after fall emigration.

			Detection Sites (rkm)						
Season	Months		MR (843.003)	RRE (763)	RIS (730)	MCN (470)	JDA (347)	BON (234)	TWX (40)
Spring	March-May	No. of fish	1	0	2	4	5	1	1
		Mean (d)	1	--	32	28	31	13	32
		Median (d)	--	--	--	28	29	--	--
		Range (d)	--	--	20-43	21-36	24-41	--	--
Summer	June-August	No. of fish	0	0	0	0	0	0	0
		Mean (d)	--	--		--	--	--	--
		Median (d)	--	--		--	--	--	--
		Range (d)	--	--		--	--	--	--
Fall	September-November	No. of fish	0	0	0	0	0	0	0
		Mean (d)	--	--		--	--	--	--
		Median (d)	--	--		--	--	--	--
		Range (d)	--	--		--	--	--	--
Winter	December-February	No. of fish	0	0	0	0	0	0	--
		Mean (d)	--	--		--	--	--	--
		Median (d)	--	--		--	--	--	--
		Range (d)	--	--		--	--	--	--

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Table 9. Hatchery steelhead detected at one or more of ten PIT-tag interrogation sites in Beaver, Libby, and Gold creeks in the Methow River watershed. Species: STH=steelhead. Location: TwispR= Twisp River @rkm 18, ChewuR=Chewuch River, Twis2P=Twisp River @rkm 2, WINT=Winthrop Fish Hatchery, WELH=Wells Hatchery, METHR=Methow River, CHIWAR=Chiwawa River, RINH=Ringold Hachery, WENATR=Wenatchee River, NASONC=Nason Creek. Hatchery: WELH=Wells Hatchery, WINT=Winthrop Hatchery, EBNK=Eastbank Hatchery, RINH=Ringold Hatchery. Site Encountered: A6=Lower Beaver Creek Interrogator, B0=Large Beaver Creek Interrogator, C2=Middle Libby Creek interrogator, C4=Lower Libby Creek interrogator, D6=South Fork Gold Interrogator, E0=Large Gold Creek Interrogator, D6=South Fork Gold Interrogator.

Hatchery steelhead at release						Hatchery steelhead at Methow PIT tag detectors					
Species	Length (mm)	Location	Hatchery	RKM	Date	Watershed	Lifestage	Sites encountered	RKM	First detection	Last detection
STH	120	TwispR	WELH	843.066.018	5/1/2003	Beaver	Adult	A6-B0-A6	843.057.005	4/7/2005	4/25/2005
STH	91	TwispR	WELH	843.066.018	5/2/2003	Beaver	Adult	A6	843.057.001	4/7/2005	4/18/2005
STH	83	ChewuR	WELH	843.080.026	4/26/2004	Beaver	Adult	A6	843.057.001	4/2/2006	4/26/2006
STH	75	TwispR	WELH	843.066.018	5/7/2004	Beaver	Juv	A6	843.057.001	2/2/2005	3/21/2005
STH	99	WINT	WINT	843.081	4/22/2005	Beaver	Juv	A6	843.057.001	5/5/2005	
STH	90	WINT	WINT	843.081	4/22/2005	Beaver	Juv	A6	843.057.001	5/6/2005	6/20/2005
STH	84	WINT	WINT	843.081	4/22/2005	Beaver	Juv	A6	843.057.001	5/13/2005	5/17/2005
STH	79	WINT	WINT	843.081	4/22/2005	Beaver	Juv	B0	843.057.005	6/13/2005	
STH	90	WINT	WINT	843.081	4/22/2005	Beaver	Juv	A6	843.057.001	10/18/2005	
STH	110	Twis2P	WELH	843.066.002	6/2/2005	Beaver	Juv	A6-B0	843.057.005	4/26/2006	4/28/2006
STH	96	WELH	WELH	830	4/15/2003	Gold	Adult	E0	843.035.001	4/22/2006	
STH	103	WELH	WELH	830	4/15/2003	Gold	Adult	E0	843.035.001	4/22/2006	
STH	104	METHR	WELH	843.104	4/25/2003	Gold	Adult	E0	843.035.001	4/23/2006	
STH	--	CHIWAR	EBNK	754.077.013	4/29/2003	Gold	Adult	E0	843.035.001	4/9/2006	4/17/2006
STH	98	TwispR	WELH	843.066.018	5/2/2003	Gold	Adult	E0	843.035.001	3/31/2006	
STH	--	TwispR	WELH	843.066.018	5/2/2003	Gold	Adult	E0	843.035.001	4/6/2006	
STH	122	TwispR	WELH	843.066.018	5/6/2003	Gold	Adult	E0	843.035.001	4/20/2006	
STH	116	TwispR	WELH	843.066.018	5/8/2003	Gold	Adult	D6	843.035.002.002	5/5/2005	
STH	112	Twis2P	WELH	843.066.002	5/12/2003	Gold	Adult	E0	843.035.001	3/26/2006	
STH	90	RINH	RINH	567	4/12/2004	Gold	Adult	E0	843.035.001	4/7/2006	

Continued.

Table 9. Continued.

Hatchery steelhead at release						Hatchery steelhead at Methow PIT tag detectors					
Species	Length (mm)	Location	Hatchery	RKM	Date	Watershed	Lifestage	Sites encountered	RKM	First detection	Last detection
STH	92	METHR	WELH	843	4/21/2004	Gold	Adult	E0-D6	843.035.002.002	4/22/2006	5/3/2006
STH	104	WENATR	EBNK	754.052	5/5/2005	Gold	Adult	E0	843.035.001	4/24/2006	
STH	97	WINT	WINT	843.081	4/22/2005	Gold	Juv	E0	843.035.001	4/3/2006	
STH	82	TwspR	WELH	843.066.018	5/10/2005	Gold	Juv	E0	843.035.001	4/3/2006	
STH	94	WELH	WELH	830	4/15/2003	Libby	Adult	C4	843.042.001	5/1/2006	
STH	103	WELH	WELH	830	4/15/2003	Libby	Adult	C4	843.042.001	4/26/2006	
STH	--	NASONC	EBNK	754.089.012	4/30/2003	Libby	Adult	C4	843.042.001	4/27/2006	
STH	--	NASONC	EBNK	754.089.012	4/30/2003	Libby	Adult	C2	843.042.002	6/9/2005	
STH	122	TwispR	WELH	843.066.018	5/1/2003	Libby	Adult	C4	843.042.001	4/26/2006	
STH	92	METHR	WELH	843.104	4/28/2004	Libby	Adult	C2-C4	843.042.002	4/8/2006	4/20/2006
STH	85	METHR	WELH	843.104	4/21/2005	Libby	Adult	C2	843.042.002	6/8/2005	
STH	82	WINT	WINT	843.081	4/22/2005	Libby	Juv	C4	843.042.001	10/23/2005	

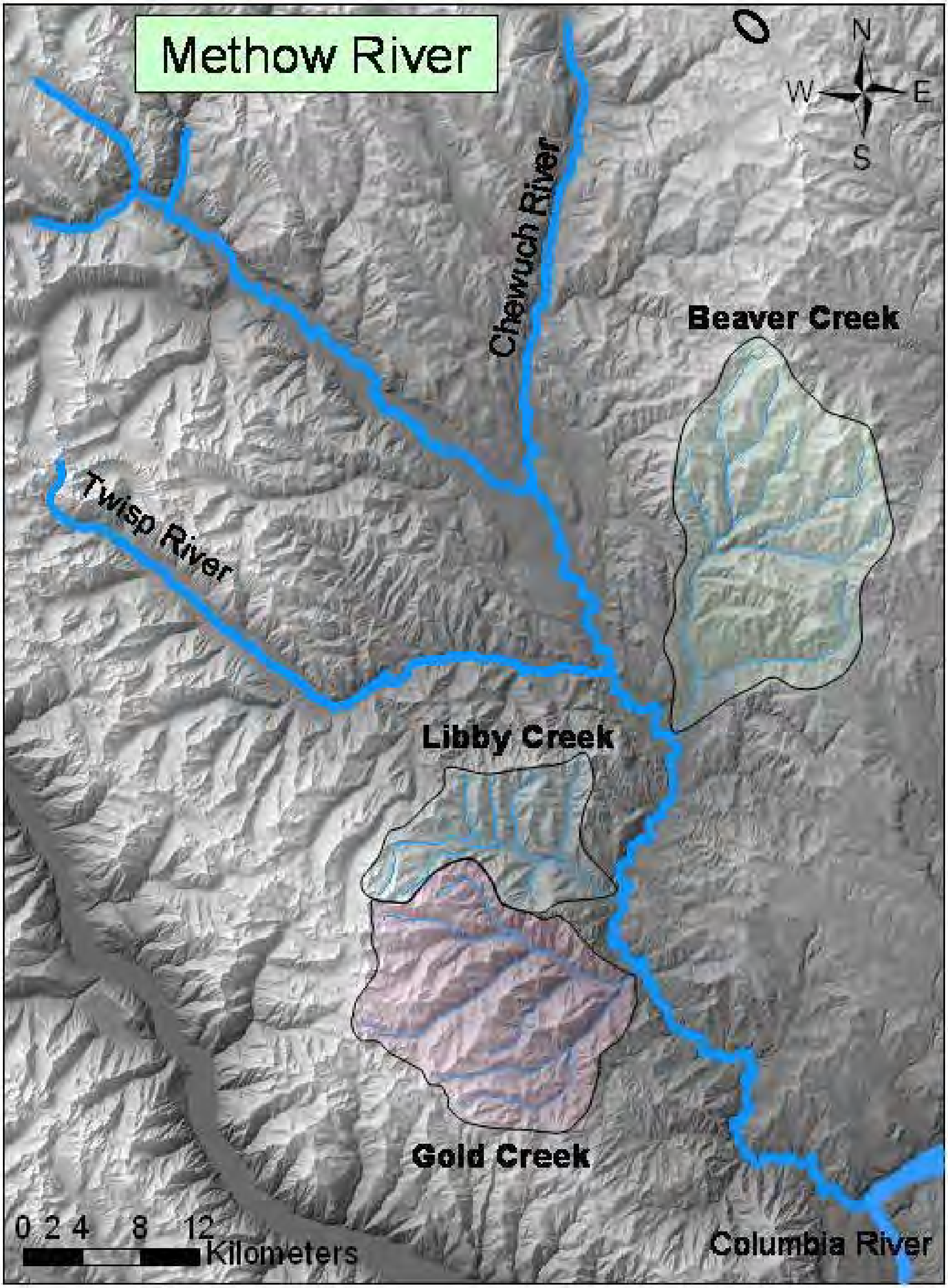


Figure 1. Map of the Methow River with Beaver Creek, Libby Creek, and Gold Creek watersheds outlined.

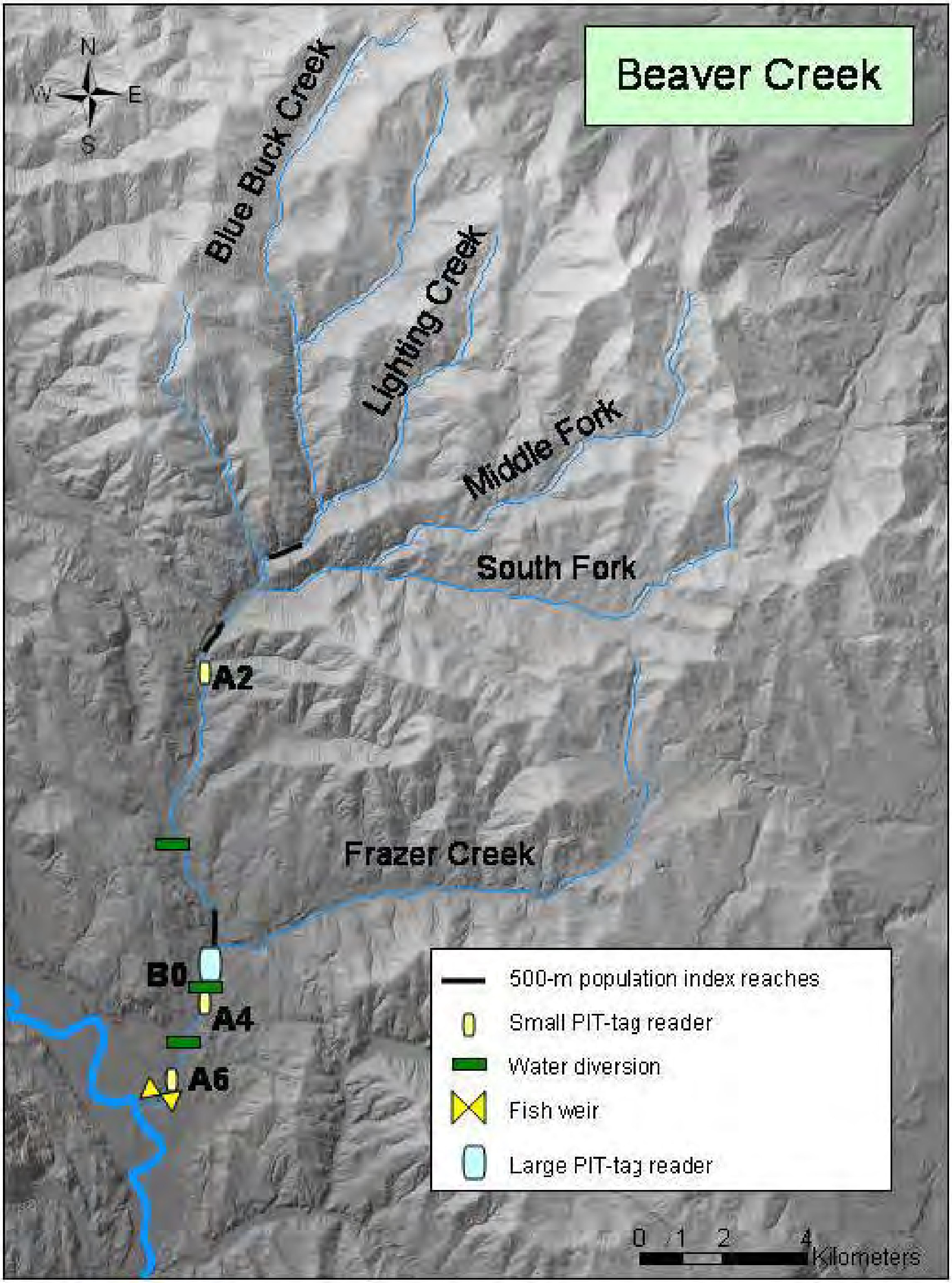


Figure 2. Sites for locations of PIT-tag interrogators, fish trap, and 500-m population electrofishing surveys in Beaver Creek. A2=Upper Beaver Creek small interrogator, B0=R1 large interrogator, A4=R1 small interrogator, and A6=Lower Beaver Creek small interrogator

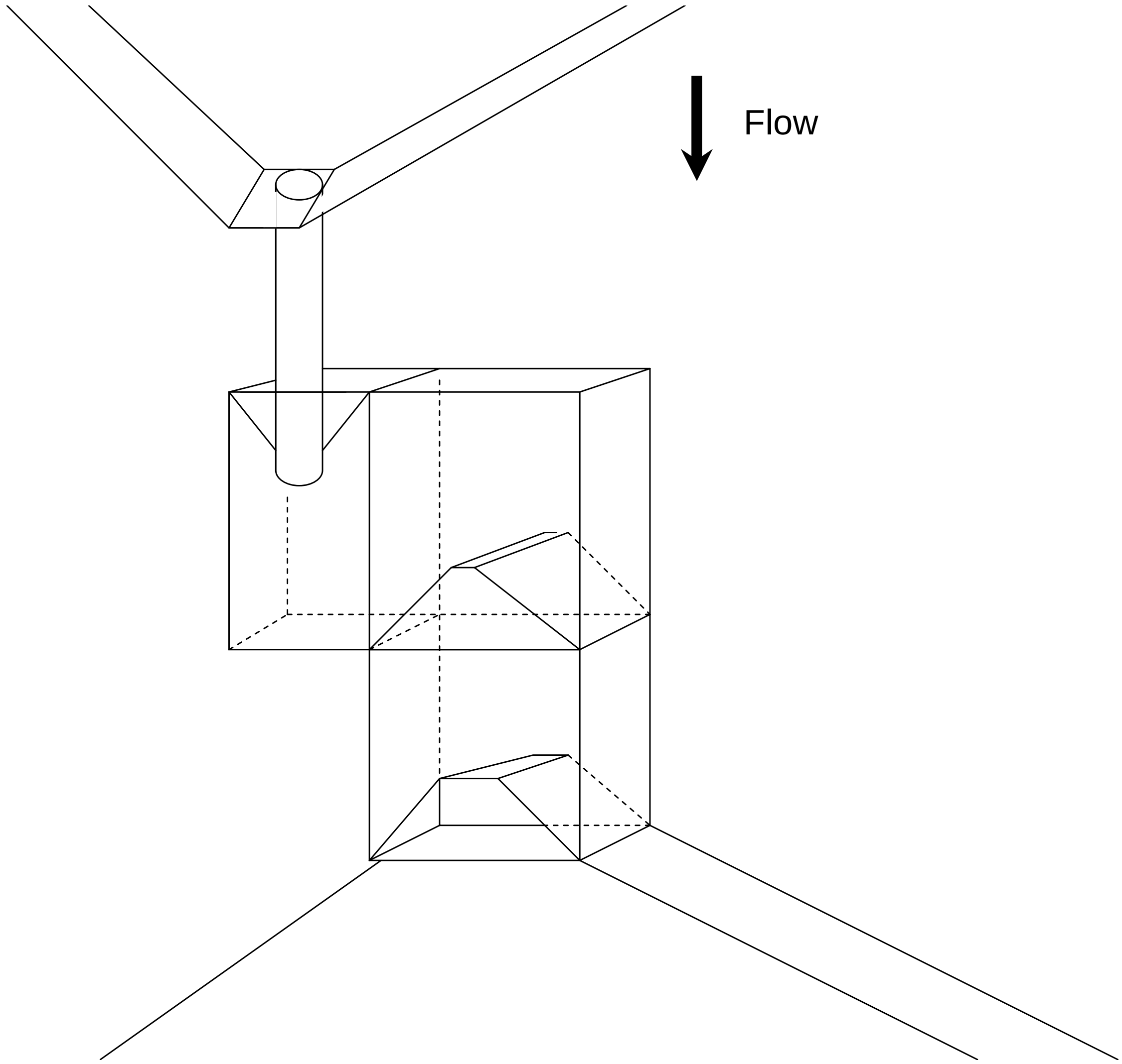


Figure 3. Diagram of the two-way, multi-life stage fish collection trap with picket-style weir installed in Beaver Creek (rkm 1).

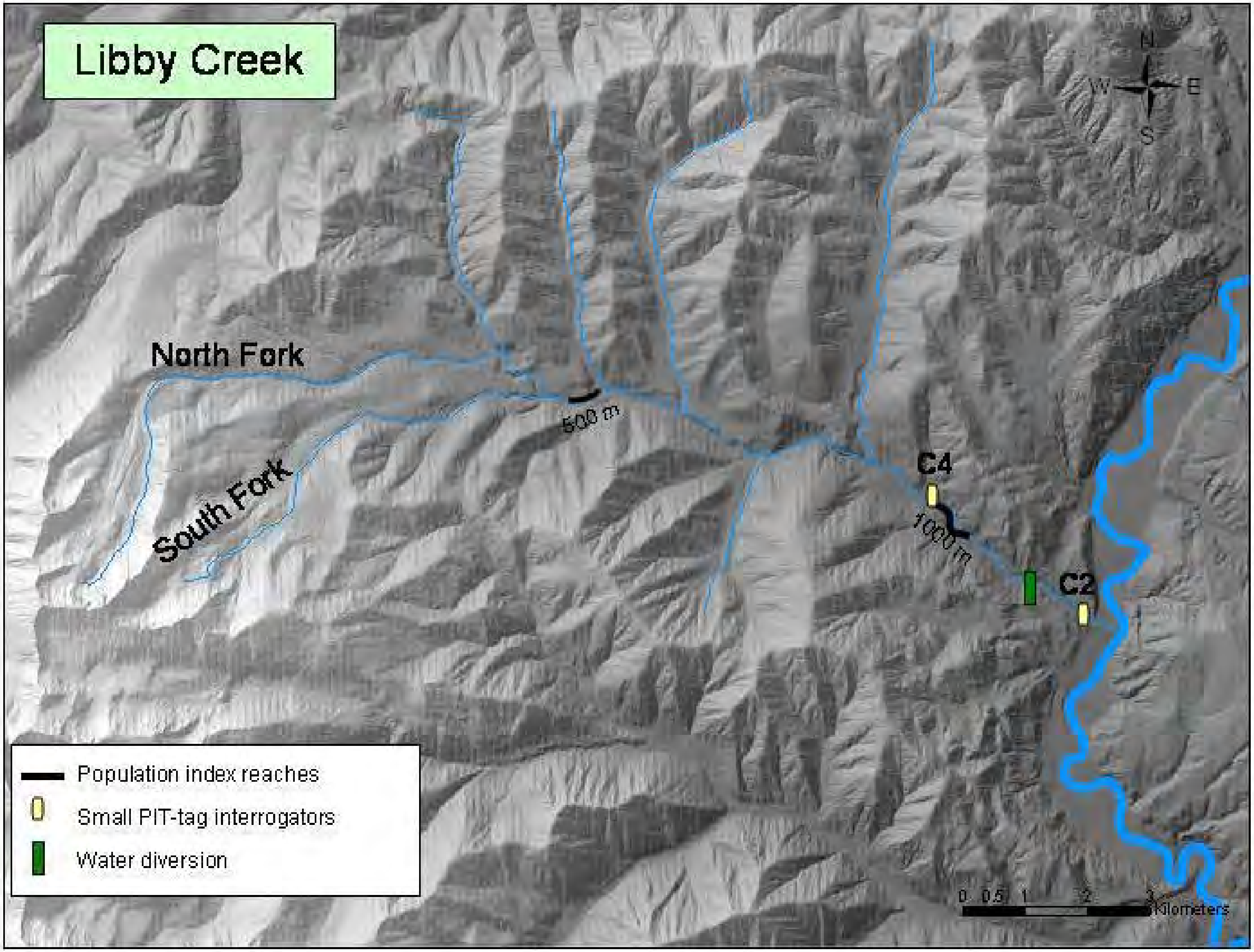


Figure 4. Locations of PIT-tag interrogators and population electrofishing surveys in Libby Creek. C4=Middle Libby Creek small interrogators and C2=Lower Libby Creek small interrogators

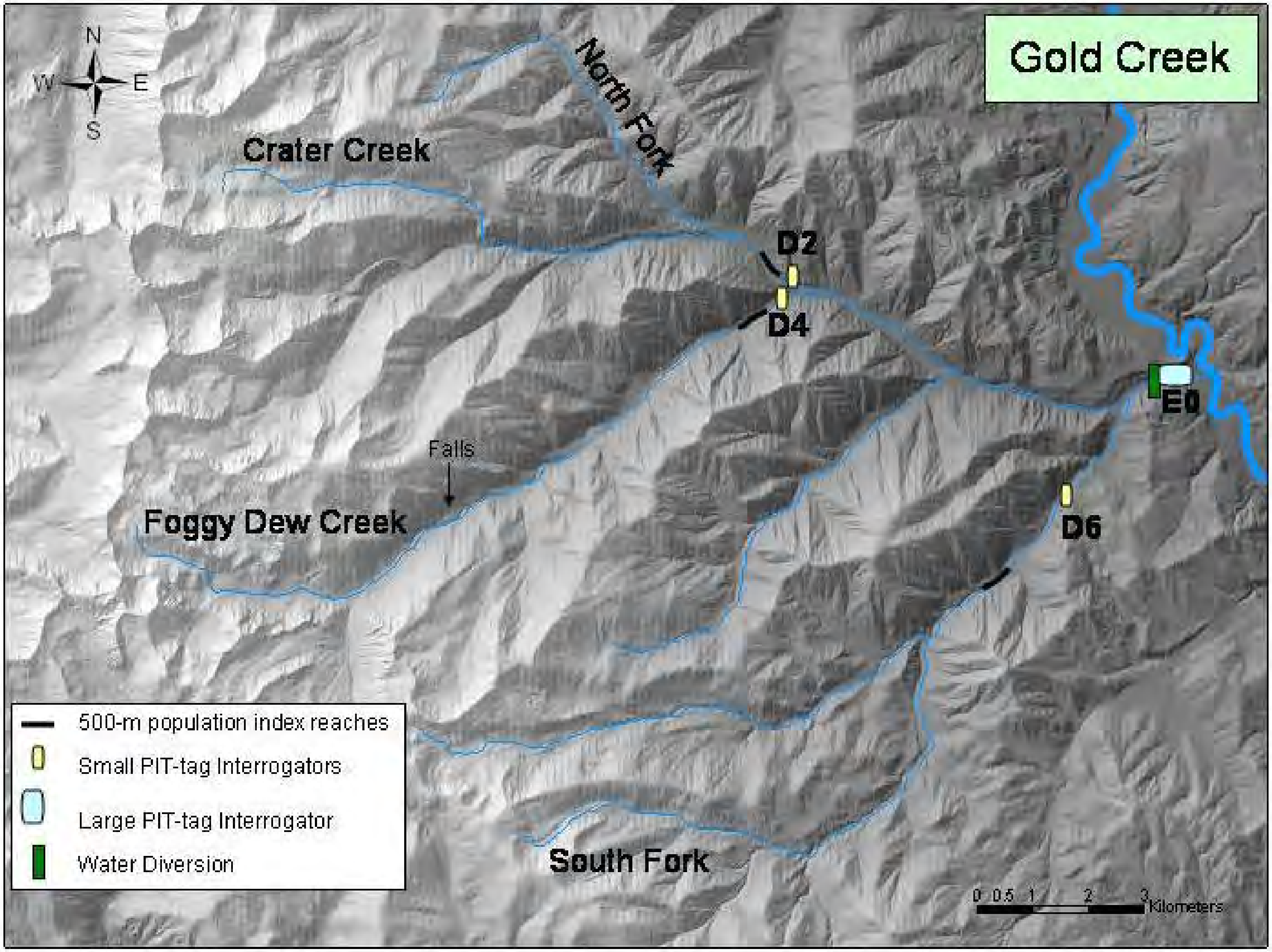


Figure 5. Locations of PIT-tag interrogators and 500-m sites for population electrofishing surveys in Gold Creek. D2=Upper Gold Creek small interrogator, D4=Foggy Dew Creek small interrogators, D6=South Fork Gold Creek small interrogator, and E0=Lower Gold Creek large interrogator

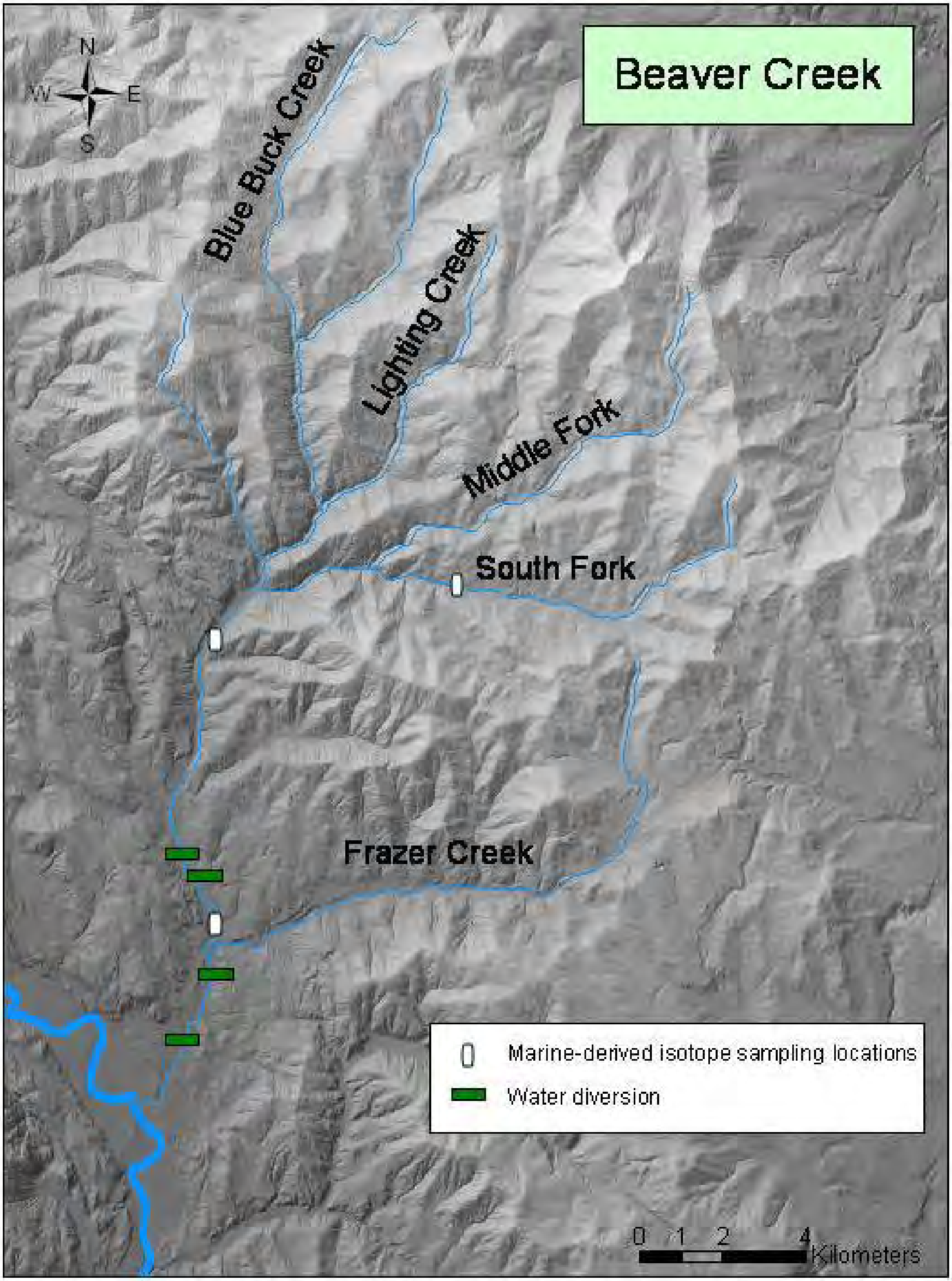


Figure 6. Locations of isotope sampling locations in Beaver Creek.

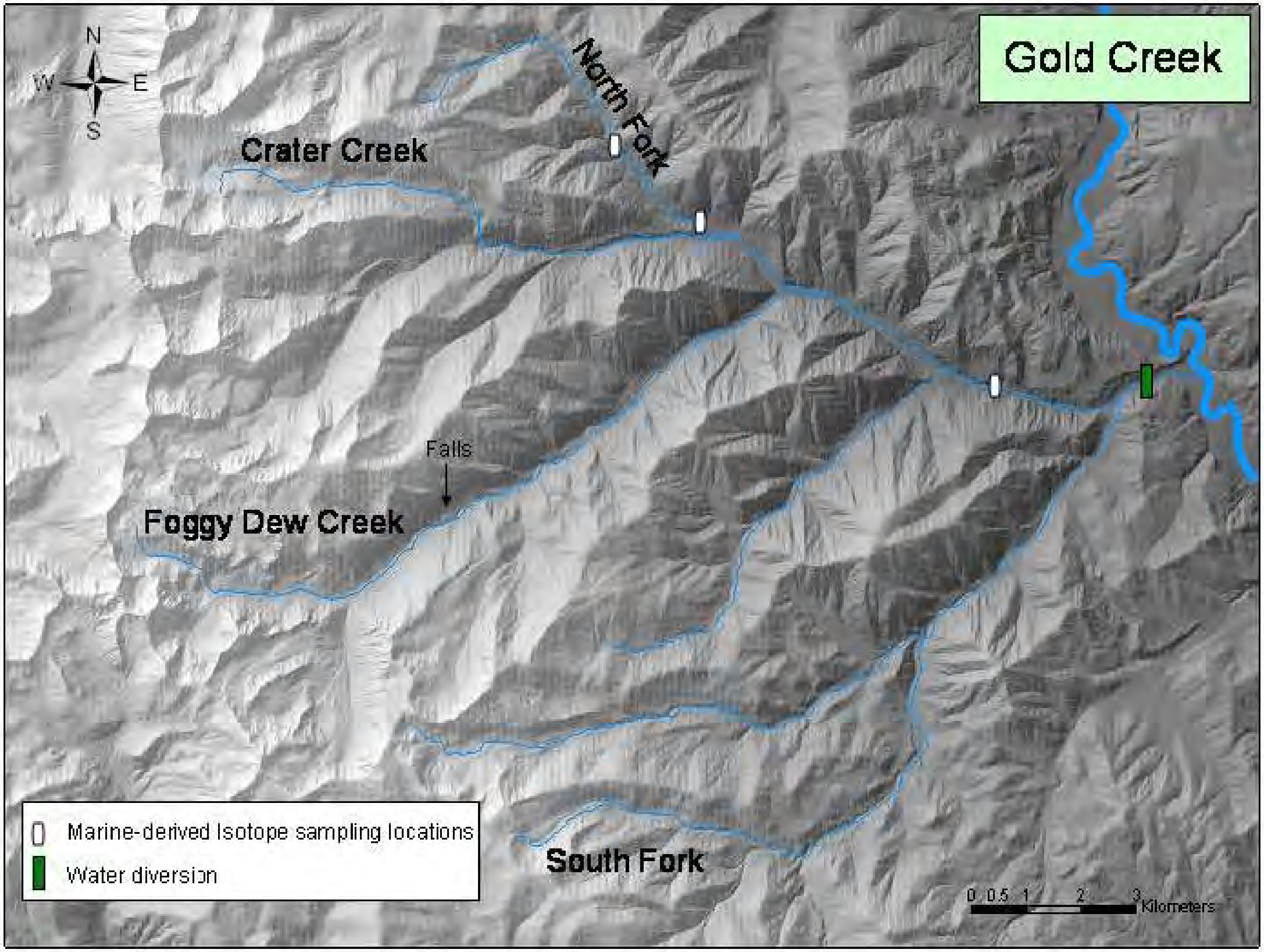


Figure 7. Locations of isotope sampling locations in Gold Creek.

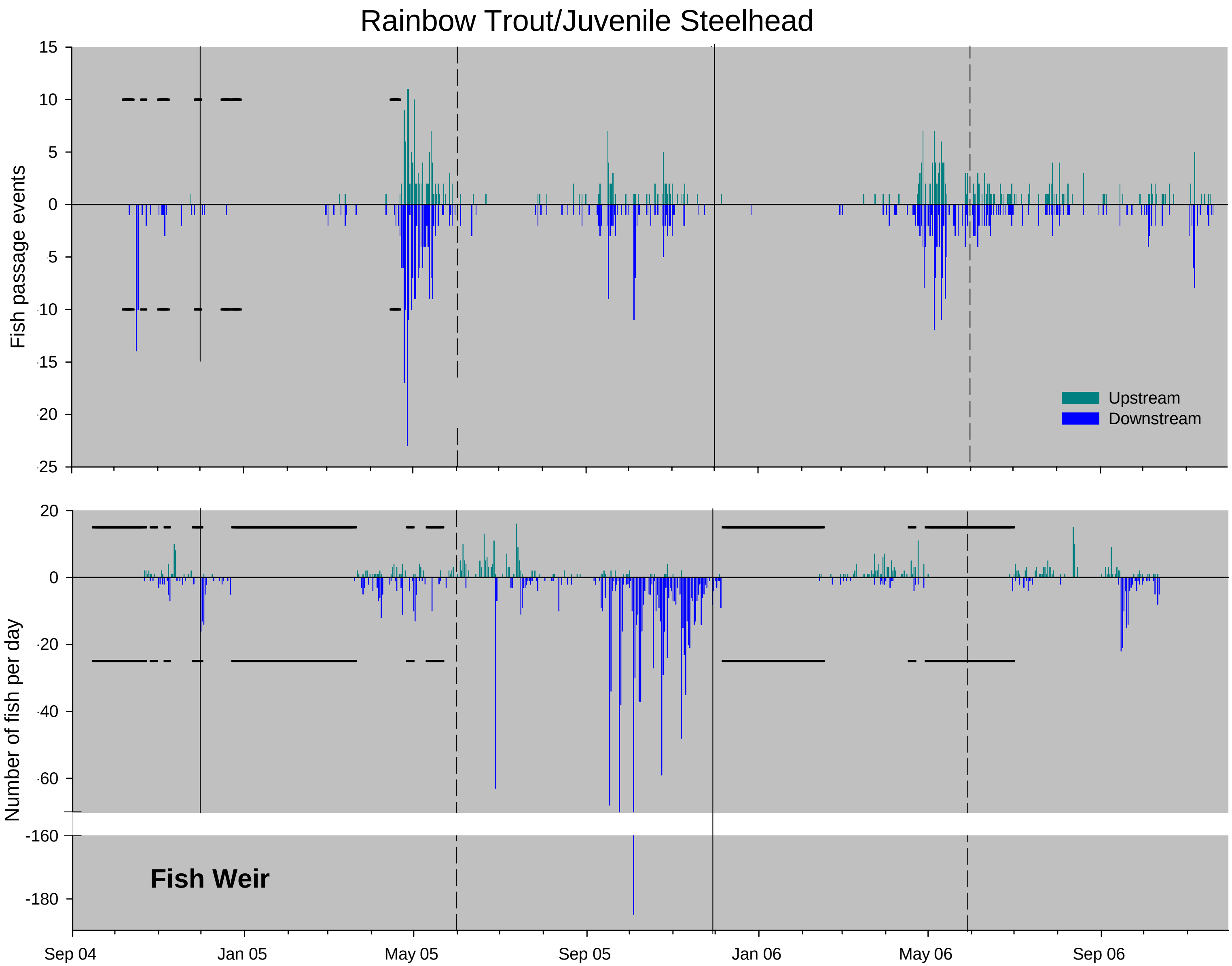


Figure 8. Rainbow trout/juvenile steelhead collected at two-way fish trap in Beaver Creek, fall 2004 to 2006. The black dashes (▬) indicate days when the fish trap or PIT-tag interrogator was not operating.

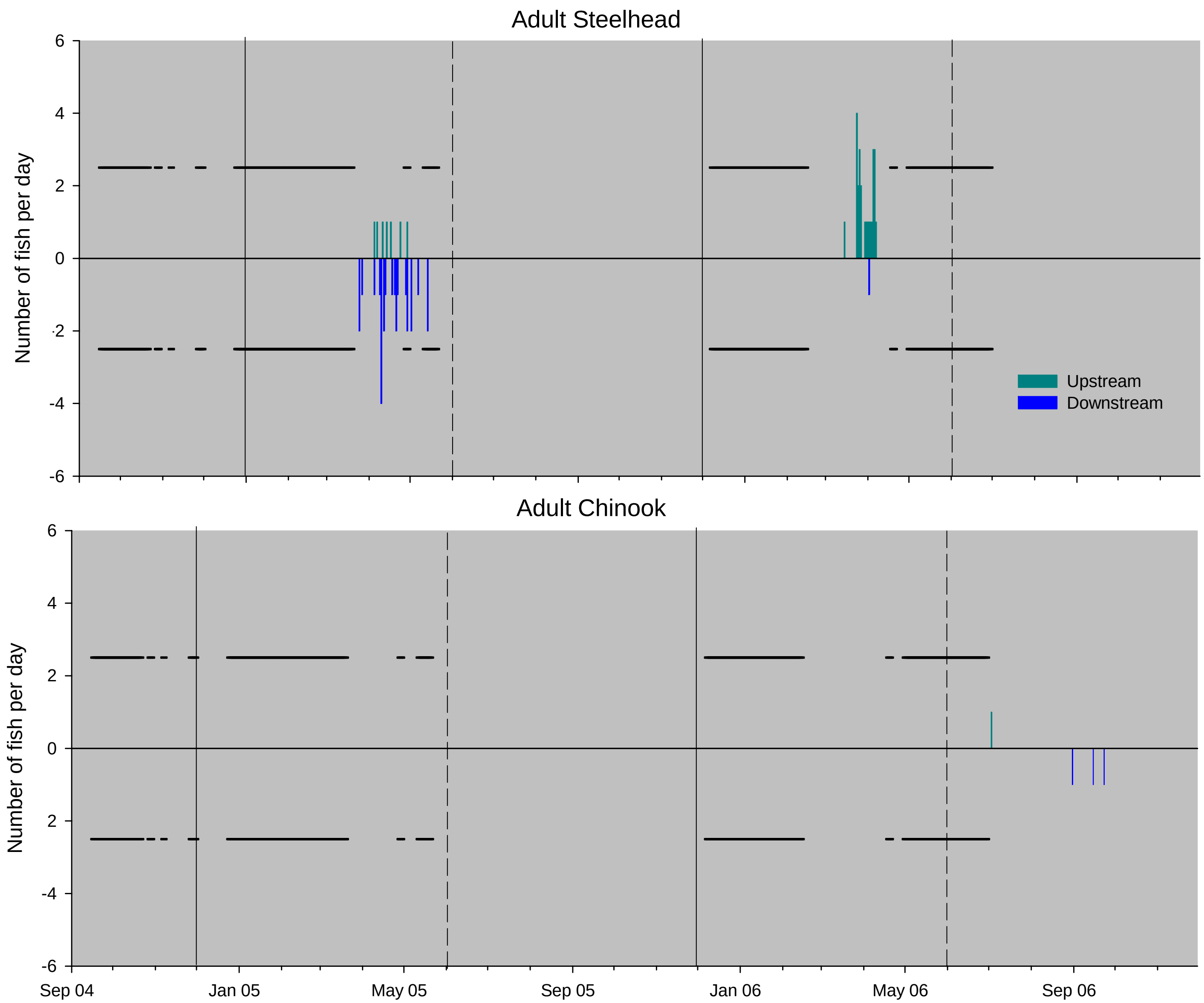


Figure 9. Adult steelhead and adult Chinook collected at two-way fish trap in Beaver Creek, fall 2004 to 2006. The black dashes (▬) indicate days when the fish weir was not operating.

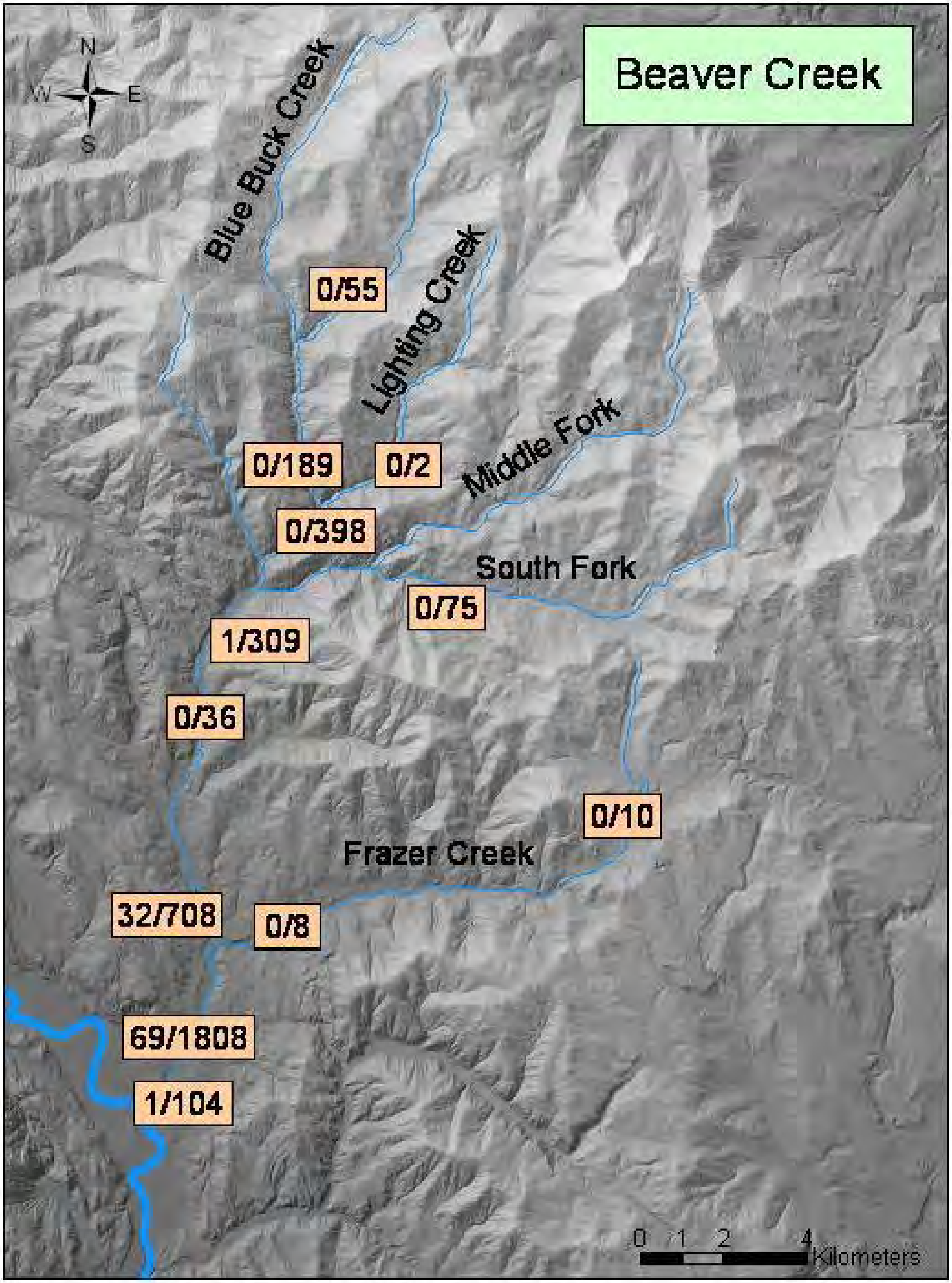


Figure 10. Rainbow trout/juvenile steelhead tagged and released in Beaver Creek from 2004 into 2006, and the number of fish detected in the mainstem Methow River or a PIT-tag interrogation site in the Columbia River.

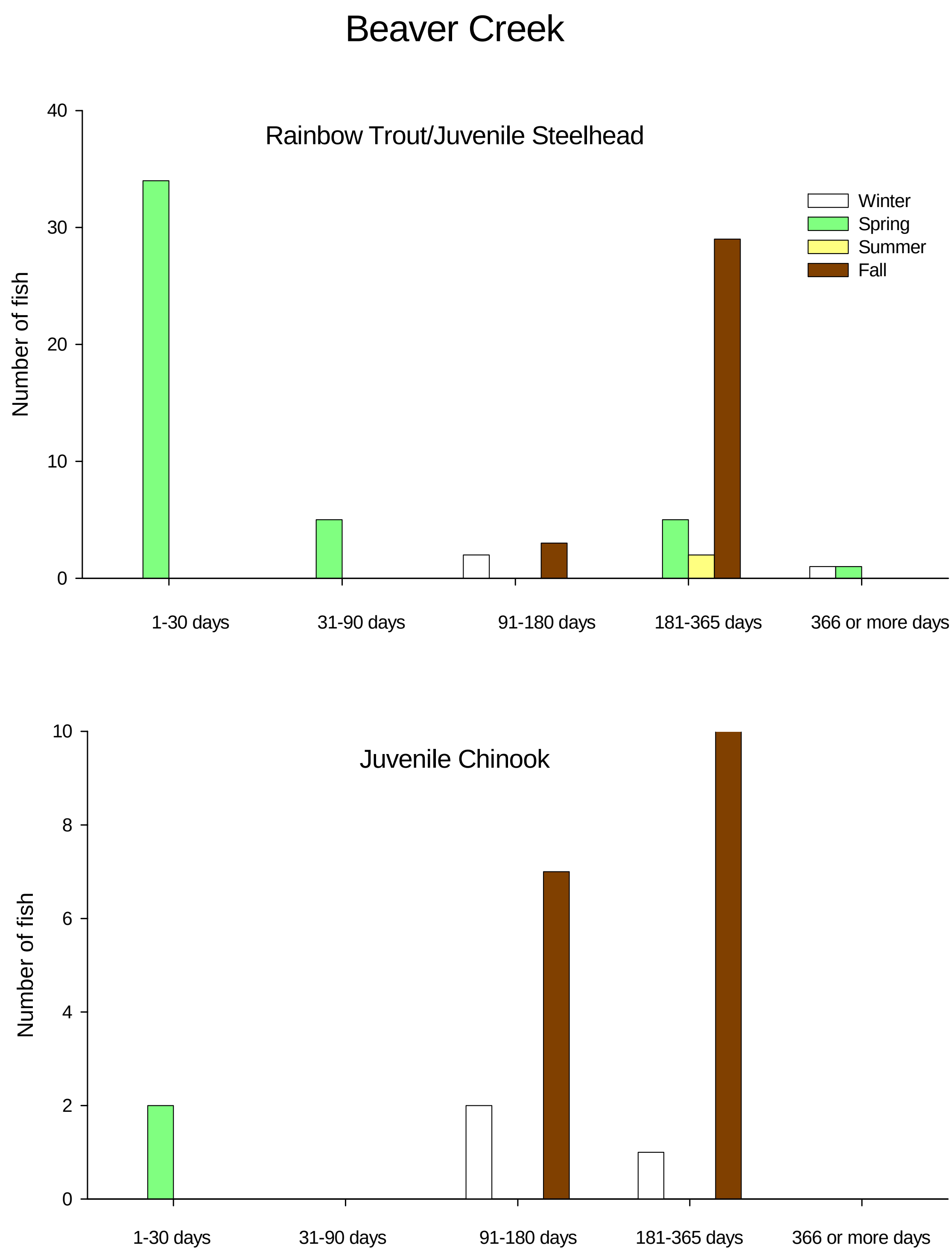


Figure 11. The number of days between the migration of rainbow trout/juvenile steelhead and juvenile Chinook from Beaver Creek and the first detection in the Columbia River.

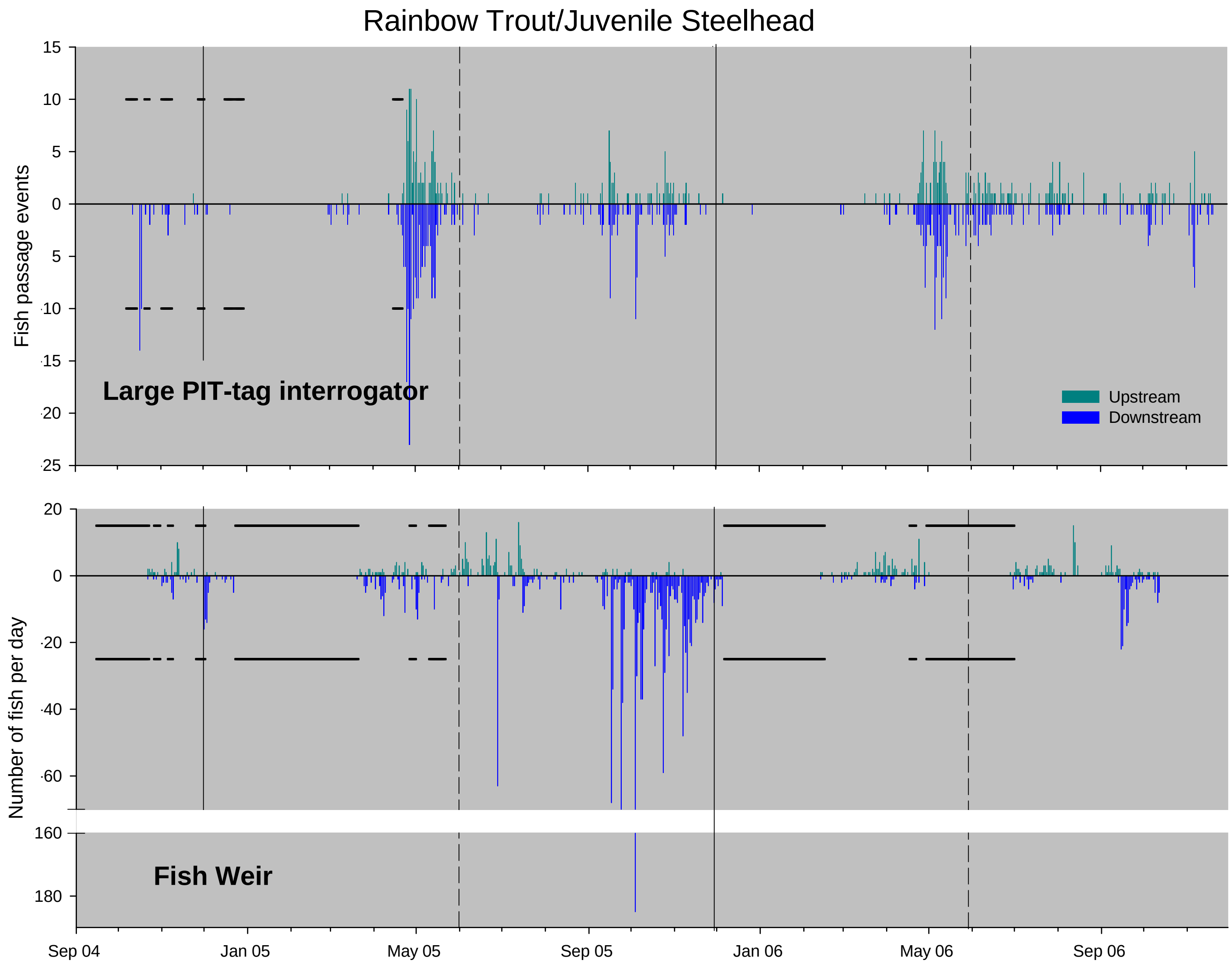
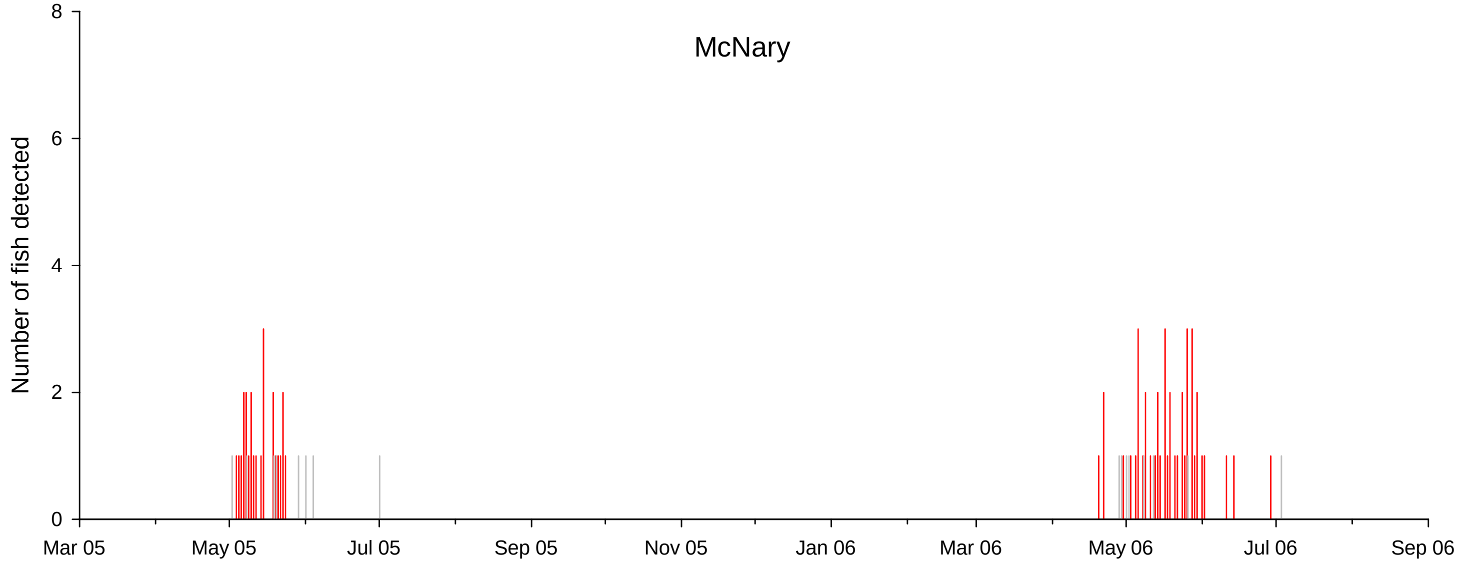


Figure 12. Rainbow trout/juvenile steelhead detected at the large PIT-tag interrogator or collected at the fish trap in Beaver Creek. The black dashes ▬ indicate days when the fish trap or large PIT-tag interrogator was not operating.



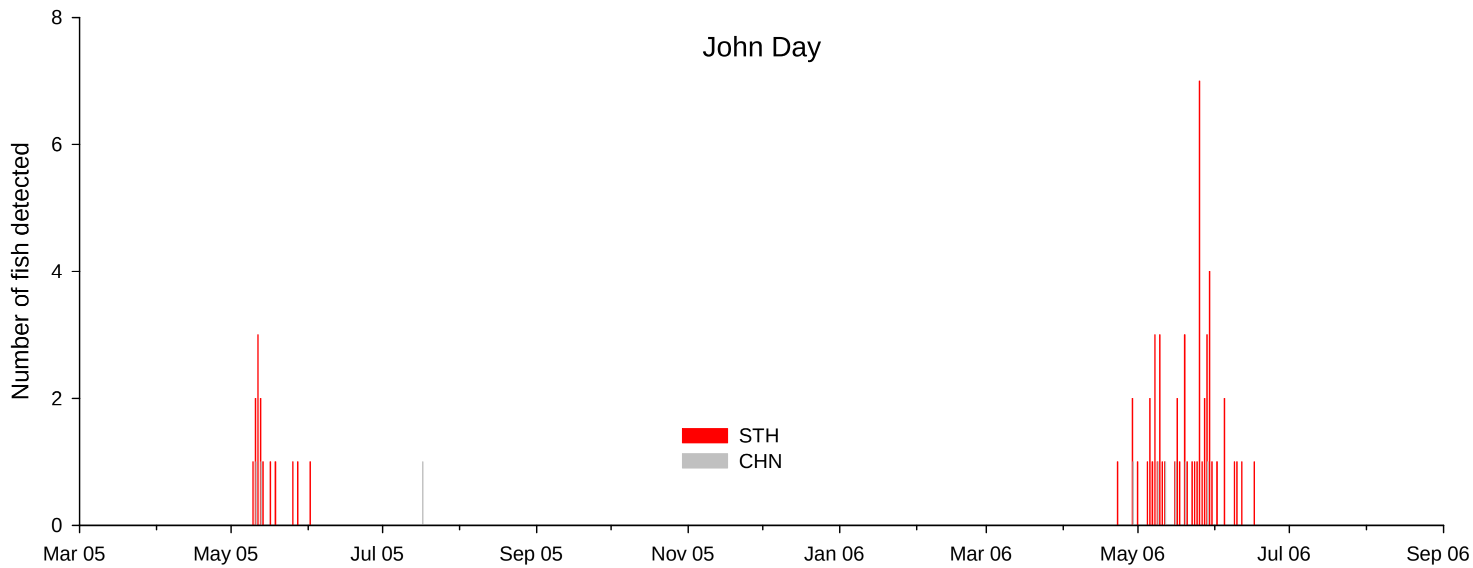


Figure 13. Rainbow trout/juvenile steelhead tagged and released in Beaver Creek from 2004-2005 and the number of fish detected at McNary and John Day dams.

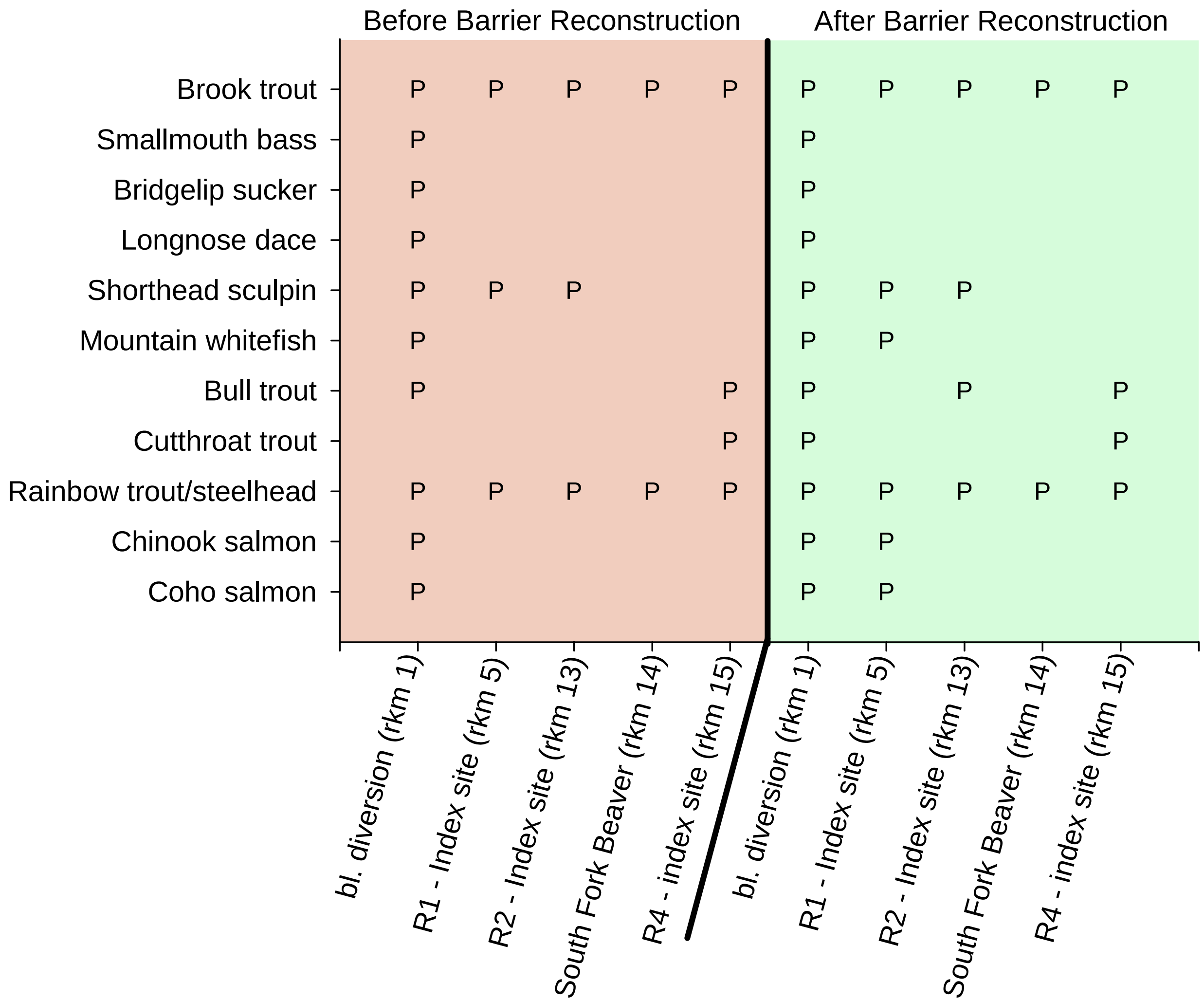


Figure 14. The presence of fish species in selected sections of Beaver Creek before and after the reconstruction of the lowest remaining water diversion.

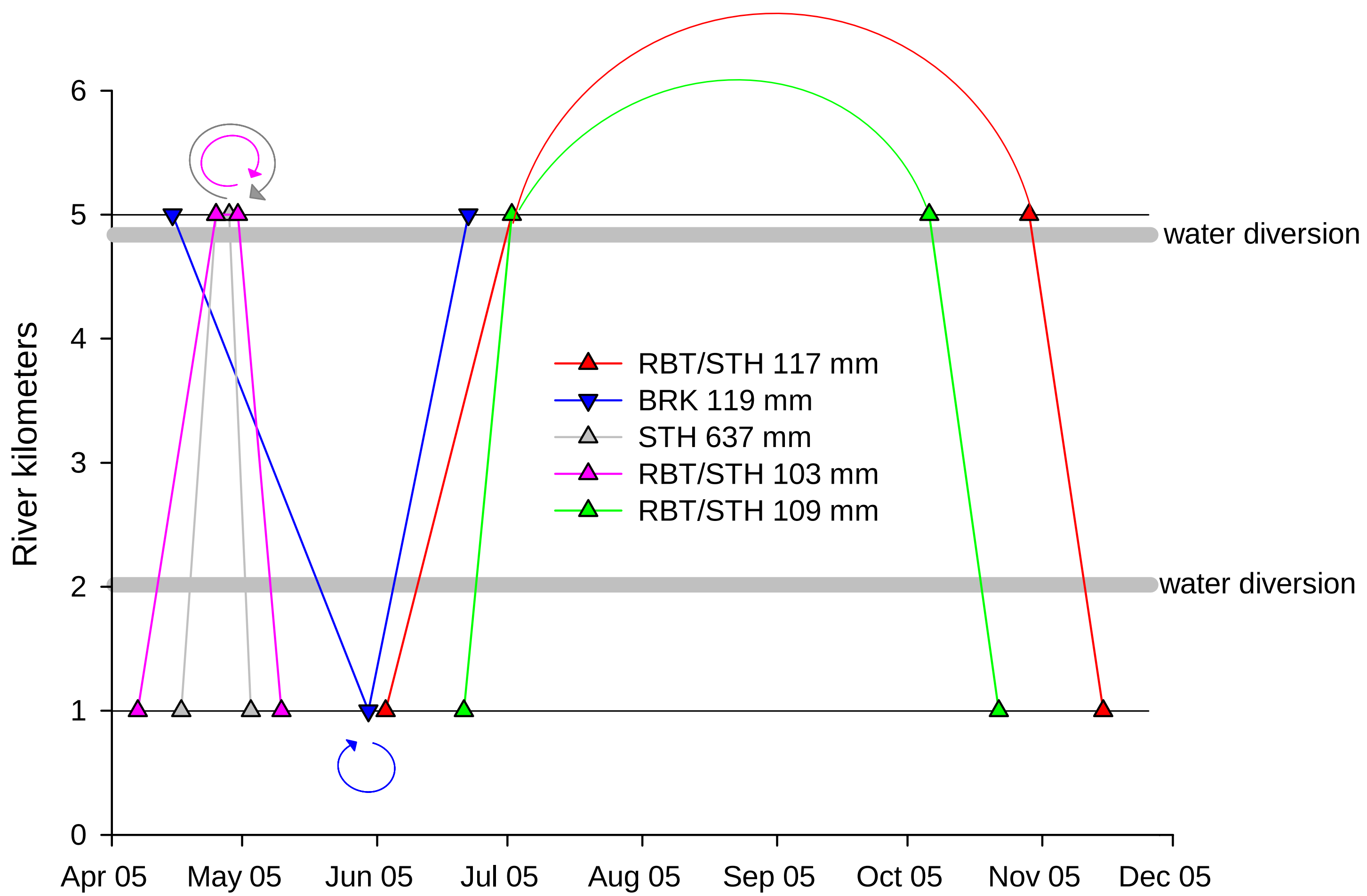


Figure 15. Movement of five fish that were successfully detected moving from rkm 1 to rkm 5, or from rkm 5 to rkm 1, and then back again across two reconstructed water diversions in Beaver Creek.

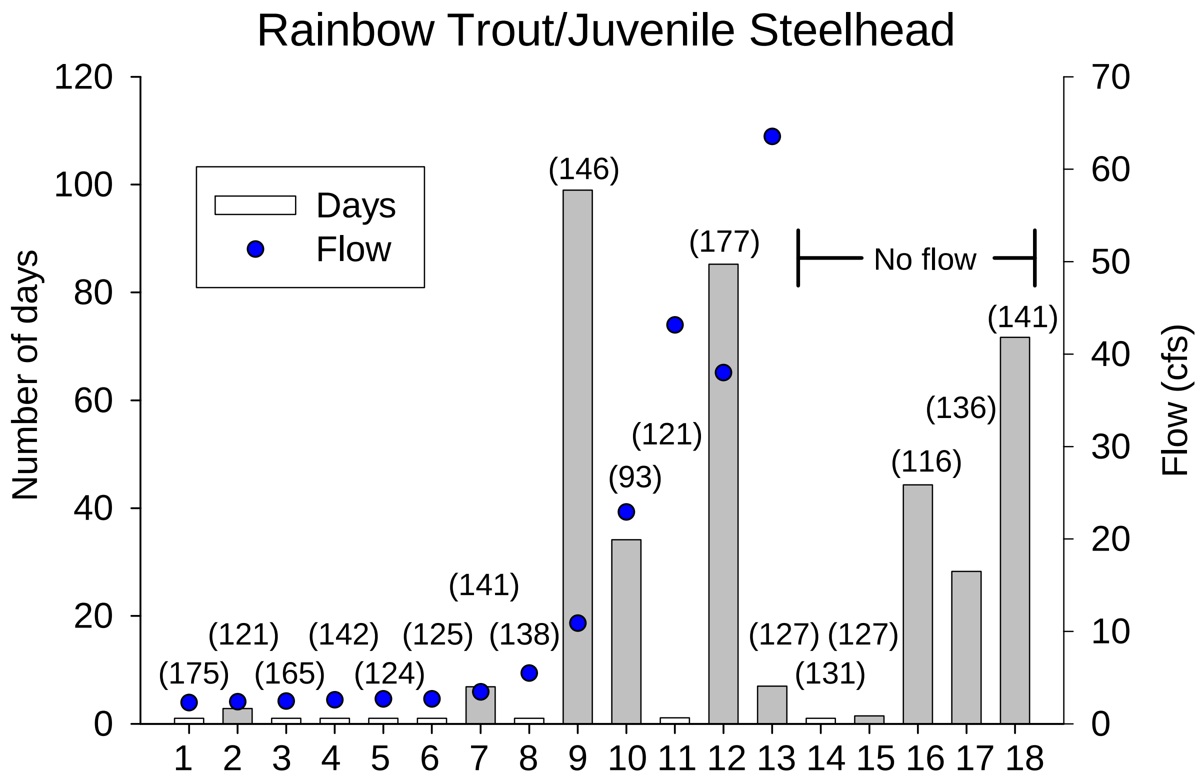


Figure 16. The amount of time and flow for rainbow trout/juvenile steelhead and to move upstream over one reconstructed water diversion. Fish length (mm) is indicated above each fish’s travel times.

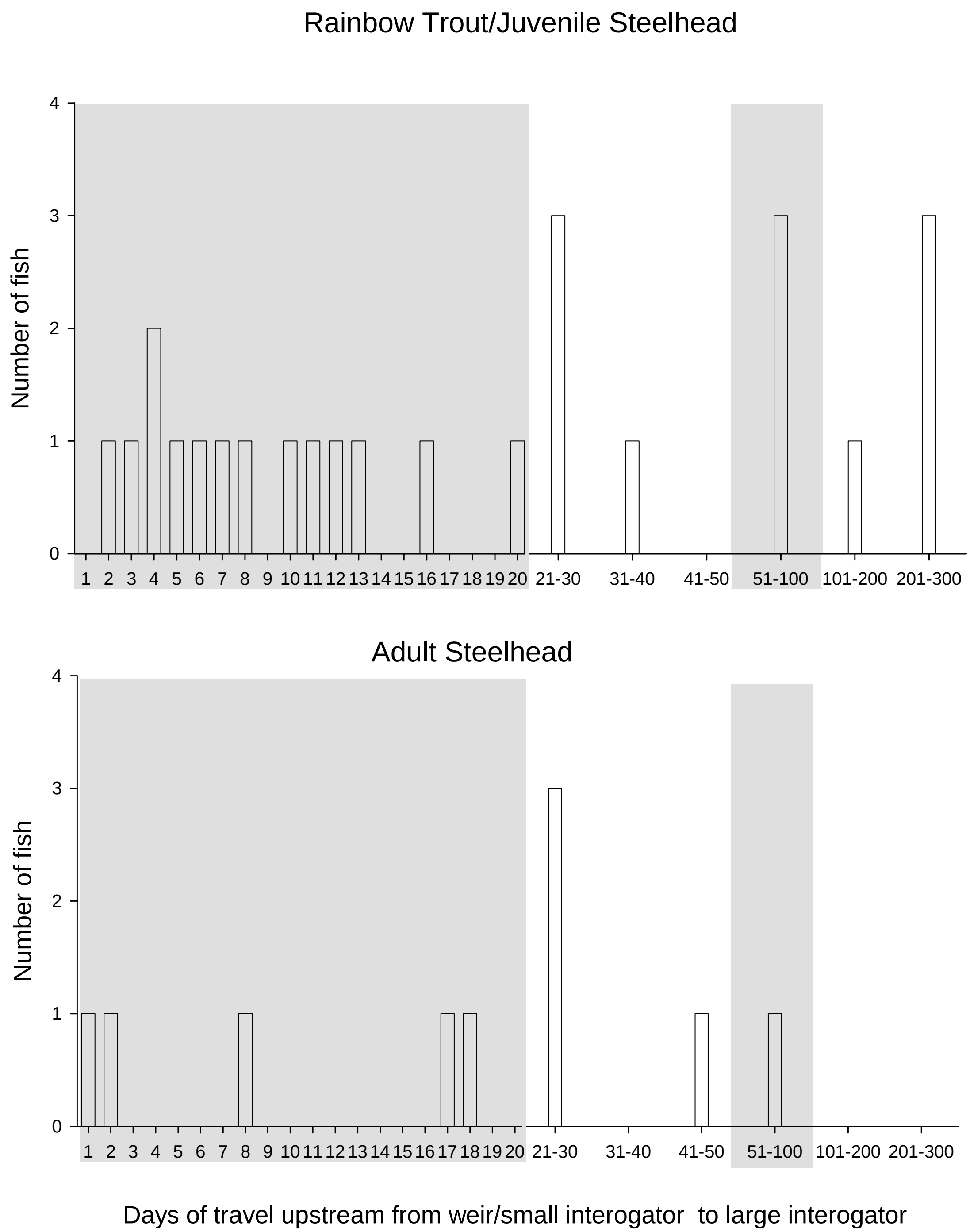
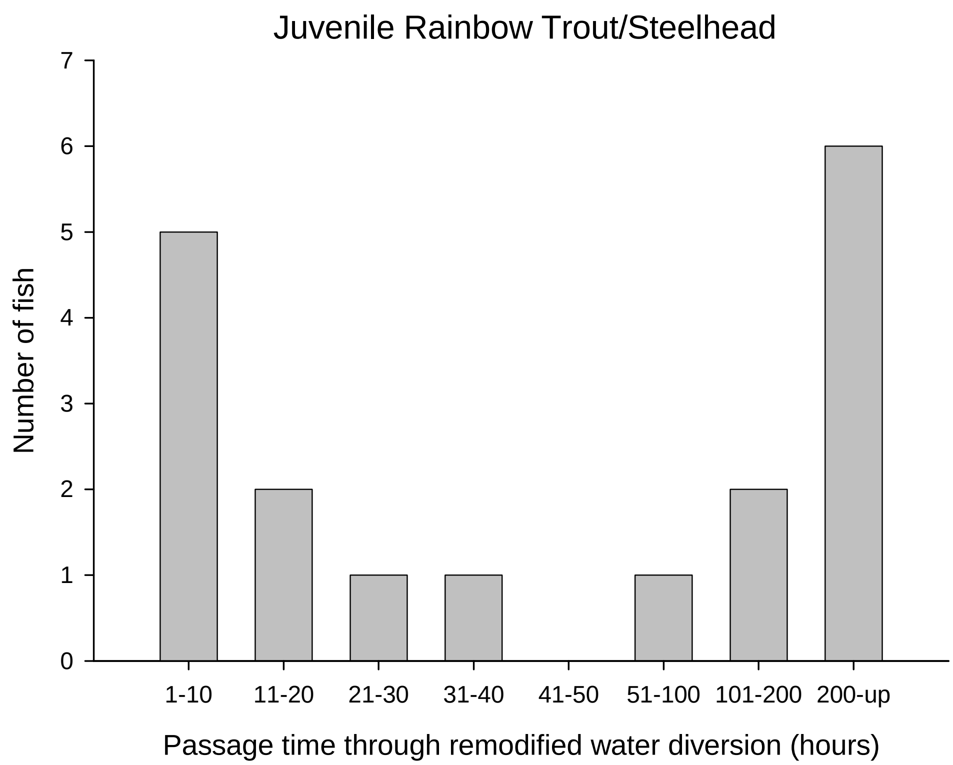


Figure 17. The number of days for juvenile steelhead and adult steelhead to move upstream from the trap/small PIT tag interrogator (rkm 1) to the large PIT-tag interrogator (rkm 5) over two reconstructed water diversions in Beaver Creek.



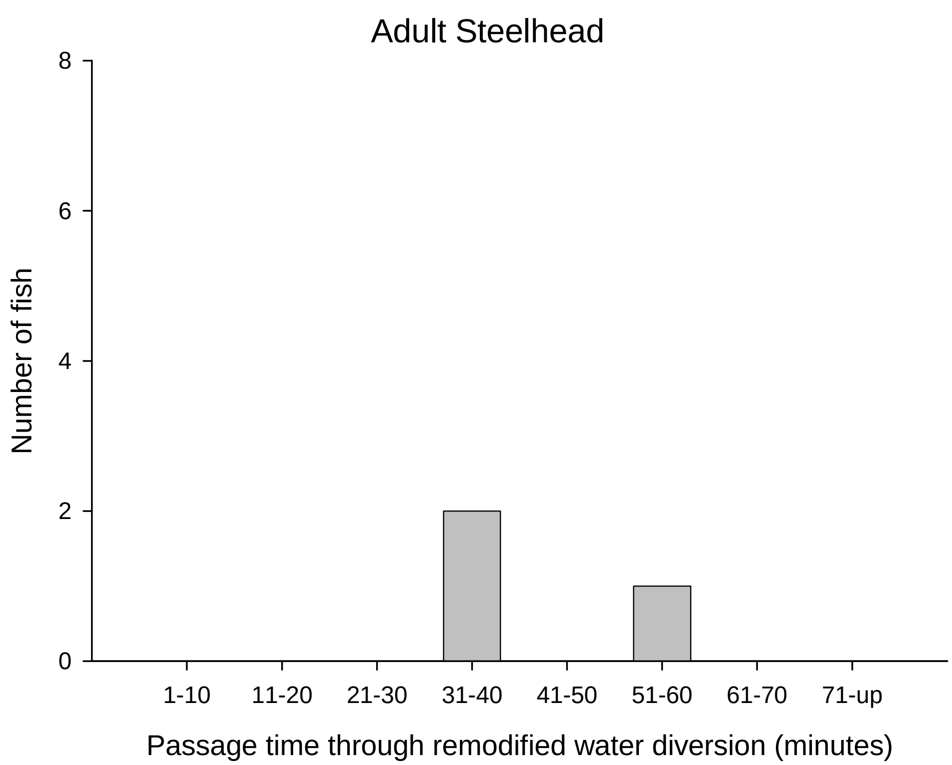


Figure 18. The amount of time for rainbow trout/juvenile steelhead and adult steelhead to move upstream over one reconstructed water diversion.

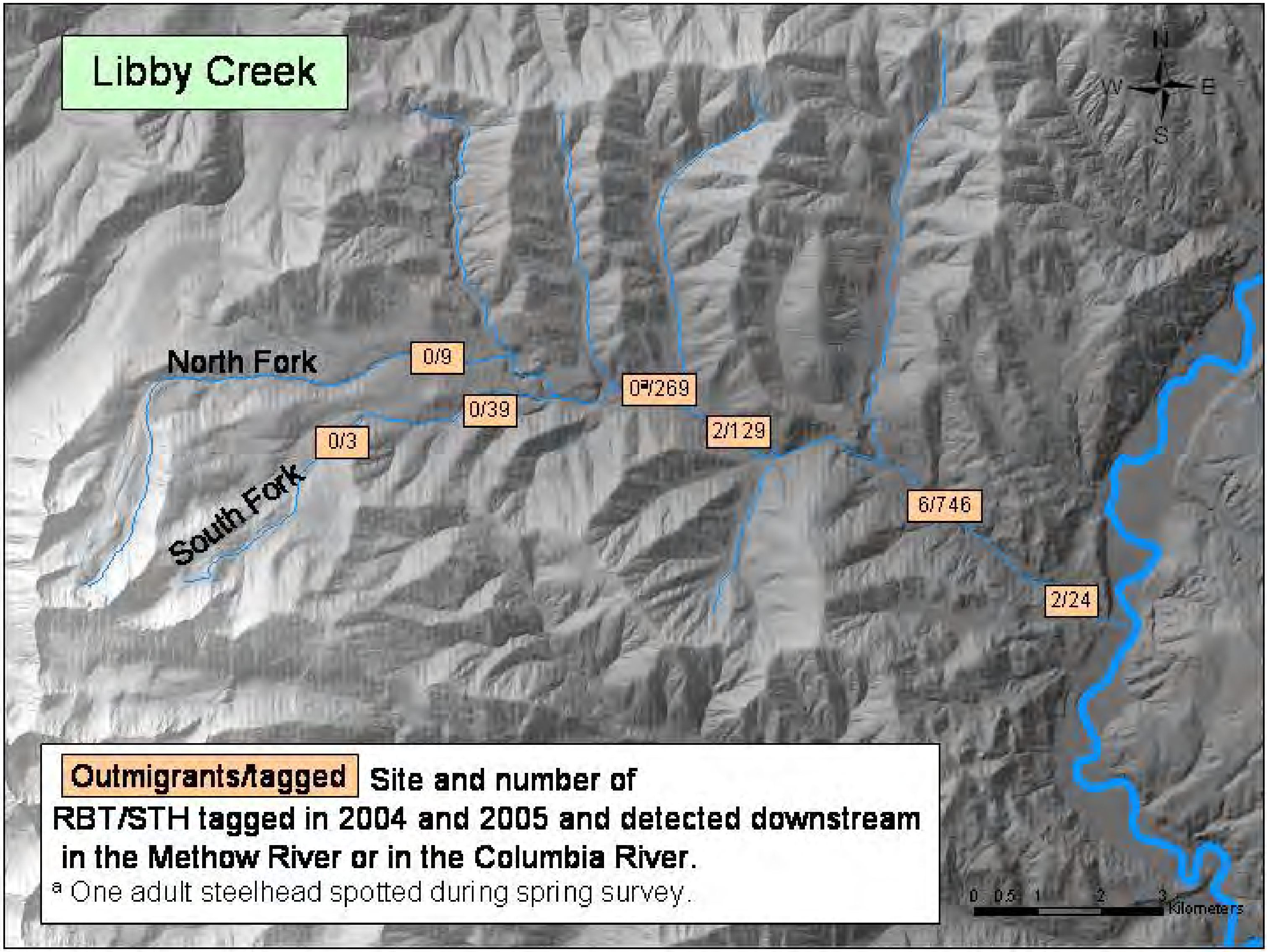


Figure 19. Rainbow trout/juvenile steelhead tagged and released in Libby Creek from 2004 to 2005 and the number of fish detected in the mainstem Methow River or a PIT-tag interrogation site in the Columbia River.

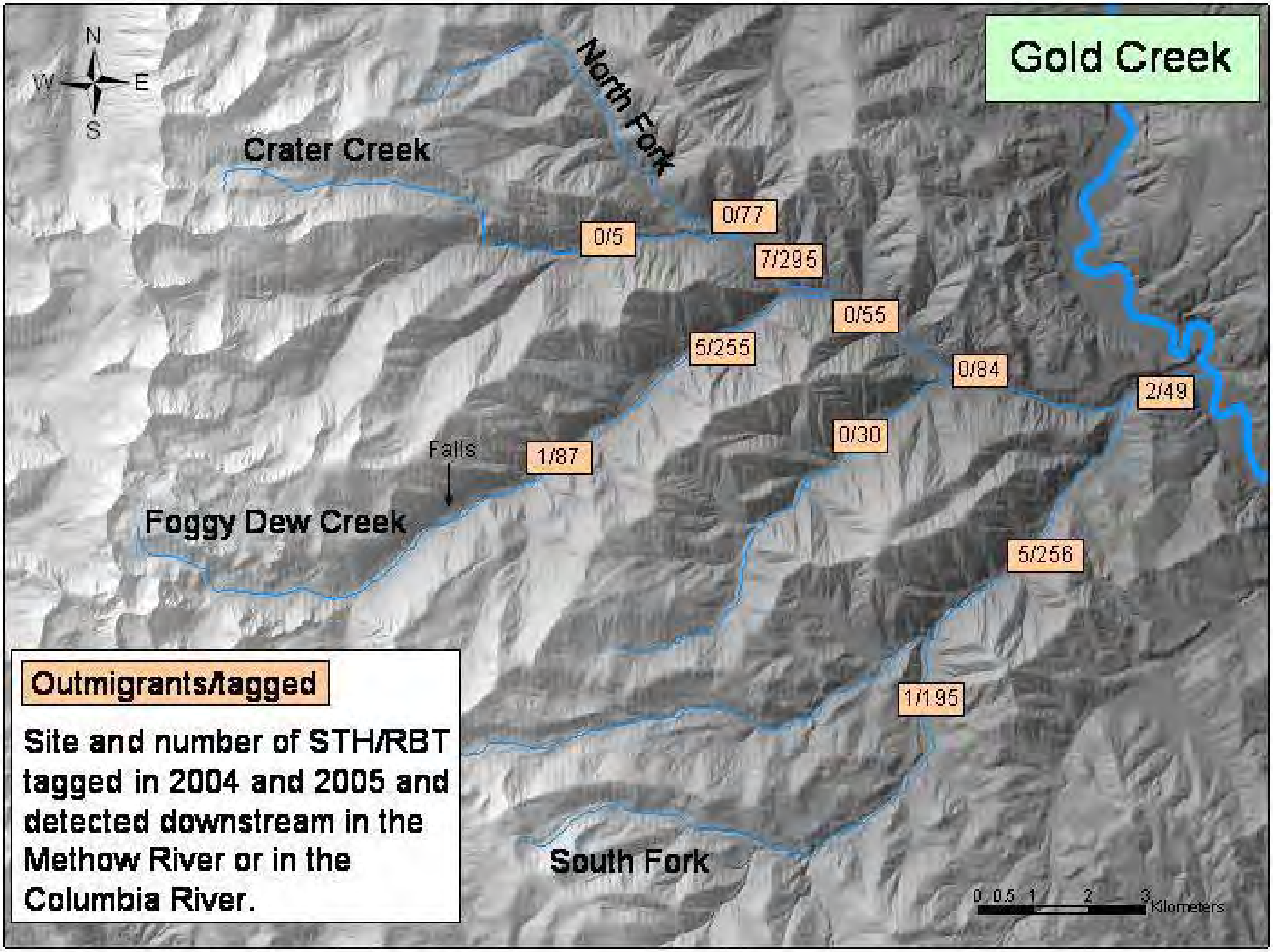


Figure 20. Rainbow trout/juvenile steelhead tagged and released in Gold Creek from 2004 to 2005 and the number of fish detected in the mainstem Methow River or a PIT-tag interrogation site in the Columbia River.

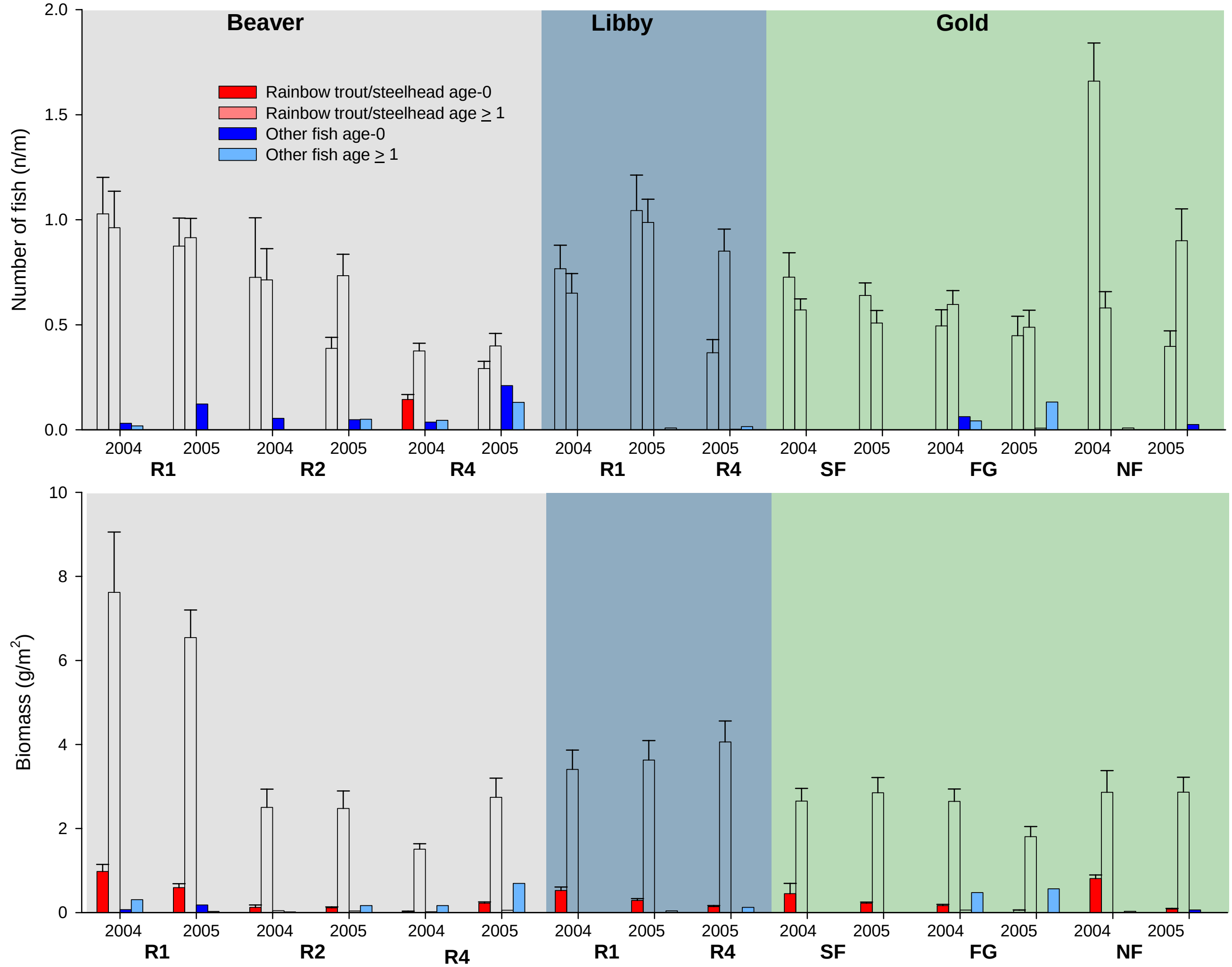


Figure 21. The number of fish per meter and biomass per meter squared of rainbow trout/steelhead and other species encountered at eight index population sites during 2004 and 2005. R1= Reach 1, R2= Reach 2 (rkm 13) R4= Reach 4 (rkm 15) SF=South Fork Gold Creek FG=Foggy Dew Creek NF=North Fork Gold Creek.

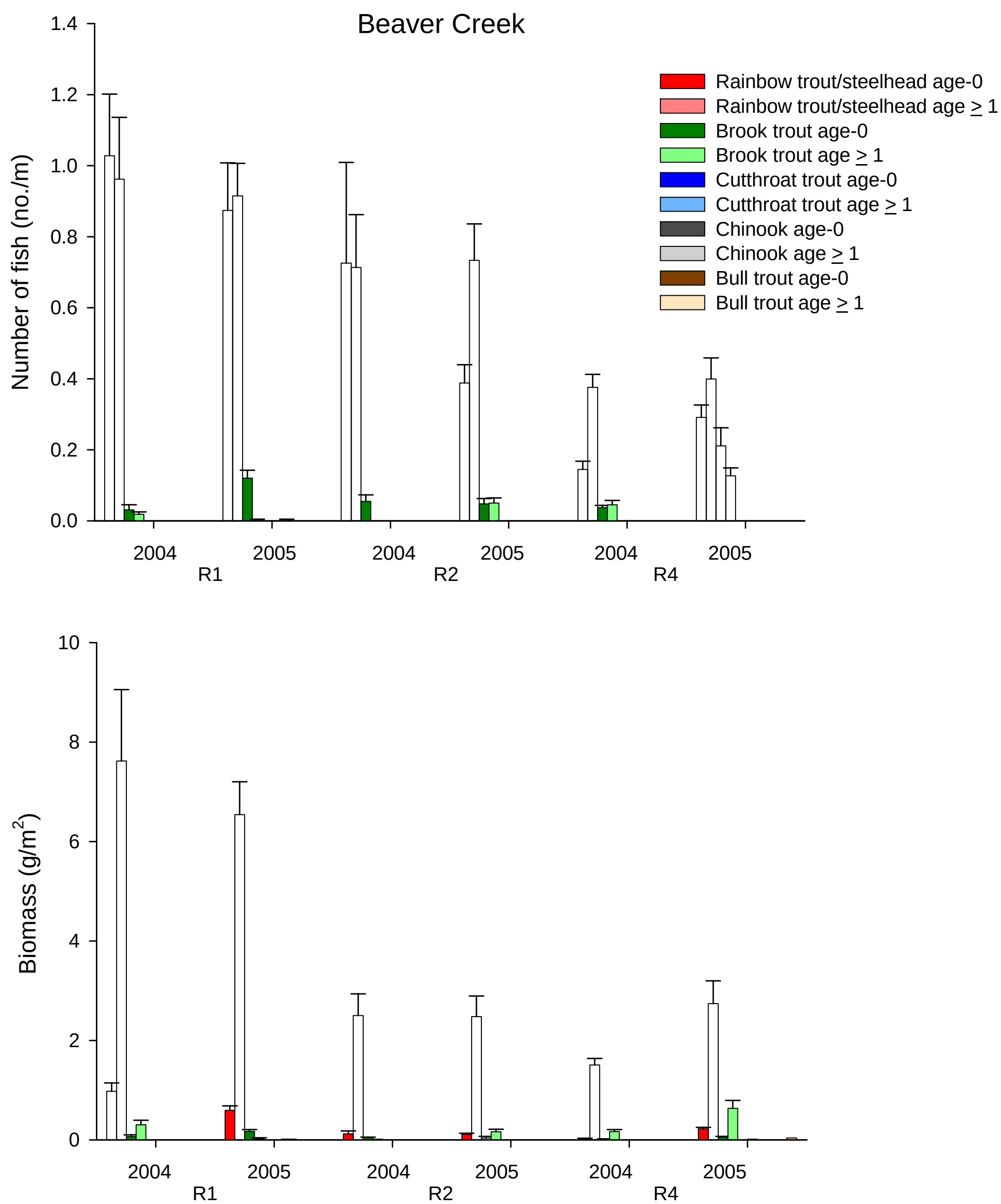


Figure 22. The number and biomass of fish sampled in Beaver Creek during summer 2004 and 2005. R1=Beaver Creek Reach 1 (rkm 5) R2= Beaver Creek Reach 2 (rkm 13) R4=Beaver Creek Reach 4 (rkm 15).

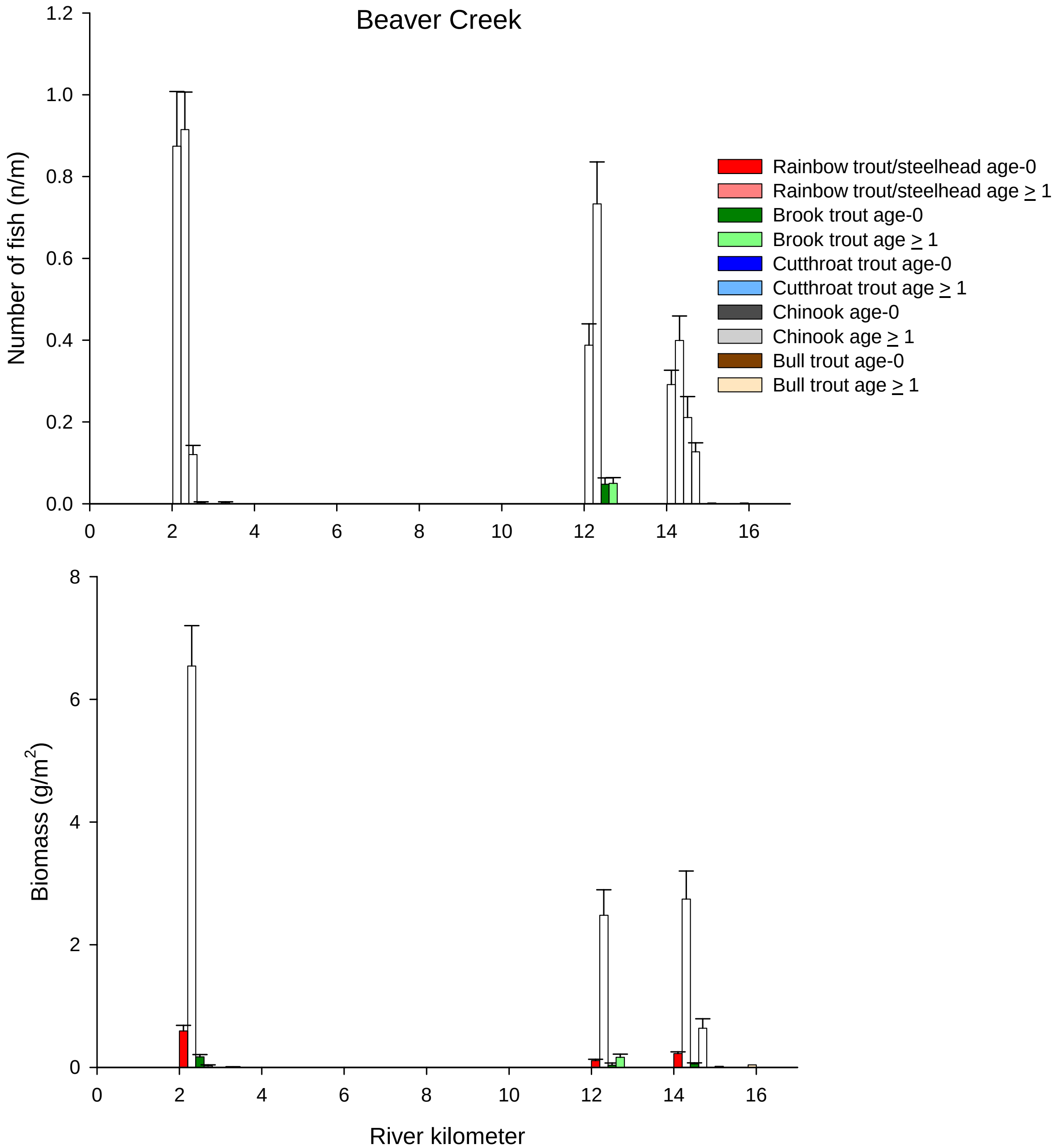


Figure 23. The number and biomass of fish sampled at three index sites during 2005 field season in Beaver Creek.

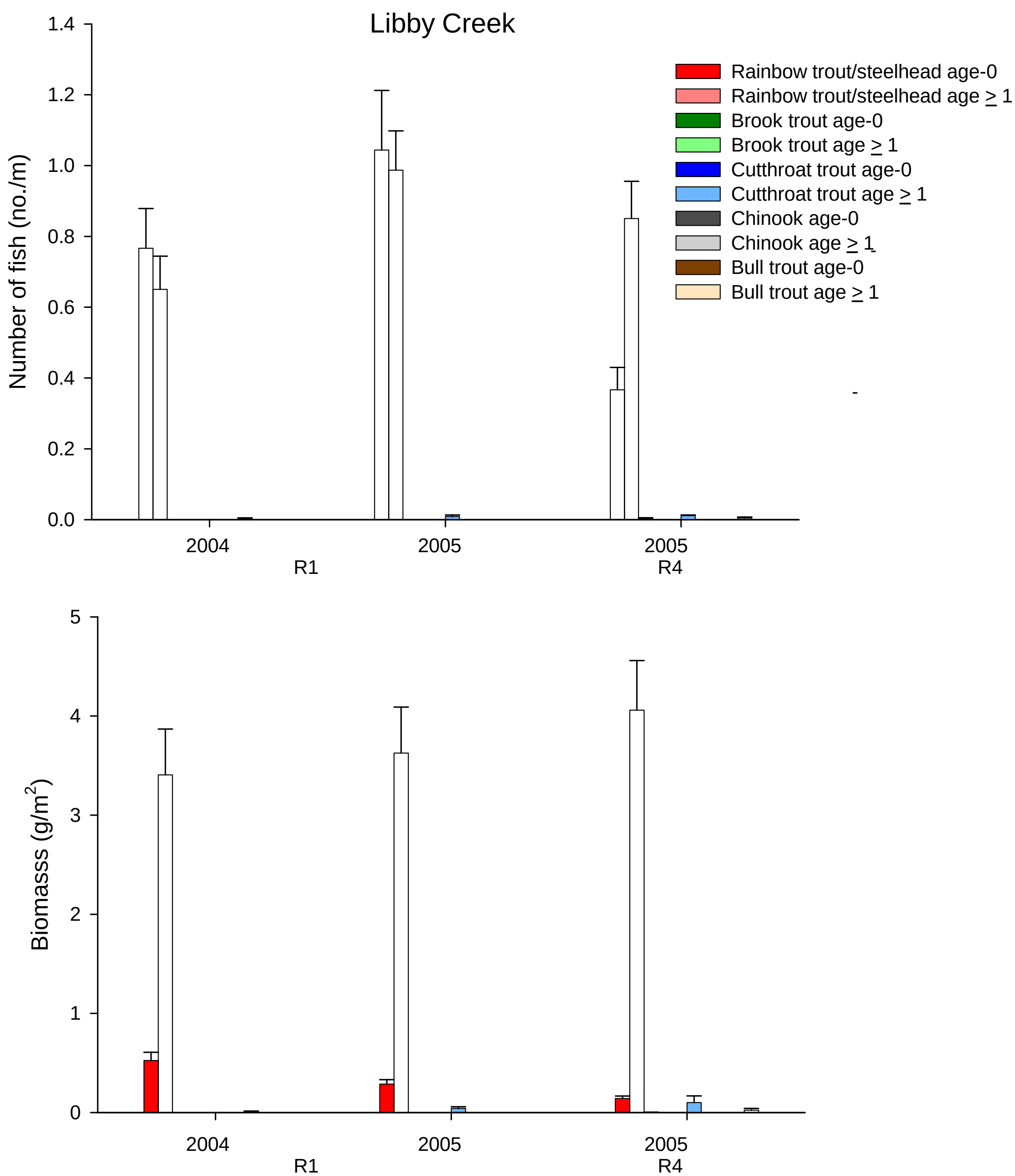


Figure 24. The number and biomass of fish sampled in Libby Creek during summer 2004 and 2005. R1=Libby Creek Reach 1 (rkm 2) R4= Libby Creek Reach 4 (rkm 10).

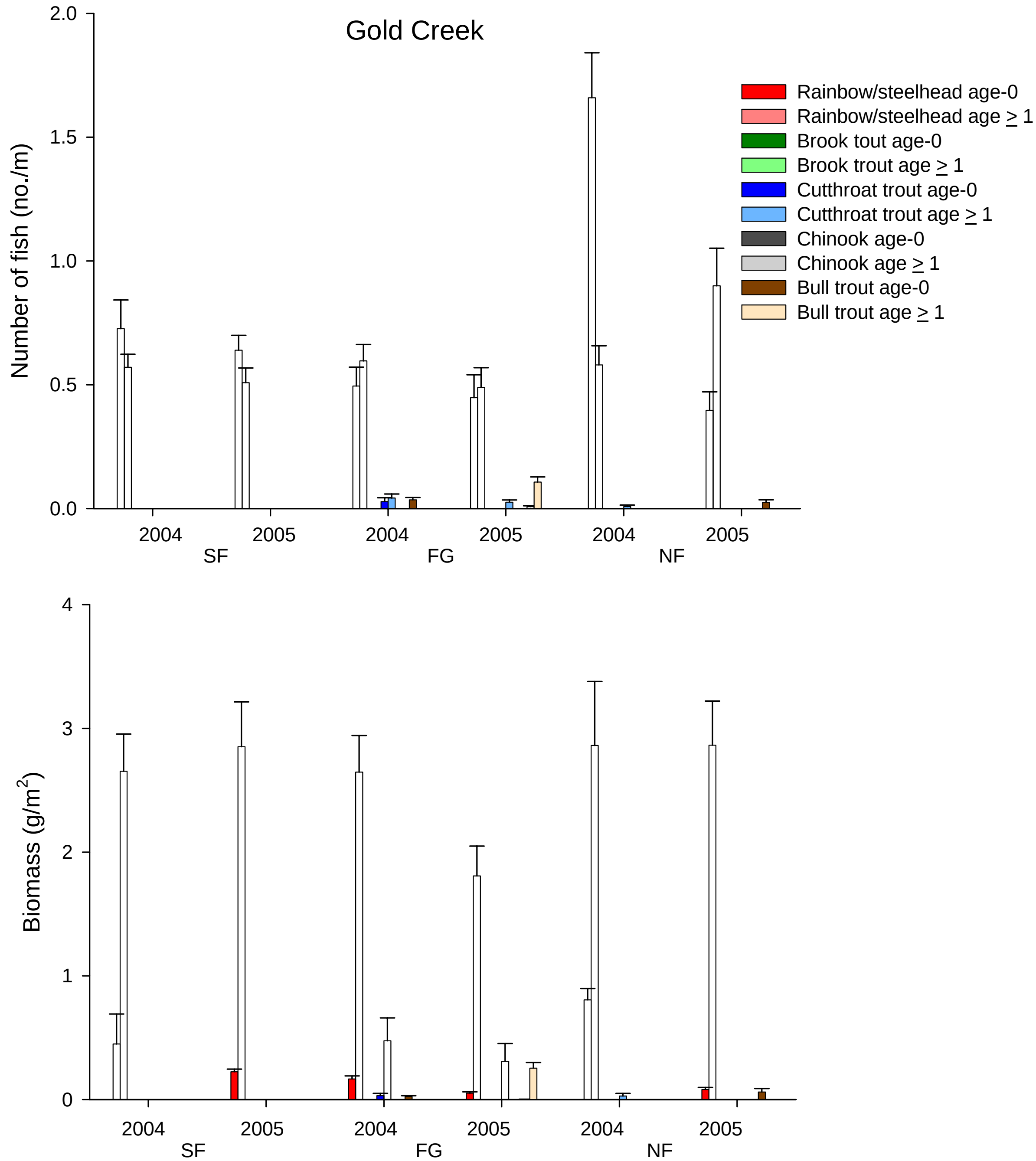


Figure 25. The number and biomass of fish sampled in Gold Creek during summer 2004 and 2005. SF=South Fork Gold Creek (rkm 2) FG= Foggy Dew Creek (rkm 2) NF=North Fork Gold Creek (rkm 9).

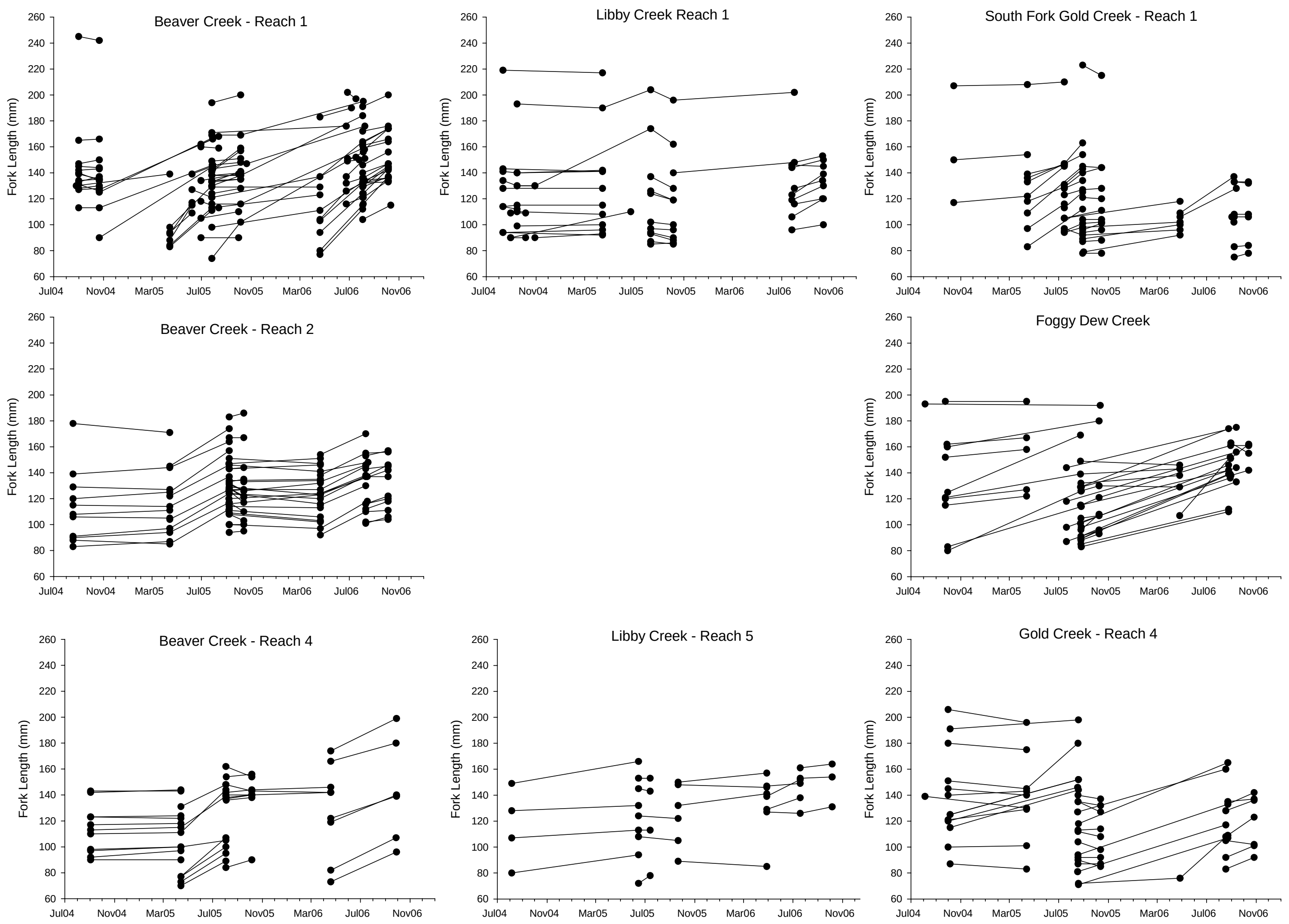


Figure 26. Fork length (mm) of rainbow trout/juvenile steelhead at tagging and at recapture times in reaches of Beaver, Libby, and Gold creeks.

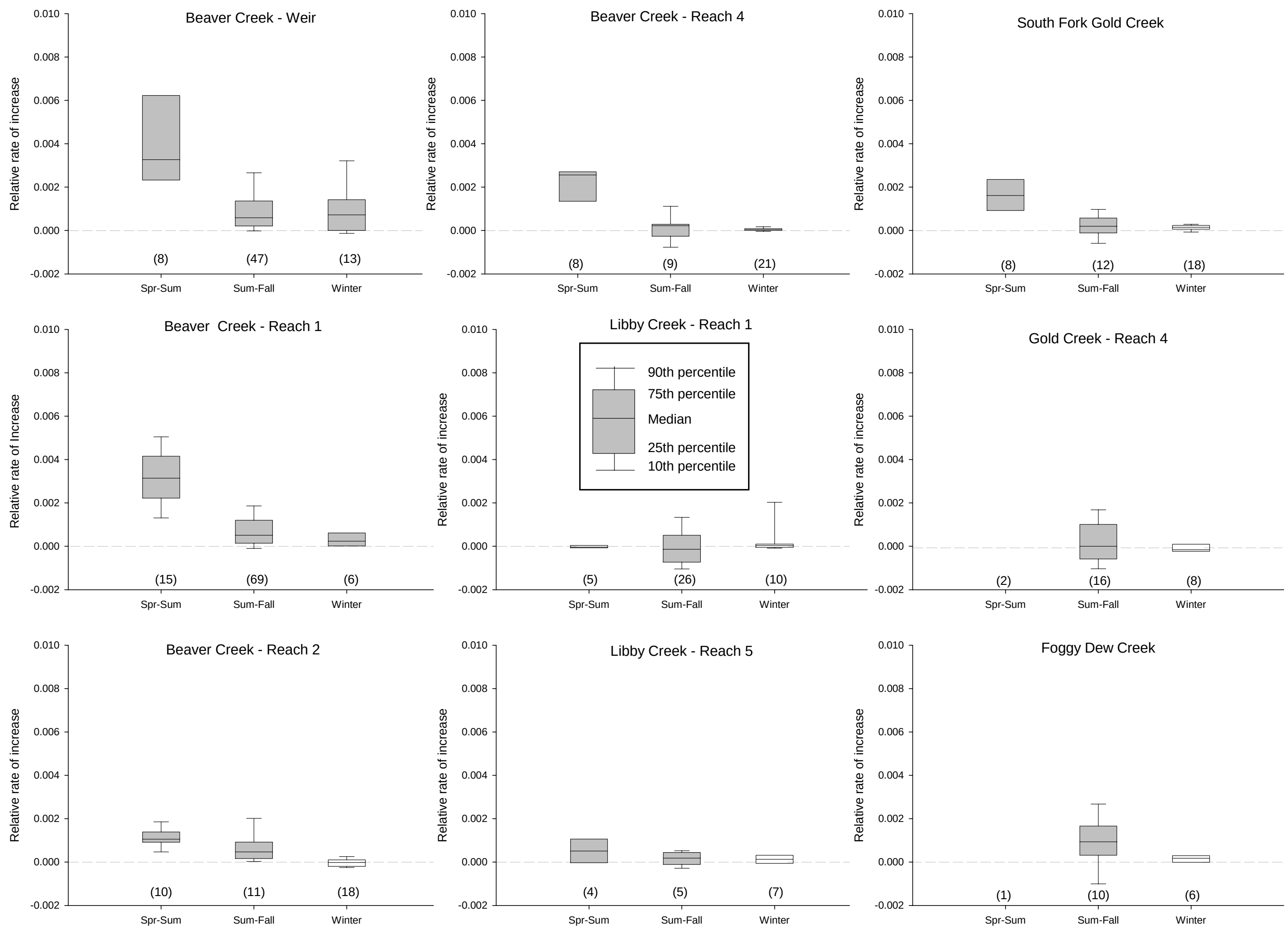


Figure 27. Seasonal relative rate of growth (mm) per day for rainbow trout/juvenile steelhead in reaches of Beaver, Libby, and Gold creeks.

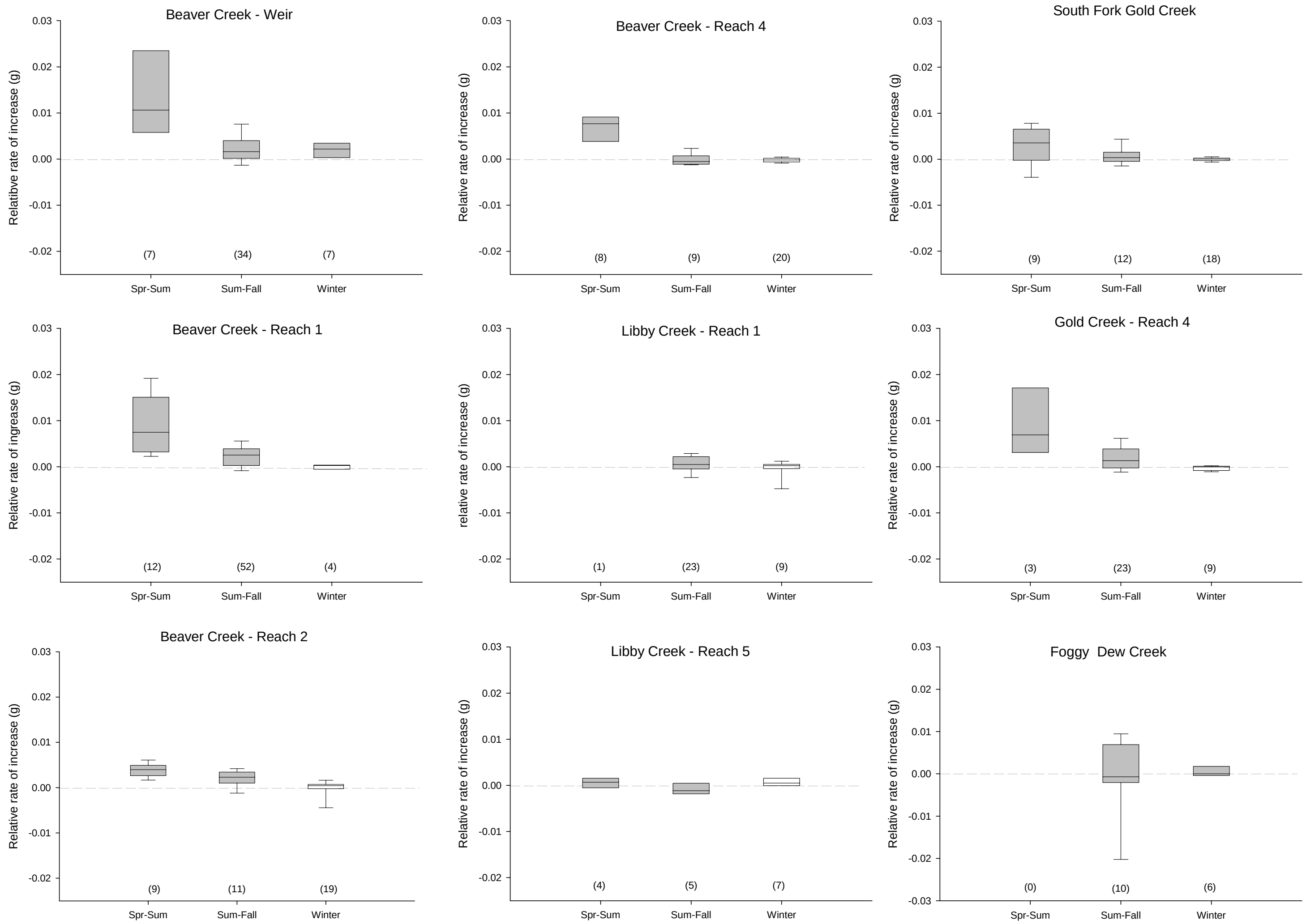


Figure 28. Seasonal relative rate of growth (g) per day for rainbow trout/juvenile steelhead in reaches of Beaver, Libby, and Gold creeks.

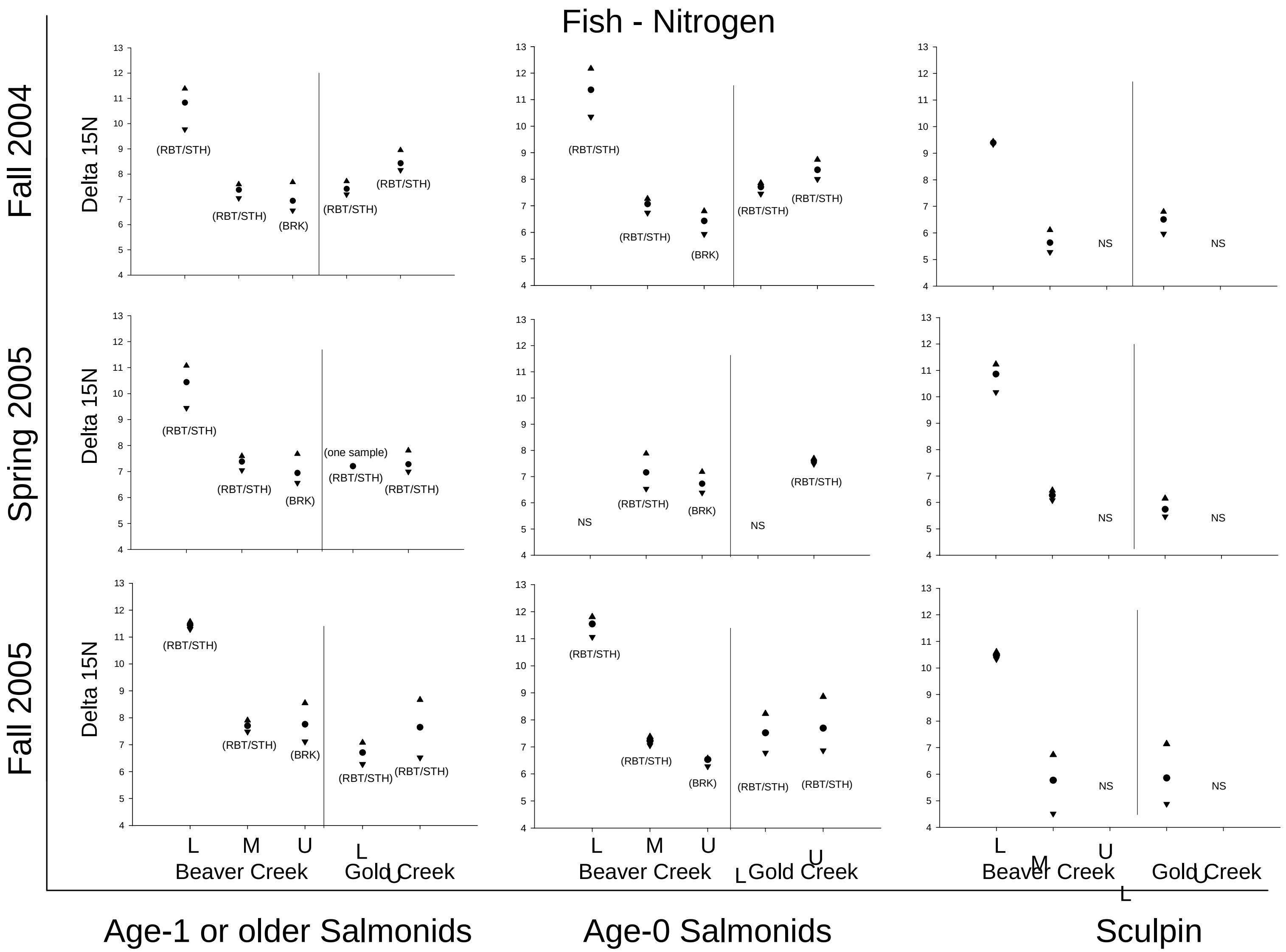


Figure 29. The minimum, average, and minimum ratio of Nitrogen 15 in fish at five sites in two subwatersheds of the Methow River watershed for three sampling times: Fall 2004, Spring 2005, and Fall 2005. L=Lower sampling site, M=Middle sampling site. U=Upper sampling site. RBT/STH=rainbow trout/juvenile steelhead, and BRK=brook trout. NS= No sample.

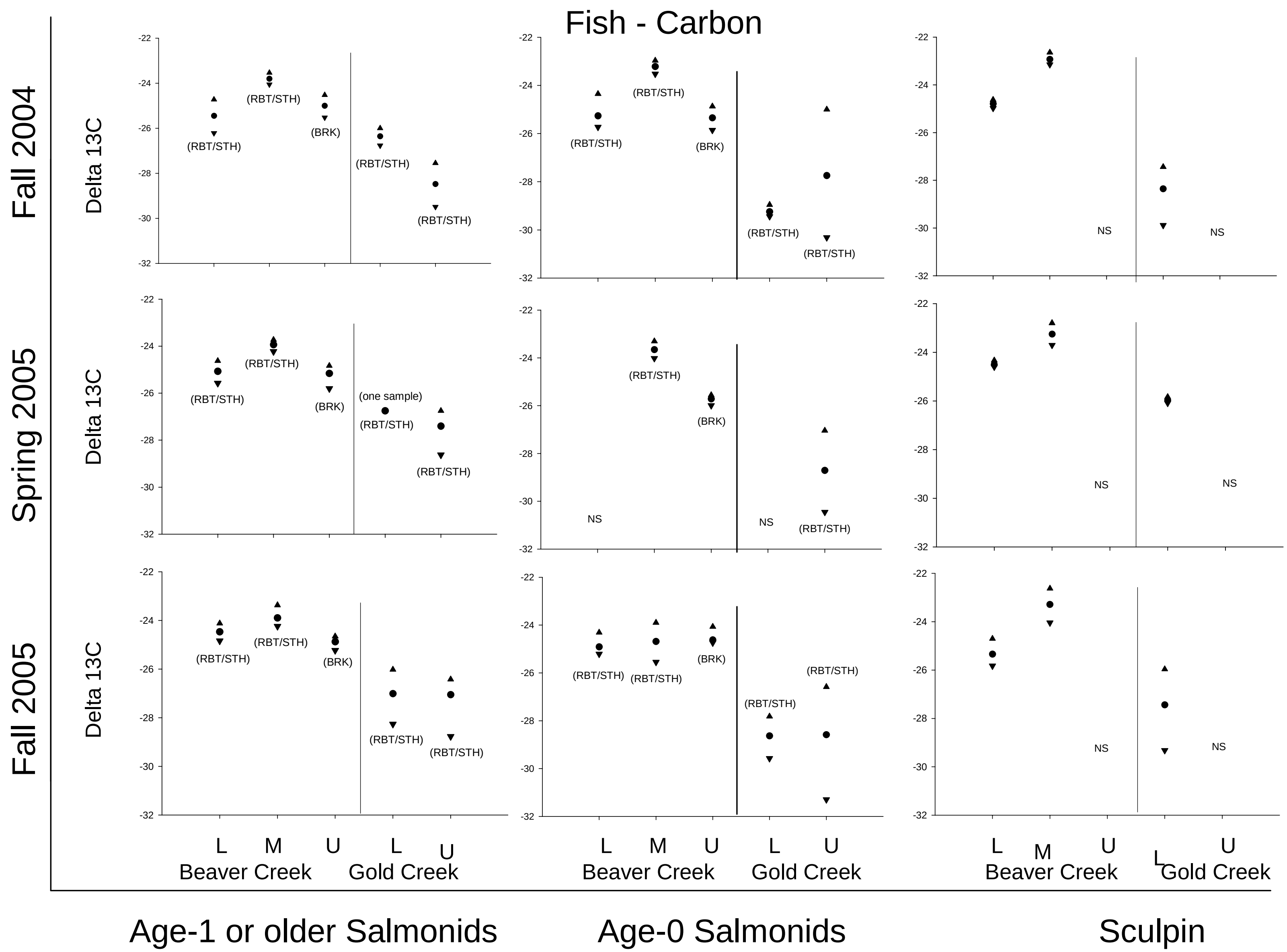


Figure 30. The minimum, maximum, and average ratio of Carbon 13 in fish at five sites in two subwatersheds of the Methow River watershed three sampling times: Fall 2004, Spring 2005, and Fall 2005. L=Lower sampling site, M=Middle sampling site. U=Upper sampling site. RBT/STH=rainbow trout/juvenile steelhead, and BRK=brook trout. NS= No sample.

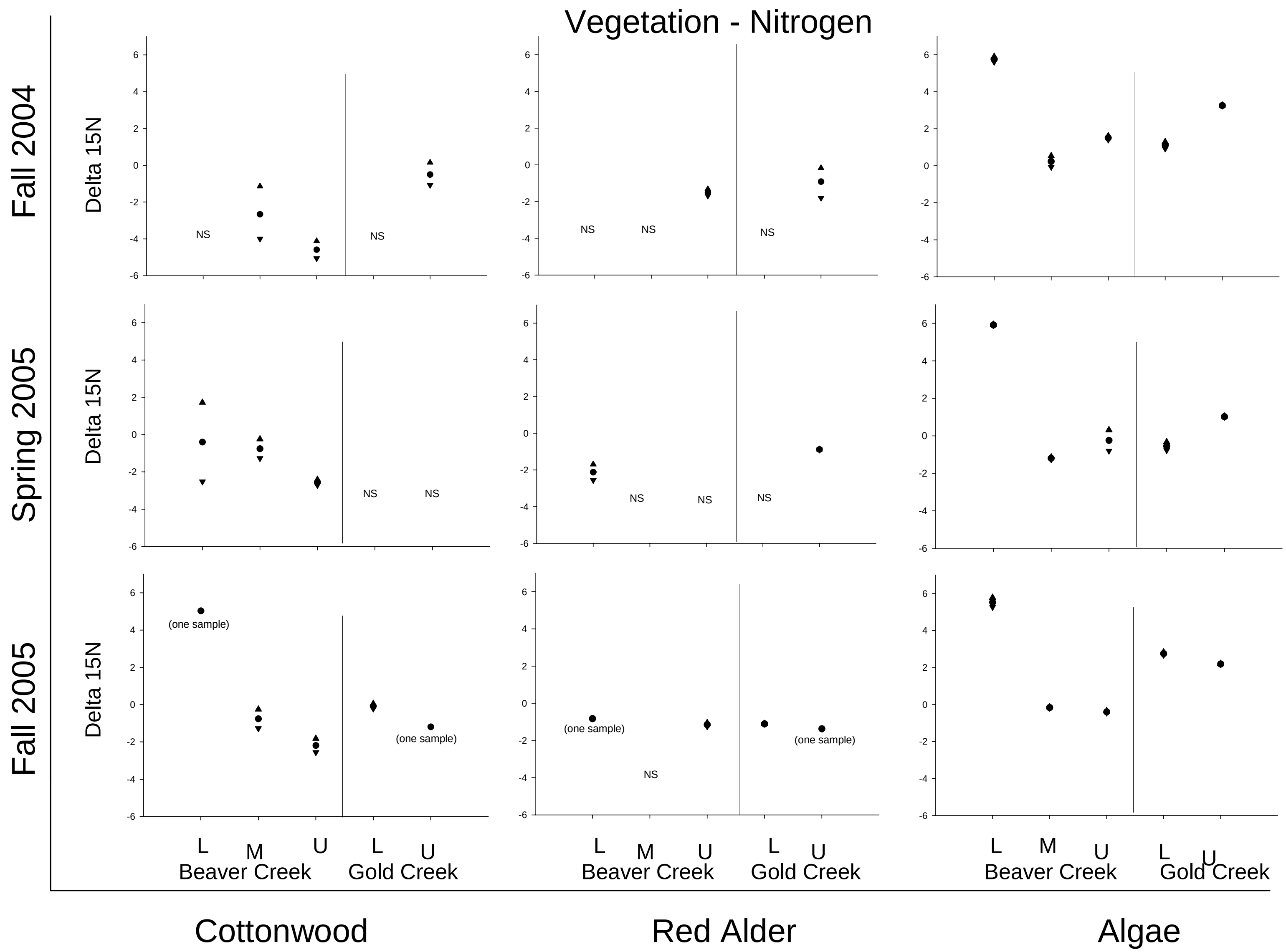


Figure 31. The minimum, maximum, and average ratio of Nitrogen 15 in vegetation found at five sites in two subwatersheds of the Methow River watershed three sampling times: Fall 2004, Spring 2005, and Fall 2005 L=Lower sampling site, M=Middle sampling site. U=Upper sampling site. NS= No sample.

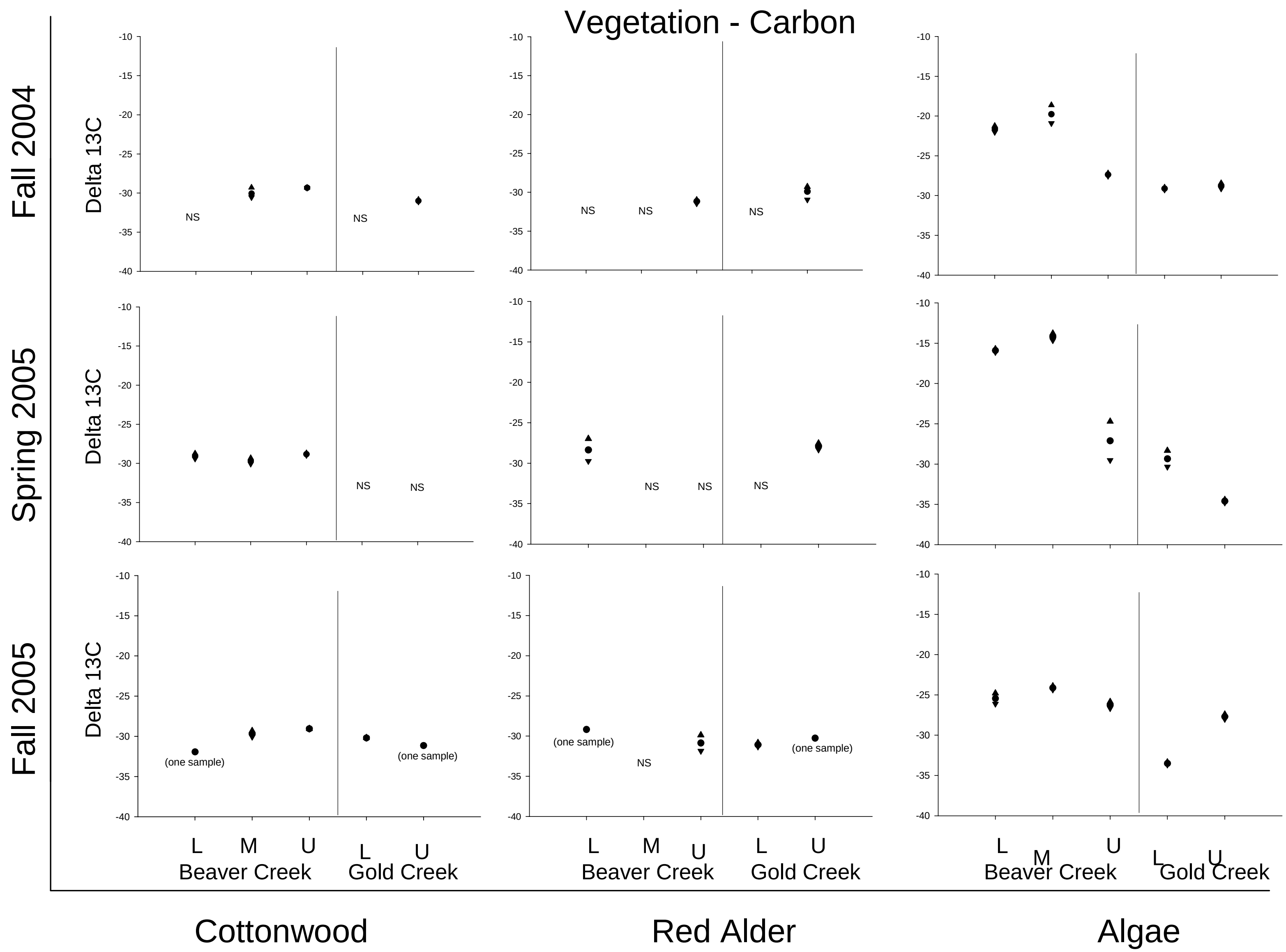


Figure 32. The minimum, maximum, and average ratio of Carbon 13 in vegetation found at five sites in two subwatersheds of the Methow River watershed three sampling times: Fall 2004, Spring 2005, and Fall 2005. L=Lower sampling site, M=Middle sampling site. U=Upper sampling site. NS= No sample.

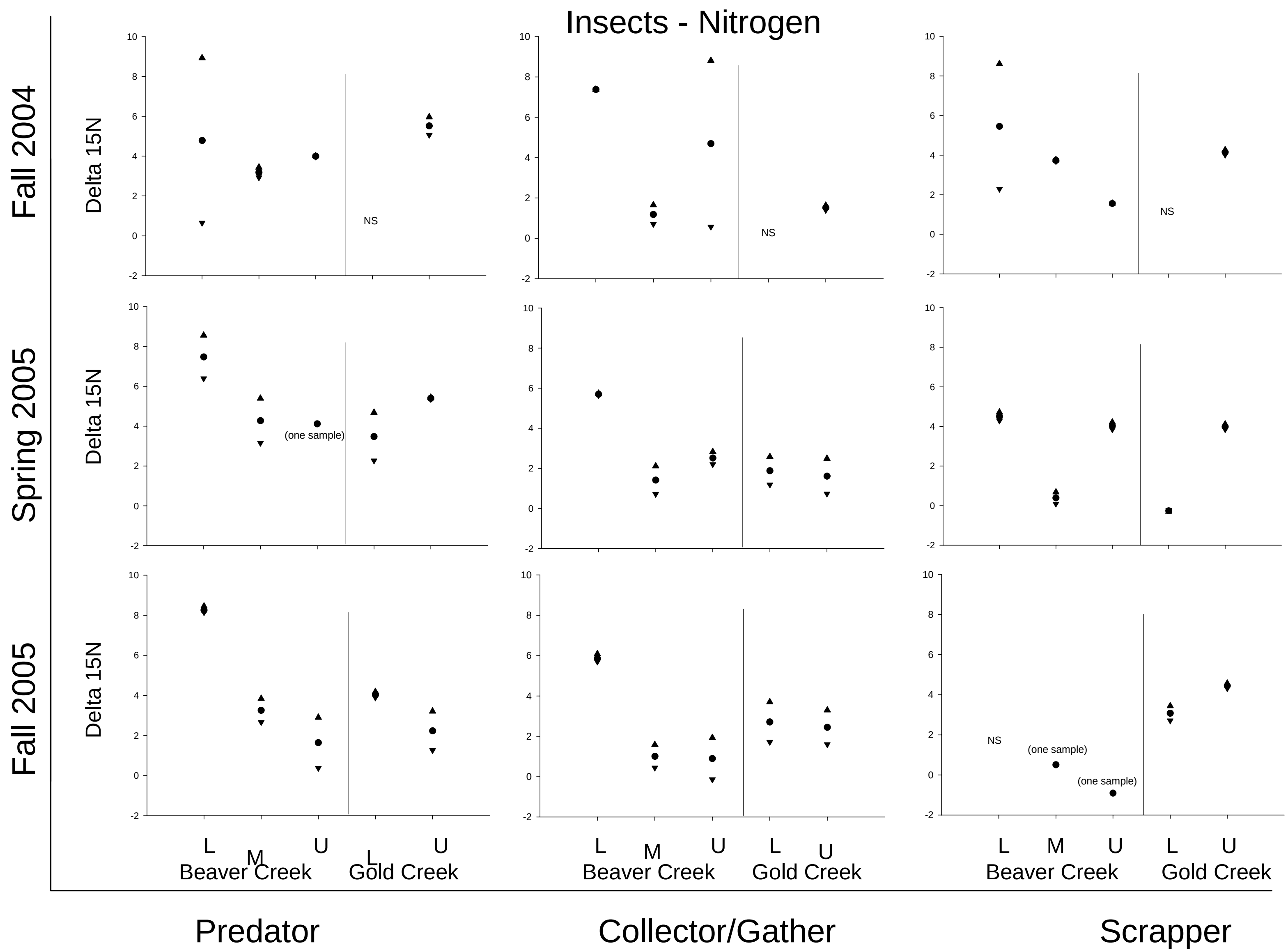


Figure 33. The minimum, maximum, and average ratio of Nitrogen 15 in insects at five sites in two subwatersheds of the Methow River watershed three sampling times: Fall 2004, Spring 2005, and Fall 2005. L=Lower sampling site, M=Middle sampling site. U=Upper sampling site. NS= No sample.

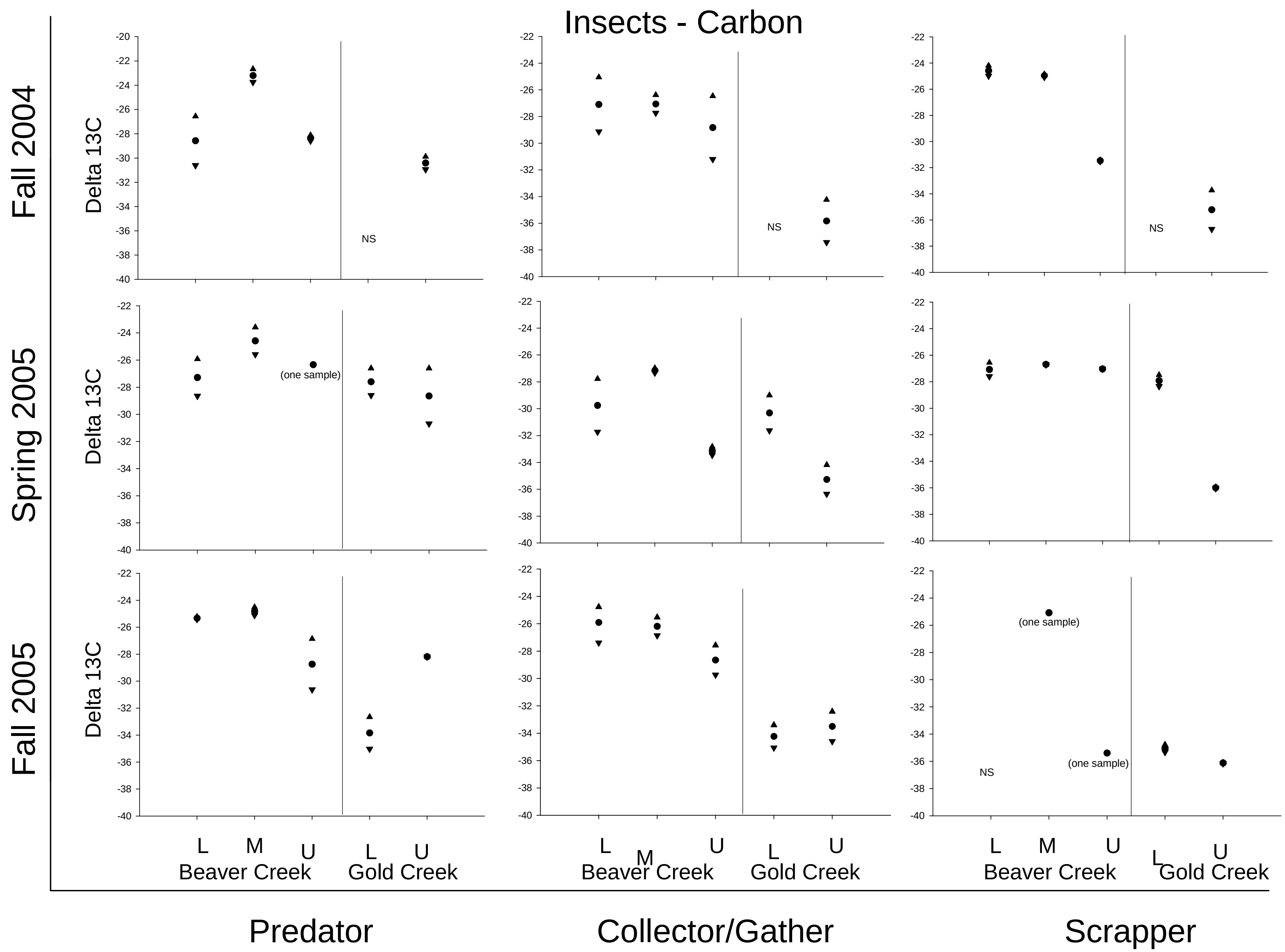


Figure 34. The minimum, maximum, and average ratio of Carbon 13 in insects at five sites in two subwatersheds of the Methow River watershed three sampling times: Fall 2004, Spring 2005, and Fall 2005. L=Lower sampling site, M=Middle sampling site. U=Upper sampling site. NS= No sample.

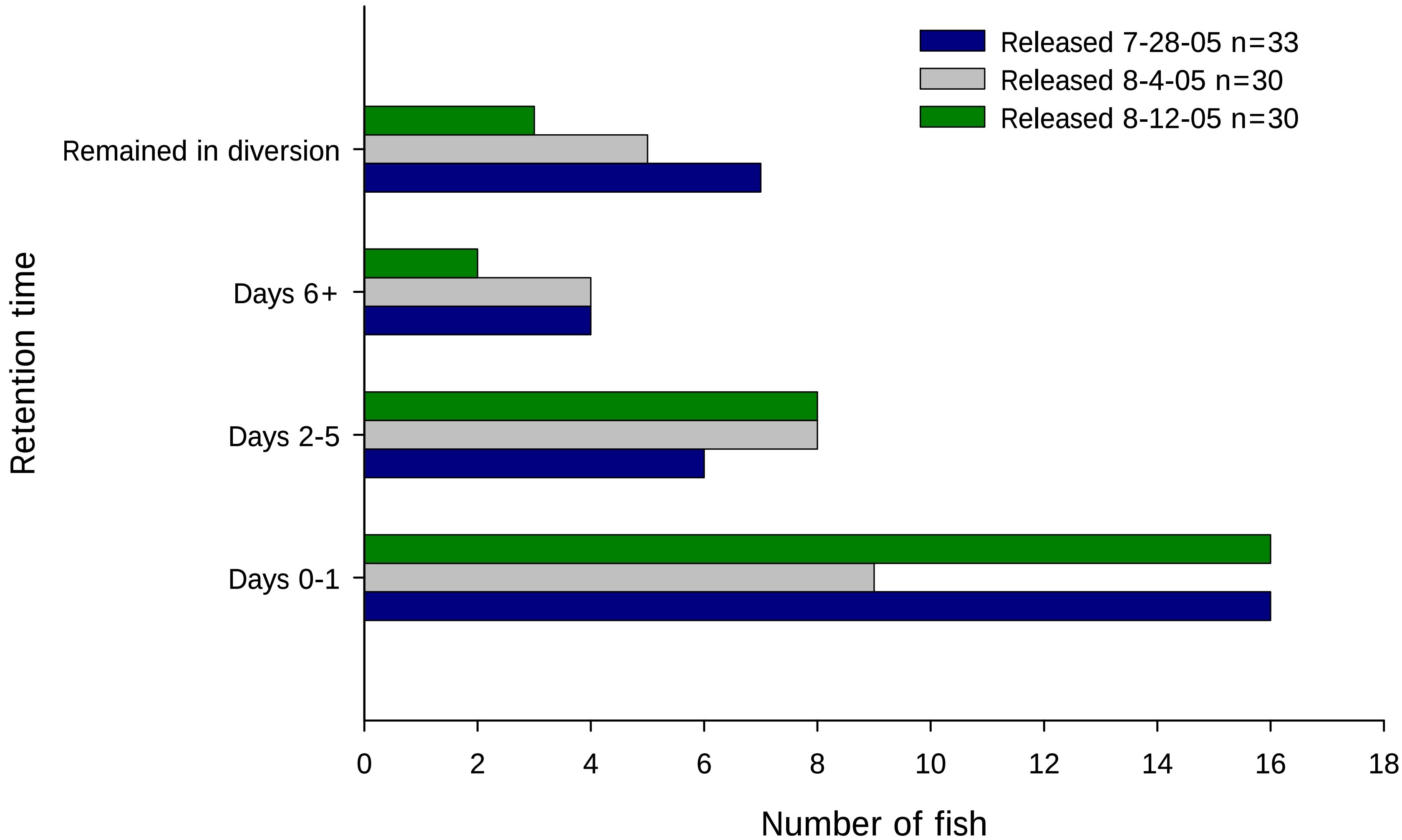


Figure 35. The retention time of fish released into a water diversion water canal for three trials in 2005 at reach one of Beaver Creek.

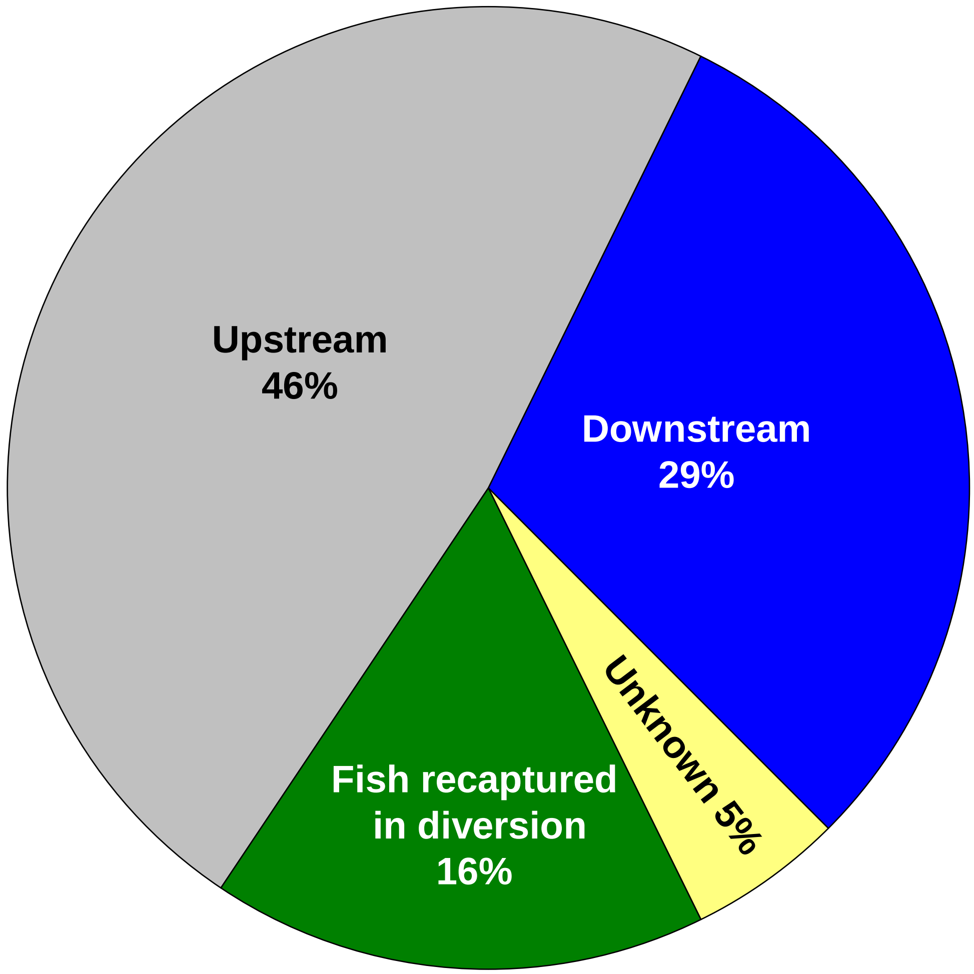


Figure 36. The outcomes of fish released into a water diversion water canal for three combined trials in 2005 at reach one of Beaver Creek.

Appendix Table 1. Total growth (mm) and daily relative rate of increase (mm) for PIT-tagged and recaptured rainbow trout/juvenile steelhead in reach 1 of Beaver Creek, 2004-2006.

	Total growth (mm)					Avg. daily relative rate of increase (mm)				
Season of growth	n	Mean	Median	Min	Max	n	Mean	Median	Min	Max
Spring -summer	15	25	27.0	7	35	15	0.0031	0.0031	0.0005	0.0056
Summer- Fall	69	7	5.0	-6	59	69	0.0009	0.0005	-0.0008	0.0089
Winter	6	9	5.5	-1	33	6	0.0003	0.0002	-0.0001	0.0010

Appendix Table 2. Total growth (mm) and daily relative rate of increase (mm) for PIT-tagged rainbow trout/juvenile steelhead that were recaptured in a weir in Beaver Creek, 2004-2006.

	Total growth (mm)					Avg. daily relative rate of increase (mm)				
Season of growth	n	Mean	Median	Min	Max	n	Mean	Median	Min	Max
Spring -Summer	8	24	22.0	7	44	8	0.0039	0.0033	0.0015	0.0071
Summer- Fall	47	10	9.0	-11	31	47	0.0010	0.0006	-0.0008	0.0051
Winter	13	16	10.0	-4	73	13	0.0009	0.0007	-0.0001	0.0037

Appendix Table 3. Total growth (mm) and daily relative rate of increase (mm) for PIT-tagged and recaptured rainbow trout/juvenile steelhead in reach 2 of Beaver Creek, 2004-2006.

Season of growth	Total growth (mm)					Daily relative rate of increase (mm)				
	n	Mean	Median	Min	Max	n	Mean	Median	Min	Max
Spring -Summer	10	15	15.5	7	21	10	0.0011	0.0010	0.0004	0.0019
Summer- Fall	11	4	4	0	17	11	0.0007	0.0005	0	0.0023
Winter	18	-1	-0.5	-8	7	18	-0.0000	0.0000	-0.0003	0.0003

Appendix Table 4. Total growth (mm) and daily relative rate of increase (mm) for PIT-tagged and recaptured rainbow trout/juvenile steelhead in reach 4 of Beaver Creek, 2004-2006.

Season of growth	Total growth (mm)					Avg. daily relative rate of increase (mm)				
	n	Mean	Median	Min	Max	n	Mean	Median	Min	Max
Spring -Summer	8	22	22.5	5	33	8	0.0022	0.0026	0.0004	0.0035
Summer- Fall	9	0.4	2	-8	6	9	0.0001	0.0002	-0.0008	0.0011
Winter	21	1	1	-1	5	21	0.0001	0.0000	0.0000	0.0002

Appendix Table 5. Total growth (mm) and daily relative rate of increase (mm) for PIT-tagged and recaptured rainbow trout/juvenile steelhead in reach 1 of Libby Creek, 2004-2006.

Season of growth	growth (mm)					daily relative rate of increase (mm)				
	n	Mean	Median	Min	Max	n	Mean	Median	Min	Max
Spring -Summer	1			14	14	1			0.0006	0.0006
Summer- Fall	26	0	-1	-12	16	26	-0.0001	-0.0001	-0.0012	0.0017
Winter	10	8	1	-3	Avg. 24	10	0.0002	0.0000	-0.0001	0.0022

Appendix Table 6. Total growth (mm) and daily relative rate of increase (mm) for PIT-tagged and recaptured rainbow Total trout/juvenile steelhead in reach 5 of Libby Creek, 2004-2006.

of growth	Total growth (mm)					Avg. daily relative rate of increase (mm)				
	n	Mean	Median	Min	Max	n	Mean	Median	Min	Max
Season Spring -Summer	4	6	5.5	-1	13	4	0.0005	0.0005	-0.0001	0.0011
Summer- Fall	5	1	1	-3	5	5	0.0001	0.0001	-0.0003	0.0005
Winter	7	5	4.0	-4	20	7	0.0001	0.0001	-0.0002	0.0005

Appendix Table 7. Total growth (mm) and daily relative rate of increase (mm) for PIT-tagged and recaptured rainbow trout/juvenile steelhead in North Fork Gold Creek of Gold Creek watershed, 2004-2006.

	Total growth (mm)					Avg. daily relative rate of increase (mm)				
Season of growth	n	Mean	Median	Min	Max	n	Mean	Median	Min	Max
Spring -Summer	2	34	34	33	35	2	0.0028	0.0028	0.0019	0.0037
Summer- Fall	16	1	0	-8	15	16	0.0001	0	-0.0011	0.0020
Winter	8	-2	-4.5	-10	8	8	-0.0001	-0.0002	-0.0003	0.0003

Appendix Table 8. Total growth (mm) and daily relative rate of increase (mm) for PIT-tagged and recaptured rainbow trout/juvenile steelhead in South Fork Gold Creek of Gold Creek watershed, 2004-2006.

	Total growth (mm)					Avg. daily relative rate of increase (mm)				
Season of growth	n	Mean	Median	Min	Max	n	Mean	Median	Min	Max
Spring -Summer	8	18	16.5	2	36	8	0.0015	0.0016	0.0001	0.0026
Summer- Fall	12	1	1	-8	6	12	0.0002	0.0002	-0.0008	0.0011
Winter	18	3	3.5	-2	7	18	0.0001	0.0001	-0.0001	0.0003

Appendix Table 9. Total growth (mm) and daily relative rate of increase (mm) for PIT-tagged and recaptured rainbow trout/juvenile steelhead in Foggy Dew Creek of Gold Creek watershed, 2004-2006.

	Total growth (mm)					Avg. daily relative rate of increase (mm)				
Season of growth	n	Mean	Median	Min	Max	n	Mean	Median	Min	Max
Spring -Summer	1			45	45	1			0.0034	0.0034
Summer- Fall	10	4	4.5	-8	12	10	0.0013	0.0009	-0.0011	0.0028
inter	6	4	5.5	-1	7	6	0.0002	0.0002	-0.0000	0.0003

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AN EVALUATION OF FISH PASSAGE AT ROCK VORTEX WEIRS

A Thesis Study Presented
in Partial Fulfillment of the Requirements for the
Degree of Master of Science

with a

Major in Civil Engineering

in the

College of Engineering
University of Idaho

by
Denis Ruttenberg

April 16, 2007

Major Professor: Dr.-Ing. Klaus Jorde

ABSTRACT

In the Upper Columbia River basin, many streams are diverted for irrigation. Some diversion dams are considered to block passage of endangered salmonids to spawning and rearing habitat. In addition, water diversions affect natural cycles of discharge, substrate composition, sediment transport, and channel morphology. On Beaver Creek, a tributary to the Methow River, in north-central Washington, the U.S. Bureau of Reclamation replaced irrigation diversion dams with a series of rock vortex weirs, with the goal of passing salmonids and maintaining irrigation diversion. To evaluate the effectiveness of the project for fish passage at rock vortex weirs, a monitoring program was implemented. At the subwatershed scale, temperature, discharge, and fish movement were monitored. At the site scale, discharge, temperature, channel topography, and substrate were monitored. A linear decoupled approach was applied to develop a four-mode hydraulic model that described flow over the rock vortex weirs as orifice flow, gap flow, weir flow, and rough boundary flow. Using this four-mode model and field observations, rating curves for hydraulic variables important to fish passage were developed and applied to continuous flow records at the study sites, resulting in a chronological record of critical hydraulic parameters. These data were combined with records of fish passage collected by the U.S. Geological Survey's Columbia River Research Laboratory, allowing a comparison of field hydraulic conditions to observed fish migration. Hydraulic drops during fish migration periods were estimated from 0.11 to 0.27 m, compared to the fish passage guideline of 0.24 m, maximum. The ratio of pool depth to hydraulic drop ranged from 1.6 to 6.1, compared to guideline value of 1.5, minimum. Energy dissipation factors in the weir pools varied from 66 to 450 W/m^3, versus a guideline of 250 W/m^3, maximum. Cross section averaged velocity at the weir crest varied from 0.14 to 0.65 m/s, compared to a guideline of 0.37 m/s, maximum. Using these data, effectiveness of rock vortex weirs on fish passage was quantified by applying a grading scale from A to F to the percent of time over the migration season that hydraulic parameters met existing fish passage guidelines for culverts, as set by the National Marine Fisheries Service and the Washington Department of Fish and Wildlife. The rock vortex weirs demonstrated favorable performance in the first two years following their installation. Methods for application of the four-mode model and hydraulic parameter rating curves are suggested for design of rock vortex weirs, with a focus on upstream fish passage.

Hydraulic modeling and upstream fish passage effectiveness evaluation at rock vortex weirs based on field observations

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Abstract

In the Upper Columbia River basin, many streams are diverted for irrigation by diversion dams, some of which are considered to block passage of endangered salmonids to spawning and rearing habitat. In Beaver Creek, a tributary to the Methow River, the U.S. Bureau of Reclamation replaced irrigation diversion dams with a series of rock vortex weirs to provide upstream passage for salmonids and maintain irrigation diversion. A monitoring program was implemented to evaluate the effectiveness of the rock vortex weirs for fish passage. Temperature, discharge, channel topography, and fish movement were monitored. Through a linear decoupled approach, a four-mode hydraulic model was developed to describe flow over the rock vortex weirs as orifice flow, gap flow, weir flow, and rough boundary flow. Using this four-mode model and field observations, rating curves for hydraulic variables important to fish passage were developed and applied to continuous flow records at the study sites, resulting in a chronological record of critical hydraulic parameters. These data were combined with records of fish passage collected by the U.S. Geological Survey's Columbia River Research Laboratory to compare hydraulic conditions to observed fish migration. Hydraulic drops during fish migration periods were estimated from 0.16 to 0.28 m, versus a guideline of 0.24 m, maximum. The ratio of pool depth to hydraulic drop ranged from 1.6 to 20, versus a guideline 1.5, minimum. Energy dissipation factors in the weir pools varied from 63 to 573 W/m^3, versus a guideline of 250 W/m^3, maximum. Cross section averaged velocity at the weir crest varied from 0.14 to 0.94 m/s, versus a guideline of 0.37 m/s, maximum. Based on a hydraulic analysis and recorded fish passage data, the rock vortex weirs demonstrated favorable performance in the first two years following their installation.

Introduction

In the Beaver Creek watershed, located within the Methow River basin, some small irrigation diversion dams for farms and ranches are considered barriers to upstream passage for spawning and rearing habitat for native stocks of summer steelhead (*Oncorhynchus mykiss*) and spring Chinook (*O. tshawytscha*), both listed as endangered under the Endangered Species Act (COE UPA 2004). State and federal agencies have focused on the Methow River basin to improve and increase habitat for these endangered fish. Pilot projects to remove existing diversion barriers and replace them with rock vortex weirs were implemented along Beaver Creek (USFS

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1992, BOR 2004). The goals were to provide opportunity for upstream migration of adult and juvenile fish and maintain water diversion for stakeholders. Limited studies have been done on juvenile fish passage at natural and man-made barriers, and more study is needed (Pearson 2005). Specifically, performance of rock vortex weirs for upstream fish passage is relatively unstudied, prompting the U.S Bureau of Reclamation (BOR) to evaluate performance through hydraulic modeling, monitoring fish movement, and assessing upstream fish passage. Selected findings from Ruttenberg (2007) thesis work are presented here, as performed by the University of Idaho, Center for Ecohydraulics Research (CER) in collaboration with the U.S. Geological Survey's Columbia River Research Laboratory (USGS-CRRL).

Description of the Beaver Creek watershed and pilot projects

The Beaver Creek watershed is a 290 km^2 basin located in north-central Washington on the eastern side of the Methow River, which meets the Columbia River upstream of Wells Dam, approximately 843 km from the Columbia River estuary. Average annual rainfall in the Beaver Creek watershed is about 58 cm and run-off in the late spring is rainfall-driven, which is typical for the basins on the eastern side of the Methow River Basin. Temperatures in the Methow River basin range from -29 to +38 °C and topography ranges from elevation 240 m to 2,730 m. Average stream slope is from 1.5 to 2.0 percent within the study reaches on Beaver Creek. Land use in the Beaver Creek basin includes managed forest land in the upper watershed, privately owned cropland and farms in the lower watershed, and recreational uses throughout. Collectively, land use and recreational use have impacted aquatic habitat in much of the Beaver Creek basin (USFS 1992). Sedimentation has embedded cobbles and gravels in the Beaver Creek basin, inhibiting salmonid spawning.

Utilizing grant funding from the State of Washington's Salmon Recovery Funding Board (SRFB), pilot projects were implemented in Beaver Creek by the BOR in collaboration with the Okanogan Conservation District (OCD), and voluntary efforts of landowners. Three projects implemented on Beaver Creek were studied: Lower Stokes, Thurlow, and Upper Stokes, located 4, 6, and 7 km above the mouth of Beaver Creek, respectively. Typical original diversion dams were composed of stacked logs and plastic sheeting about 1 m tall, which were removed and replaced with a series of trapezoidal rock vortex weirs, designed based on Rosgen (2001). The stream profile was designed for maximum hydraulic drop of 0.24 m at each structure, as required by regulatory authorities. The weirs were strategically placed to provide grade control and maintain backwater for agricultural diversion (BOR 2004). The rock vortex weirs were designed and installed by BOR engineers, in accordance with the National Marine Fisheries Service (NMFS), Washington Department of Fish and Wildlife (WDFW), Endangered Species Act, and COE UPA (2004).

Project collaboration with USGS-CRRL and fish movement data

Concurrent with the CER hydraulic study, monitoring of fish movement was conducted by the USGS-CRRL along Beaver Creek. The USGS-CRRL trapped fish in a weir, PIT-tagged captured fish, and installed a network of interrogation systems for PIT-tagged fish. The weir was located 2 km below Lower Stokes (Site A, about 3 km above the mouth of Beaver Creek). The four PIT tag interrogation systems were located 3 km downstream of Lower Stokes (Site B, just upstream of the fish weir), 20 m downstream of Lower Stokes (Site C), 100 m upstream of Lower Stokes (Site D), and about 5 km upstream of Lower Stokes (Site E). These types of instream PIT tag interrogation systems are further described in Connolly et al. (2008). During 2004 and 2005, about 3,900 juvenile and adult fish were captured, measured, inventoried, and injected with passive integrated transponder tags (PIT-tags) by the USGS-CRRL. Between deployment on 27 September 2004 and end of operation on 22 November 2005, a total of 21 rainbow trout / juvenile steelhead, 4 juvenile brook trout, and 4 adult steelhead were detected moving upstream past the rock vortex weirs at Lower Stokes. Adult steelhead moved upstream past the Lower Stokes rock weirs in late April 2005, and juveniles moved in a group from early June to early July 2005.

Performance criteria from NMFS and WDFW

Existing agency guidelines for fish passage at culverts were adapted to evaluate weir performance for upstream fish passage (NMFS 2000, WDFW 2003). These guidelines specify hydraulic parameters to be satisfied during the primary migration season while the flow is between exceedance flows of 5- and 95-percent. For summer steelhead and spring Chinook, the primary migration period in Beaver Creek for all life stages was considered to be from February 1 to July 7, based on records of fish movement by the USGS-CRRL. The four hydraulic parameters and their threshold values evaluated were maximum hydraulic drop of 0.24 m, minimum ratio of pool depth to hydraulic drop of 1.5, maximum average cross section velocity at the weir crest of 0.37 m/s, and maximum energy dissipation factor (EDF) of 250 W/m^3. A volume-based EDF was calculated as $\gamma \cdot \left(Q \cdot h_{drop}\right)/V_p$, where Q is discharge in m^3/s; h_{drop} is hydraulic drop in m, determined from hydraulic modeling; and V_p is pool volume in m^3, calculated from stage-volume relation developed from ground survey.

Modeling approach

The modeling approach determined basin hydrology, developed new techniques to model fish passage hydraulic parameters around rock vortex weirs, simulated continuous records of hydraulic parameters during fish passage at rock vortex weirs, and evaluated performance of rock weirs over a range of flows in meeting existing regulatory fish passage guidelines developed for culverts.

The hydrology of the Beaver Creek basin was derived from USGS records and continuous flow data collected by the CER at the pilot project sites on Beaver creek from pressure transducers and calibrated, log-based rating curves. Average daily flows from the USGS historical record from 1959 to 1978 and measured flow from 2004 to 2005 were combined for flow duration and Log Pearson Type III distribution flood frequency analysis (USGS 1981) (Table 1).

Table 1. Hydrology of Beaver Creek basin

	Flow Duration		Flow Frequency (years)						
units	Qlow (95%)	Qfp (5%)	1	2	5	10	25	50	100
m^3/s	0.1	3.5	0.7	4.2	6.9	8.7	10.7	12.2	13.5
cfs	3.5	124	25	149	245	306	380	430	478

The hydraulic modeling approach studied the Lower Stokes site as a calibration site, with the Thurlow and Upper Stokes as quasi-validation sites for the modeling methods. Velocities and spot discharges were measured by an acoustic doppler velocimeter (ADV) using protocols established by the USGS. Continuous discharge data from the pressure transducers in 2004 and 2005 were applied to hydraulic modeling. Water surface profiles were measured by visual observation of staff gages. Site topography was measured using total station ground survey equipment.

Field data were developed into four-mode, hydraulic models (Figure 1) for each rock vortex weir using a linear decoupled approach, calculating orifice flow (through cracks in the boulders), gap flow (between boulder gaps), weir flow (over the estimated weir crest), and rough boundary flow (over a drowned weir). A spreadsheet-based model was developed to simulate the first three flow modes over rock vortex weirs as water stage increases. As water surface increases each flow mode gains influence on the flow characteristic. The individual flow modes of the hydraulic model were calibrated by varying selected parameters and coefficients until the net calculated stage versus total discharge ($Q_{combined}$) curve matched field measurements (Table 2). Initiation of flow modes and transitions (h_{T1} and h_{T2}) between modes were determined from weir geometry, relative roughness relationships, and field observations (Ruttenberg 2007).

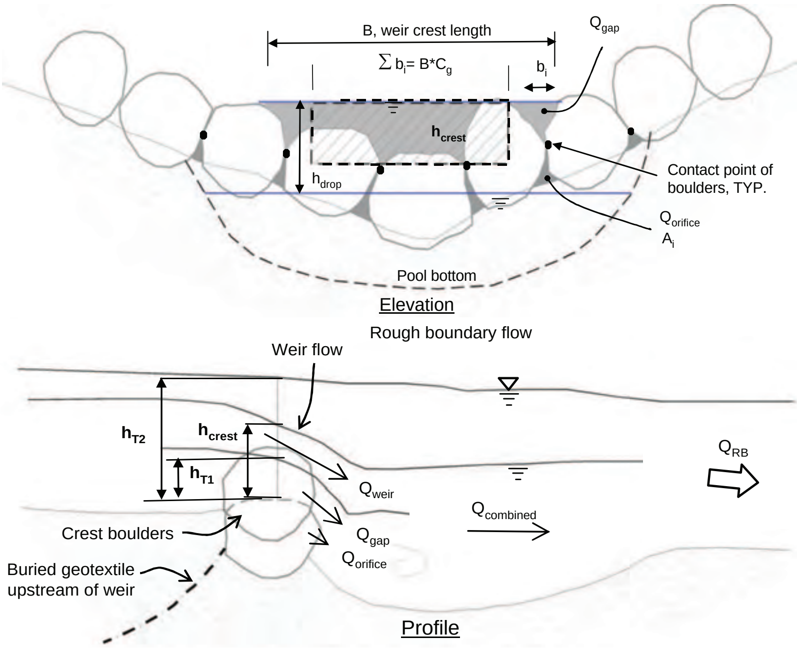

Figure 1. Elevation and profile of four-mode hydraulic model at rock vortex weirs.

Formulae for each flow mode were drawn from traditional theories and general formulations (Table 2). The orifice flow equation was standard formulation from Chow (1959). Gap flow was derived from balancing specific energy upstream with specific energy and critical flow in the gaps between the boulders of the weir crest, plus friction losses (DVWK 2002, Ruttenberg 2007). Weir flow used the general form of the Poleni equation (Chow 1959) and projected weir length, initiating at the threshold height h_{T1}. By adding each flow mode to calculated total combined flow, $Q_{combined}$, a stage discharge curve was constructed to represent each flow mode and total flow. The transition from gap flow to weir flow (h_{T1}) was estimated using weir length versus depth (Ruttenberg 2007). Transition to rough boundary flow (h_{T2}) was estimated based on relative roughness relations from Chow (1959), where rough boundary flow begins when the ratio of water depth to weir boulder roughness, is about 3.0–5.0 (Chow 1959).

Table 2. Formulations for flow modes of hydraulic model

Flow mode	Formulation	Calibration terms
Orifice	$Q_{orifice} = \sqrt{2g \cdot h_{drop}} \cdot A_{eff} \cdot K$	K, A_{eff}
Gap (before weir flow)	$Q_{gap} = \left(\frac{2}{3} \cdot \frac{h_0 + \frac{v_0^{\ 2}}{2g}}{\left(1 + \frac{\xi}{3}\right)} \right)^{\frac{3}{2}} \cdot \sqrt{g} \cdot B \cdot C_g$	ξ, C_g
Gap (during weir flow)	$Q_{gap} = V_{weir} \cdot A_{gap*}$	None, driven by weir flow
Weir	$Q_{weir} = \frac{2}{3} \cdot \mu \cdot C_w \cdot B \cdot \sqrt{2g} \cdot h_{weir}^{\ 1.5}$	μ
Rough Boundary	One dimensional modeling, replaces orifice, gap, and weir flow modes	

Where:
A_{eff} = total assumed effective flow area in rock orifices, in m^2
K = friction loss coefficient for orifice flow, fixed at 0.6 to reflect higher losses
h_0 = Head just upstream of the boulder crest, based on field observation of staff gages, in m
v_0 = Velocity upstream of the boulders crest, based on discharge, in m/s
Cg = Contraction and roughness coefficient, dimensionless
ξ = Sharp-edged inlet loss coefficient, assumed to be 0.5, dimensionless
B = Total profile length of rock vortex weir crest, from weir geometry, in m
V_{weir} = average cross section velocity according to weir flow, in m/s
A_{gap*} = total flow area below transition to weir flow per h_{T1}, in m^2
μ = Weir coefficient, function of geometry, varies from 0.6 to 0.8
C_w = Contraction coefficient for projected weir crest length, function of weir geometry
h_{weir} = Depth at weir crest for weir flow = depth above transition from gap to weir flow (h_{T1}), in m

Results

Calibration and validation coefficients for the models are shown in Table 3. Sample results from a developed four-mode hydraulic model are shown on Figure 2.

Table 3. Calibration and validation data for hydraulic models of rock vortex weirs.

	Calibration site			Validation sites	
Beaver Creek pilot project sites	Lower Stokes			Thurlow	Upper Stokes
	Weir 1	Weir 2	Weir 3	Weir 1	Weir 1
Weir crest width (m)	1.5	1.5	1.5	1.5	1.8
Average plan angle of wing wall (degrees)	32	28	30	22	40
Wing wall profile slope (percent)	9	10	9	7	11
C_g, contraction factor for gaps	0.10	0.17	0.45	0.07	0.15
μ, weir coefficient	0.80	0.70	0.80	0.50	0.57
C_w, contraction coefficient	ranges from 0.42 to 1.00, varies by geometry				
Transitions for four-mode hydraulic model, estimated					
Gap to Weir, discharge, (m^3/s)	0.15	0.15	0.20	0.09	0.07
Gap to Weir, depth, (m)	0.37	0.34	0.34	0.21	0.18
Weir to Rough boundary, depth, (m)	0.6	0.6	0.4	0.6	0.6

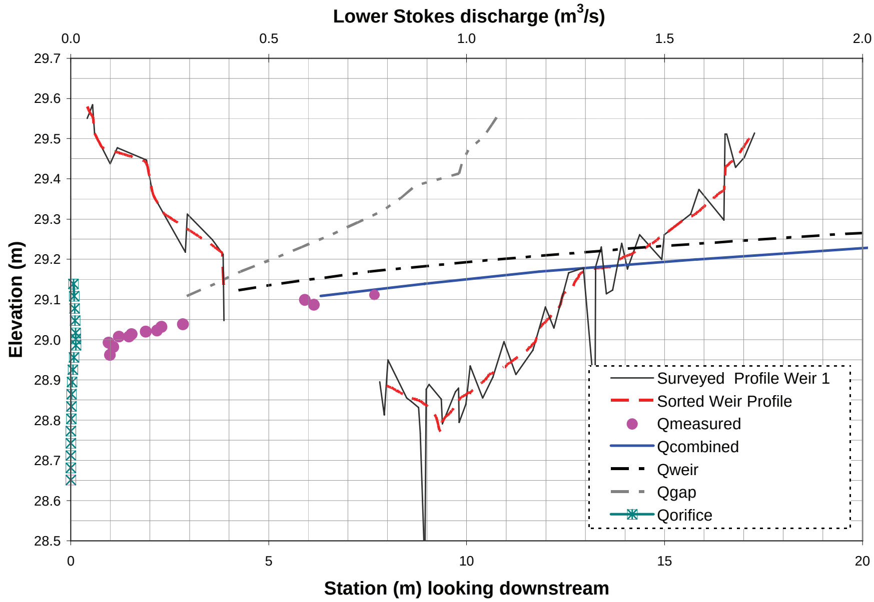

Figure 2. Hydraulic model at Lower Stokes, weir 1. Cross section compared to stage-discharge relations for the hydraulic model. Axes for cross section station and discharge on bottom and top, respectively. Individual flow modes ($Q_{orifice}$, Q_{gap} , and Q_{weir}) and total modeled flow ($Q_{combined}$) compared to measured stage versus discharge. Relative flow contributions of flow modes versus stage shown.

Time series for hydraulic parameters at using rating curves

The four-mode hydraulic models and additional observed data were applied to develop rating curves for hydraulic parameters versus discharge. At each weir, four rating curves were developed: hydraulic drop, ratio of pool depth to hydraulic drop, EDF, and average velocity over the weir (Ruttenberg 2007). Using these rating curves and continuous records of discharge from field recorders, continuous records of critical hydraulic parameters for upstream fish passage were generated for each weir. Fish movement data, as collected by the USGS-CRRL, were compared to time series for these key hydraulic parameters. An example of an estimated time series of hydraulic drop is shown in Figure 3. The hydrograph is also shown in Figure 3 to demonstrate when flow was within the calibrated range *and* within the low and high fish regulation flows (Qlow and Qfp). Additional data are available in Ruttenberg (2007). Summary statistics on hydraulic parameters are shown in Table 4.

Model results show the orifice flow mode had minimal contribution to $Q_{combined}$ of about 0.014 m^3/s, likely due to geotextile sealing the weir crest. The weir coefficient, μ, varied from 0.5 to 0.8 and the gap contraction factor, C_g, varied from 0.07 to 0.45. Transition from gap to weir flow, h_{T1}, occurred from 0.18 to 0.37 m above the weir crest low point, within the trapezoidal shape of the rock vortex weir. Hydraulic parameters for upstream fish passage, based on model output and field observations, indicated values beyond thresholds set by guidelines for culverts. Records of upstream fish movement from the USGS-CRRL confirm fish passage when guidelines were exceeded.

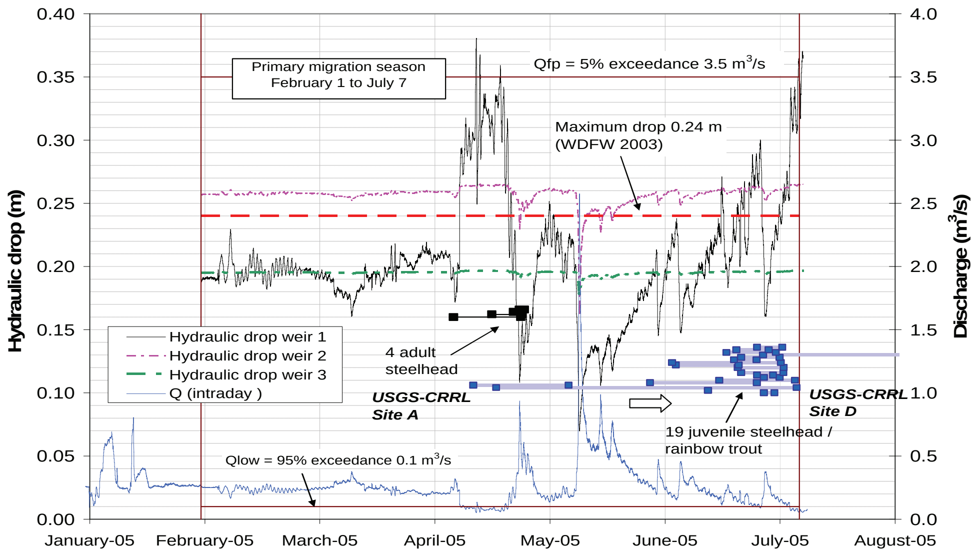

Figure 3. Comparison of fish movement from USGS-CRRL to calibrated hydraulic model of drop at rock vortex weirs at Lower Stokes during 2005 primary migration season. Horizontal bars for fish movement from left to right indicate detection time 3 km downstream (Site A or Site B) to detection time upstream, about 100 m upstream of the rock vortex weirs at Lower Stokes (Site D).

Table 4. Estimated maximum and minimum values for hydraulic parameters at Lower Stokes site during fish passage. Data shown for migration season from February 1 to July 7, within calibrated range of discharge measurement.

Hydraulic parameter		Weir 1	Weir 2	Weir 3
Hydraulic drop (0.24 m max.)	max. (m)	0.28	0.27	0.20
	min. (m)	0.17	0.16	0.18
Ratio of pool depth to hydraulic drop (1.5 min.)	max. (m/m)	20.4	6.7	6.9
	Min.(m/m)	1.6	2.6	2.7
Energy dissipation factor ($250\ W/m^3$ max.)	max. (W/m3)	281	448	573
	min. (W/m3)	177	63	119
Average velocity (0.37 m/s max.)	max. (m/s)	0.71	0.84	0.94
	min. (m/s)	0.14	0.15	0.32

Conclusions

1. A calibrated, four-mode hydraulic model for flow over a rock vortex weir effectively simulated stage versus discharge for rock vortex weirs. These data could be used for stage-discharge relationships at other rock weirs, with field verification.
2. The combination of PIT-tag technology, continuous stage recorders, and models for hydraulic parameters at rock vortex weirs were effective tools to quantify, qualify, and evaluate upstream fish passage at rock vortex weirs.
3. During detected upstream fish movement, comparison of hydraulic parameters to fish passage guidelines for culverts indicated the hydraulic parameters slightly exceeded the guidelines. Further study is needed to better understand effectiveness of rock weirs for leaping versus swim-through behavior during upstream passage.
4. The rock vortex weirs demonstrated favorable performance, based on comparison of hydraulic parameters to fish passage guidelines for culverts and fish movement.

These data and field measurements demonstrate the hydraulic heterogeneity of rock weirs and their effectiveness for upstream passage of salmonids in a wider range of flow conditions than indicated by current literature and guidelines.

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Currently, there are 10 smolt traps operating in the Upper Columbia region, including a trap at the lower end of each population (Table 1). Having a trap at the lower end of each population allows for the opportunity to evaluate population level productivity status and trend, if appropriate expansions can be made. Having smolt traps in sub-watersheds allows for comparisons between Major Spawning Areas, comparing Major Spawning Areas to the population as a whole, and potentially comparing Major Spawning Area or population estimates to reference watersheds.

Results and Discussion

The smolt trap survey in the Chiwawa River Basin provides the longest term data set in the Upper Columbia, with 19 years of operation (Table 1). Annual status as well as longer term trends can be evaluated from data sets of this length. For example, the density dependent response in juvenile productivity is suggested by the much higher smolts/redd observed during the low adult escapement years of the mid-late 1990s (Figure 1). Data sets for most other smolt traps are not long enough to evaluate long-term trends or have confidence that the mean across years shows the year-to-year environmental variability that is natural and expected (Table 1). The Chiwawa River has received very little habitat restoration and is considered highly functional habitat, so it may be a good reference watershed, if the contribution of hatchery origin fish spawning in the wild can be accounted for.

When picking a reference stream, it is important that inherent differences in productivity due to watershed specific climate, geology, geomorphology, and hydrology are understood. Analyses still need to be conducted to determine exactly how to use and compare the juvenile productivity data between subbasins. For example, it is reasonable to assume, based on an examination of the graph to conclude that the Wenatchee Subbasin as a whole is not as productive as the Chiwawa River, since every year the population level estimate from the Monitor smolt trap is less than the Chiwawa River estimate (Figure 1). A statistical analysis of a comparison between traps within and among subbasins is needed (Figure 2). Duration (years), variance, and autocorrelation (not shown on any of the graphs) will be important considerations in these comparisons. Likewise, additional information is needed to determine the definition of trend with respect to this and other juvenile fish data in order to definitively answer the key management question. However, given the length of time and quantity of habitat restoration actions that are planned and the long-term commitments in place to continue smolt monitoring, it is likely that this will prove to be a useful measure for increases in habitat productivity in the future.

Genetic Variation in Oncorhynchus mykiss in Tributaries to the Lower Methow Basin

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Background

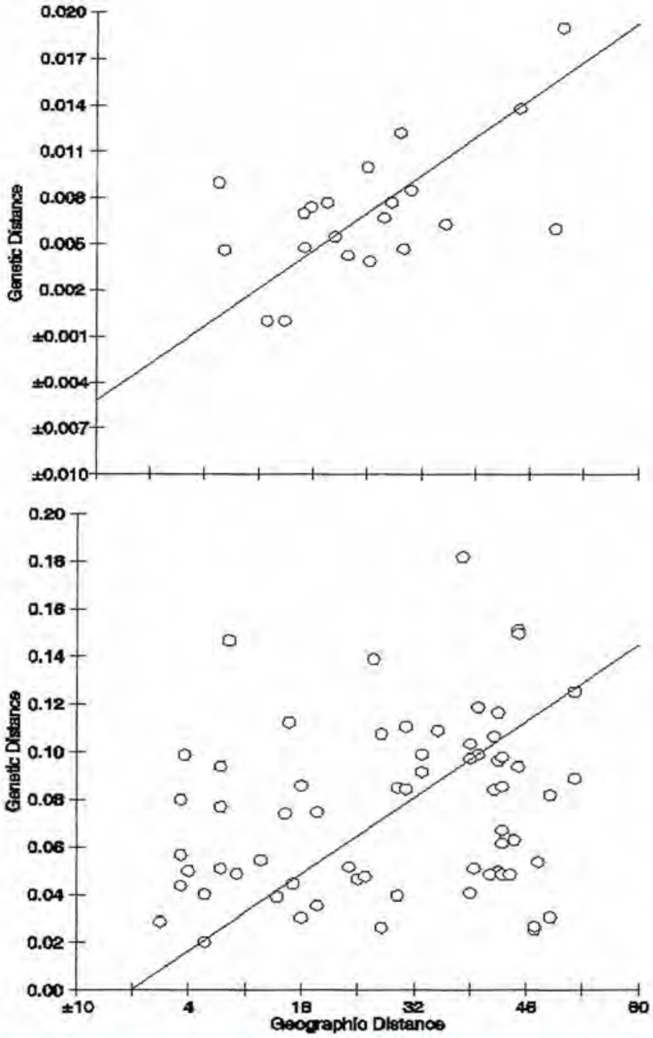
Genetic processes such as selection, mutation, and drift interact with various behavioral and environmental factors to promote reproductive opportunities for individuals in a landscape. Genetic differentiation is determined by population isolation. Salmonids are known to exhibit several isolating mechanisms such as: life history variation separated spatially and temporally, homing to natal streams, and assortative mating.

Oncorhynchus mykiss exhibit sympatric life history strategies: resident/fluvial and anadromous. Studies have shown some inter-breeding between these life history types, and plasticity in their derivation (such as resident fish parenting anadromous offspring). Hatchery fish are present in the Methow Basin, and introgression between the wild and hatchery populations is thought to occur. However, hatchery fish have much lower relative fitness in natural environments. For example, wild (W) female steelhead were found to produce about 20 times the smolts than hatchery (H) females in a study in Forks Creek, Washington (McLean et al. 2004). In addition, the cross and direction can determine the relative survival to age 1 with WxH having 58%, HxW 30%, and HxH 14% of the relative survival of WxW offspring (Miller et al. 2004).

The purpose of this study was to: describe genetic diversity and genetic differentiation in O. mykiss from 3 natal tributaries (Beaver, Libby and Gold creeks) in the lower Methow Basin, and explore the relative contribution of environmental and biological attributes. The null hypothesis tested was that O. mykiss populations in the study area were panmictic (or no detectable population differentiation). The alternative hypotheses was that population differentiation was detectable and was related to life history and/or habitat attributes.

Methods

Juvenile and adult trout were collected from 19 sites in the study area during 2004 and 2005 using electrofishing. Genetic material were collected and PIT tag interrogation data were used to determine the dominant life history strategy at each site. Trout were considered to exhibit anadromous migration patterns when PIT tags were detected at John Day/McNary dams or downstream on the lower Columbia River. Anadromous sites had >3%, and resident sites <1%, of the proportion of total tags deployed detected on the Columbia River or estuary. Stream distances between sites were calculated using the distance tool in ArcView GIS software.



Figures 1 and 2. Mantel test for isolation by distance for anadromous sites (top) and for resident sites (lower) in the lower Methow tributaries. The test is significant ($p < 0.05$) with an $R^2 = 0.35$ for anadromous sites, not significant ($p > 0.05$) and $R^2 = 0.05$ for resident sites.

DNA was extracted and amplified using standardized protocols and loci for the Columbia Basin O. mykiss (Stephenson et al. 2009). Sixteen microsatellite loci were used. The later 5 loci provided some differentiation between O. mykiss and O. clarki. Putative full siblings were identified and removed using ML Relate set to 10,000 permutations (Kalinowski et al. 2006). A Bonferroni correction was used for all multiple comparisons. Exact tests for Hardy Weinberg and linkage disequilibrium were performed using Genepop set to default values (Raymond and Rousset 1997). Genetic diversity indices (heterozygosity and allelic richness) were calculated using HP Rare (Kalinowski et al. 2005). Genetic differentiation was measured using pairwise Fst values and exact tests were calculated using Genepop set to default values. Isolation by distance, examining whether there is increased genetic differentiation with geographic distance, was tested with a Mantel test using IBD Web Service (Bohanak et al. 2002). Arlequin was used to partition variation using AMOVAs (Excoffier et al. 2005).

UCRTT Deliberations

Weigel et al. have demonstrated that populations of Oncorhynchus mykiss are more diverse in the Methow Subbasin, and presumably in the Upper Columbia, than had been previously understood. The limited geographic scope of this study does not give us a complete estimate of status that is of most interest to recovery assessment and would not provide much of a baseline against which to elucidate trends . These findings recall the question of what are the normative processes and conditions against which the spatial structure and diversity (SS/D) metrics should be compared? A spatially-balanced sampling program for steelhead throughout the Upper Columbia should be initiated to give us much better insight into the status and trends related to SS/D. Existing genetic monitoring programs that focus on the comparison between hatchery vs. natural populations are powerful and need to be included in any future genetic monitoring program. However, additional investigation would be required to 1) develop a reference condition or an idea about what is the desired condition for SS/D, 2) describe the status and trends in SS/D for steelhead for the entire ESU, and 3) elucidate the contribution of rainbow trout production and diversity to steelhead, something that recent studies suggest may be significant.

	Basin (B, L, G)	Life History (A, R)
Among group	0.40%	0.10%
Among pop. within group	3.90%	4.10%
Within Pop.	95.70%	95.80%

Table 1. The amount of variation at the basin scale (Beaver, Libby, Gold) to life history (anadromous vs. resident) (AMOVA).

Results

A total of 693 trout were collected from 19 sites. Suspected full siblings detected at each site ranged from 0 to 62% (average 23%), with more full siblings detected at resident sites. After removing all but one suspected full sibling from each site, 590 trout from 19 sites were used for the subsequent analyses. Sample sizes ranged from 7 to 55 (average 28). Of the 19 sites, 6 were anadromous, 6 were resident, 4 were resident O. m. with O. m. x O. c. hybridization present, and 2 were anadromous O. m. with O. m. and O. c. hybridization present. Three additional sites in Beaver Creek have not been analyzed yet.

Four sites had one locus each out of Hardy Weinberg Equilibrium and 7 of 2,280 comparisons showed significant linkage disequilibrium. There was no pattern to these loci or sites. Sample-wide pairwise Fst values ranged from 0 to 0.18 across all the sites. Pairwise Fst values ranged from 0 to 0.019 across the anadromous sites with about half the sites significantly different ($p < 0.003$). Generally, adjacent sites tended not to be significantly different. The Mantel test showed significant isolation by distance for all the pairwise site comparisons in the study area with an $R^2 = 0.18$. However, when we separated the data set by life history type, anadromous sites showed a stronger ($R^2 = 0.35$) and significant isolation by distance relationship, whereas resident sites did not (Figures 1 and 2). The AMOVA indicated that > 95% of the genetic variation is at the individual level, and a small proportion is at the basin or life history level (< 0.5%). Basin explained four times the variation in the genetic data than life history, additional indication that genetic diversity is related to distance or other landscape variables more so than life history (Table 1).

	# sites	# anad sites	# loci	He (Ho)	AR	Fst	Sig IBD
Methow B, L, G	19	8	16	0.67-0.83	4.53-6.88	0-0.18	Y anad N resid
Klickitat (Narum et al 2008)	20	7	13	0.46-0.82	2.8-9.0	0-0.377	Y anad N resid
Grande Ronde (Narum et al 2006)	4	4	20	(0.76-0.81)	11.2-12.4	0.005-0.016	
Walla Walla (Narum et al 2004)	14	12	6	0.8, 0.78	14.5, 13.7	0.001-0.018	
Snake (Neilsen et al 2009)	79	75	11	0.55-0.73	4.1-6.2	0.003-0.05*	Y
Skeena, Nass, Dean – Canada BC (Heath et al. 2001)	10	10	6	0.75-0.85		Avg 0.04*	Y
Kamchatka - Russia (McPhee et al. 2007)	7	5	10	0.24-0.54	1.9-9.8	0-0.19	Y

Table 2. Comparison of *O. mykiss* data from Beaver, Libby and Gold creeks genetic diversity and differentiation measures and isolation by distance to other studies in the Columbia Basin, British Columbia, Canada, and Kamchatka, Russia. Asterisk indicates data that were pooled by subbasin and are not a direct site level comparison to the values reported in this study.

Discussion

The genetic diversity measures (heterozygosity, allelic richness), genetic differentiation measure (Fst), AMOVA and isolation by distance results from the lower Methow tributaries are similar to other studies documented in various Columbia Basin tributaries, British Columbia, Canada, and Kamchatka, Russia (Table 2). Our study is most similar in sample intensity, genotypic data and spatial extent to the Klickitat Basin, Washington study (Narum et al. 2008), aside from some low heterozygosity, allelic richness and higher Fst values that were likely the influence of more isolated resident populations sampled in the Klickitat study. The Klickitat populations were shown to have no detectable hatchery introgression thought to be due to little reproductive overlap between the native steelhead and stocked Skamania steelhead in the basin (Narum et al. 2006).

The O. mykiss sampled from the Grande Ronde basin in Oregon had higher genetic diversity (heterozygosity and allelic richness), but similar genetic differentiation (Fst) values (Narum et al. 2006). This study only compared data from two wild and two hatchery populations. Hatchery populations could be increasing these genetic diversity values due to brood management practices such as random mating. The Walla Walla basin, Snake River basin and British Columbia basins (Narum et al. 2004, Neilsen et al. 2009, Heath et al. 2001) have similar genetic results to our study. The Kamchatka populations show lower levels of heterozygosity and allelic richness, but similar levels of genetic differentiation to our study (McPhee et al. 2007).

Several of the populations tested in the Snake River basin (Neilsen et al. 2009) showed introgression between O. m. and O. c. from other studies (Weigel et al. 2002), indicating that this is not a phenomenon limited to the Methow Basin study. In conclusion, spatial genetic diversity in O. mykiss in the lower Methow tributaries is present, and most sites were significantly different. Spatial genetic diversity and differentiation is generally similar to other O. mykiss studies. Basin explained more genetic variation than life history, and isolation by distance was significant for anadromous sites, but not resident sites.

Adaptive Management Recommendations

A spatially balanced genetic sampling program for Chinook salmon and steelhead should be established throughout the Upper Columbia that can be repeated at intervals to understand the status and trends in genetic diversity. This program would be particularly useful if it was designed 1) to monitor the influences of hatchery impacts to population genetic structure, 2) to help understand what the desired condition for SS/D might be, and 3) elucidated the contribution of rainbow trout production and diversity to steelhead, something that recent studies suggest may be significant.

Status data from the Canadian portions of the Okanogan steelhead population should be incorporated into the overall status assessment that has until now focused on the portion of the Okanogan subbasin within the U.S. Included within this assessment should be the identification, delineation, and monitoring of major and minor spawning areas within Canada. Likewise, the Canadian portions of the Okanogan should be included within a spatially balanced genetic sampling program (see above point).

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Colonization of Steelhead (*Oncorhynchus mykiss*) in a Natal Stream After Barrier Removal

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Abstract

Colonization of vacant habitats is an important process to support the long term persistence of populations and species. Removal of migration barriers provide opportunities to study the colonization process identifying the source, abundance, spatial extent and rate of colonization. Salmonids and their management in the Methow Basin, Washington, provide an experimental opportunity where colonization can be studied under the influence of artificial stocking programs and life history polymorphisms. We used a before-after experimental design to follow the colonization process of anadromous *Oncorhynchus mykiss* at six monitoring sites in a natal stream after the modification or removal of numerous stream passage barriers. Passive integrated transponder tags and stationary interrogation stations were used with population genetic sampling to determine the source, extent and success of the barrier removal projects. Adult anadromous *O. mykiss* migrated into the study area the first spawning season after passage was established. Hatchery *O. mykiss*, although comprising more than 80% of the adult returns to the basin, did not appear to influence the early colonization process in the study area. Parr outmigration increased during the first four years after barrier removal from the upper sites in the basin, and population genetic measures significantly changed in the lower two monitoring sites in the basin. Colonization and expansion of anadromous *O. mykiss* was a slower process than expected when compared to other barrier removal projects with adult anadromous *O. mykiss* beginning to migrate into the upper basin sites 3 to 4 years after barrier removal.

Key Words: colonization, barrier removal, stream restoration, artificial propagation, fish passage, effectiveness monitoring

Introduction

Colonization of unoccupied habitat is an ecological process that is important to the long term persistence of species. Two conceptual theories are often used to explain the demographic processes related to range expansion and migration. The meta-population theory suggests that populations are mediated by localized extinction and colonization processes. Local populations support each other in a source-sink dynamic (Hanski and Gilpin 1996, Rieman and Dunham 2000). The member-vagrant theory suggests that members of a population have local adaptations that provide a selective advantage over vagrants from other populations (Garant et al. 2000, Primmer et al. 2006). Both theories have some empirical support suggesting that environmental stability may mediate the population demographic process (Garant et al. 2000). Yet, understanding the underlying demographic process becomes important when predicting the response of a population or species to a management action such as barrier removal.

Direct removal or damage to habitat threatens 50% of species in the United States (Richter et al. 1997) and passage barriers are responsible for the loss of one-third of the historically accessible habitat for anadromous fish in the Columbia River Basin (Sheer and Steel 2006 and citations therein). Small barriers, such as diversion dams and culverts, are more numerous and widely distributed across the landscape than the larger mainstem dams (Sheer and Steel 2006), and water diversions are cited as having the greatest adverse effect on aquatic fauna in California (Moyle and Williams 1990). In the Willamette Basin, Oregon, a significant amount (40-50%) of preferred habitat for anadromous salmonids is lost to barriers (Sheer and Steel 2006). As numerous species of fish have declined over the last several decades, extensive efforts have been made to remove or modify these barriers to allow passage of target fish species (Bernhardt et al. 2005). These management actions are aimed at re-connecting unoccupied habitats to re-establish populations of threatened or endangered species that collectively will increase production. Few studies have collected data during the colonization process of fish in stream environments (Bernhardt et al. 2005), and often times are opportunistic after unpredicted catastrophic events like volcanic eruptions (Leider 1989) or the release of toxic chemicals (Demairias et al. 1993).

Barrier removal projects create opportunities to study the colonization process using before-after treatment experimental design (Kiffney et al. 2009, Anderson et al. 2010). The rate of colonization and the need for stocking of desirable populations and/or stocks are typical management questions. The rate of colonization will be dependent on the dispersal capability of the species as well as distance and density of the unoccupied habitat to candidate source populations (Gaggiotti et al. 2004). Barrier removal projects implemented in streams with populations of target species downstream of the structure are documented to rapidly colonize with volunteers when passage is restored (Kiffney et al. 2009, Anderson et al. 2010).

Trout and salmon are typically target species of restoration actions due to their threatened and endangered status in the U.S. (McClure et al. 2003). Salmonid systems, which are largely supported by spawners homing to natal streams, do not readily appear to depend on exploration of new environments that leads to population expansion and colonization. Several species of salmonids have multiple life history strategies co-occurring in the natal streams, such as resident (stream-rearing), fluvial (river-rearing) and anadromous (ocean-rearing) (Behnke 1992). These various life history strategies are known to provide demographic and genetic support to species in variable or unstable environments and inter-breeding between these life history types is widely documented (Parker et al. 2001, Docker and Heath 2003, Araki et al. 2007, Christie et al. 2011, Weigel et al. *in review*). Barrier removal is oftentimes targeted toward increasing population distribution and abundance of the anadromous life history due to extensive impacts from harvest, hydropower, and variable ocean conditions (McClure et al. 2003).

Release of hatchery-reared conspecifics can directly impact migration and reproductive success of trout and salmon (McLean et al. 2004a, McLean et al. 2004b, Miller et al. 2004, Araki et al. 2007). These hatchery produced fish provide an over-abundant source population to colonize unoccupied habitats. Yet, hatchery salmon and steelhead are documented to have lower relative reproductive success than those naturally produced in the stream environments (Miller et al. 2004, McLean et al. 2004b, Araki et al. 2007, Araki et al. 2008). Therefore, hatchery fish may not be a desirable source population for the colonization of newly opened habitats, and their role and impact to the colonization process are not well-understood. Hatchery trout and salmon are documented to have higher rates of straying than naturally reared conspecifics (Quinn 1993). The demographic effect of hatchery fish on the colonization process due to these greater abundances and high straying rates could reduce or eliminate the contributions from naturally produced trout or salmon. Yet, this demographic advantage is likely countered by the reduced fitness that could even result in unintended genetic or fitness effects on the colonizing population.

Genetic data are often used to monitor the effect of colonization to identify inter-breeding groups (or local populations) and source population (Demairias et al. 1993, Garant et al. 2000, Gaggiotti et al. 2003, Bartron and Scribner 2004). Studies have indicated that populations of *O. mykiss* are generally stable (no significant differences in population genetic measures) over short time periods ranging from several months to 5 years (Heath et al. 2002, Narum et al. 2004, Narum et al. 2006, Nielsen et al. 2009). Over longer time periods (>20 years), temporal variation has been found to explain about 2% of molecular variation in *O. mykiss* populations, an amount similar to the variation among these populations (Beacham et al. 1999, Heath et al. 2002). These long term studies are generally influenced by genetic drift and changes in habitat condition, hatchery and harvest practices.

Barrier removal in combination with the co-existing life history strategies and hatchery populations of *O. mykiss* creates an experiment where colonization can be examined while the resident *O. mykiss* populations provide demographic stability. In this study, we use population genetic measures to determine if the anadromous population of *O. mykiss* was successfully established after the modification of several small irrigation dams in Beaver Creek, a natal tributary to the Methow River, Washington. We are particularly interested in the colonization process in *O. mykiss* because it has complex and co-occurring life history strategies combined with potentially large hatchery effects. *O. mykiss* and other species of fish were allowed to naturally colonize the unoccupied habitat. Individual migrations and movements were monitored with passive integrated transponder tags (PIT tags) and readers. The objectives of our study are to: 1) identify the source and abundance of colonizers (anadromous, hatchery or fluvial) during the first four years after barrier removal; 2) identify if and where in the basin detectable changes occurred to population genetic measures; and 3) identify if a population of anadromous *O. mykiss* was successfully established in Beaver Creek.

Study Area

The Methow Basin is located on the east side of the Cascade Mountain Range in north-central Washington. The Methow River is a tributary of the Columbia River located about 843 km upstream from the estuary. Beaver Creek is a 3rd order natal tributary that flows west into the Methow River 57 km upstream from the mouth (Fig 1). The Beaver Creek basin is 290 km^2 with basin elevations that range from 463 to 1,890 m and stream flows that ranged from 0.05 to 4.7

m^3/s during the study (Martens and Connolly 2010). The 100-year flood for Beaver Creek is estimated at 13.5 m^3/s (Ruttenberg et al. 2009). The upper portion of the basin is managed forest land administered by state or federal agencies. The lower portion of the basin is irrigated, privately-owned farm and ranch land.

Access for fish into Beaver Creek was disconnected due to water withdrawal and associated structures for more than 100 years (Martens and Connolly 2010). Resident *O. mykiss* were the most abundant species of salmonid throughout the Beaver Creek basin prior to implementing the barrier removal projects. Anadromous *O. mykiss* (steelhead) were present downstream from the lowest diversion dam (Martens and Connolly 2010). From 2000 to 2004, seven small irrigation diversion dams (1.0 to 2.0 m high) were modified to rock vortex weirs that allow fish passage (Ruttenberg et al. 2009, Martens and Connolly 2010). The most downstream irrigation diversion was a 2.0 m high concrete diversion dam that was modified to allow fish passage after the fall of 2004. Access for migratory *O. mykiss* trout was restored to Beaver Creek for the spring 2005 spawning season.

Hatchery Releases

The Grand Coulee Fish Maintenance Project mitigated for the construction of Grand Coulee Dam during the 1930s. Hatchery activities intended to replace lost production of anadromous salmon and steelhead from tributaries upstream blocked by the dam. The Wenatchee, Entiat, Methow and Okanagan rivers are located downstream of Grand Coulee Dam and are utilized to rear and release salmon and steelhead for this extensive hatchery mitigation program. The State of Washington also manages a hatchery program to mitigate for other hydropower facilities on the Columbia River.

The anadromous *O. mykiss* stock for all these hatcheries originated from collections on the Columbia River at Rock Island Dam, downstream of Wenatchee, WA. This brood stock was established from the returning adults to this dam assumed to be migrating to the major tributaries upstream, such as the Wenatchee, Entiat, Methow, Okanagan and other tributaries upstream of Grand Coulee Dam (Chapman et al. 1994). This original brood stock was later used to establish local brood stocks in each of the basins. In recent years, the Methow and the Wenatchee hatchery brood stocks have been managed as demographically independent stocks.

Currently state and federal hatchery programs in the Methow Basin release 450,000 – 550,000 *O. mykiss* smolts per year. Returning adult *O. mykiss* are spawned and the eggs are reared at Wells Hatchery on the Columbia River downstream from the mouth of the Methow River. Current practices include intentional breeding between hatchery and naturally produced adults, and progeny from these crosses are primarily released in the Methow River basin (C. Snow, WDFW, *personal communication*). Hatchery *O. mykiss* are released as age 1 smolts in the Methow and Chewuch rivers upstream from the town of Winthrop, WA. All hatchery origin *O. mykiss* were marked with an internal tag (such as PIT tag), external tag (such as elastomer tag) and/or fin clip.

Adult returns

Hatchery produced steelhead comprise more than 80% of the returning adults to Wells Dam, the nearest adult counting location to the Methow Basin. The low counts of wild adult summer steelhead led to the National Marine Fisheries Service concluding that the hatchery stock is critical to recovery of the species and included the hatchery stock as protected under the Endangered Species Act (McClure et al. 2003). Between 1999 and 2010, the wild steelhead returns ranged from 5 to 18% of the run (Fig 2). During our study (2005-2008), wild steelhead returns ranged from 9% in 2005 to 18% in 2008 (C. Snow, WDFW, *unpublished data*).

Methods

Fish Collections and Movements

Adult *O. mykiss* were captured in Beaver Creek using a picket weir installed 1.3 km upstream from the mouth (Fig. 1). This location was chosen for accessibility and stream channel topography. This trap captured fish moving upstream or downstream. The trap was operated from March 20 to May 9 and May 14 to December 5 during 2005; February 13-May 1 and June 27-November 27 during 2006; February 24 to March 30 and May 25 to November 29 during 2007; and February 24 to May 3, July 11 to July 30 and September 2 to December 10 during 2008. The date, direction of movement, fork length (mm), weight (g), sex and population origin (wild or hatchery) were recorded for adult trout.

Juvenile *O. mykiss* were sampled at 6 sites on Beaver Creek (Fig. 1). One site was downstream of the lowest diversion dam (DS Dam), 1 site was located between the various diversion dam modifications (UBR1) and 4 sites (UBR2, CMP, UBR4, SFB) were upstream from the diversion dam modifications (Fig. 1). Before barrier treatment collections were made during the fall of 2004 or the summer of 2005 sampling age 1+ juvenile *O. mykiss* in the stream. After barrier treatment collections were made during the summer or fall 2008 and 2009 sampling age 1+ juvenile *O. mykiss* present in the stream. The 4 to 5 years between the before and after collections represents about 1 generation for *O. mykiss*.

Juvenile *O. mykiss* were collected using a backpack electrofisher (Smith Root Inc. LR-24). Trout were measured to the nearest mm fork length and weighed to the nearest 0.01g using a digital scale (Ohaus, Scout Pro SP 400). Juvenile and adult trout were scanned for PIT tags and coded wire tags and inspected for any other external tags (such as fin clips, elastomer tags, etc.). If the trout did not have a PIT tag, a tag was inserted in the dorsal sinus cavity for adult trout or the body cavity for juvenile trout >65 mm (12.5mm tag, full duplex 134.2 kHz). A tissue sample was removed from the caudal fin of juvenile and adult trout and stored in 95% non-denatured ethanol.

Movements of *O. mykiss* trout were monitored using a network of stationary PIT tag interrogation stations in Beaver Creek (Fig. 1) and at dams and passage facilities on the mainstem Columbia River. One multi-antenna, multiplex PIT tag interrogation station and two single antenna PIT tag interrogation stations were operated in Beaver Creek (described in Connolly et al. 2008, Martens and Connolly 2010). Briefly, the multiplex unit was operated with a Digital Angel Model FS-1001 transceiver connected to 6 custom made antennas and a DC power source. The antennas were arranged in three arrays across the stream bed with each array having two antennas that extend across the stream bed providing redundancy and complete coverage at most stream flows. This configuration allowed us to determine direction of movement and efficiency of detection. The single antenna interrogation stations were operated using a 2001F-iso Digital Angel PIT-tag reader powered by a 12-volt battery connected to a single custom made antenna. The most downstream single antenna PIT tag interrogation station was operated from September 27, 2004 to December 2, 2008. The multiplex interrogation station was operated from July 20, 2004 to present. The upper single antenna PIT tag interrogation station was operated from August 1, 2004 to November 12, 2008.

Migratory life history (anadromous or fluvial) of the adult trout was identified using PIT tags. Fluvial *O. mykiss* trout left Beaver Creek and were not detected at any of the Columbia River facilities. Some of these fish returned in successive years. Anadromous *O. mykiss* trout were detected on the mainstem Columbia River dams during upstream and/or downstream migration. Hatchery origin trout were identified from PIT or coded wire tags, fin clips or other marks.

Lab methods

Tissue samples from the Wells Hatchery brood years 2005 and 2006 (hatchery x hatchery crosses) were provided by the Washington Department of Fisheries and Wildlife (WDFW). Sixteen microsatellite markers were used to identify individuals. Thirteen of these markers are standardized across the Columbia River Basin which allows for data sharing across labs (Stephenson et al. 2009). DNA was isolated from fin clips preserved in ethanol using Qiagen DNEasy tissue extraction kits following standard manufacturer's protocols. Sixteen microsatellite loci were amplified using the polymerase chain reaction (PCR) in three multiplex reactions using Qiagen Multiplex PCR Master Mix on Applied Biosystems GeneAmp PCR System 9700 thermal cyclers in 96 well plates. PCR products were run on an Applied Biosystems 3730 genetic analyzer. Peaks were scored using GeneMapper version 3.7 software (Applied Biosystems, Foster City, California), and labeled following the Stevan Phelps Allele Nomenclature (SPAN) convention (Stephenson et al. 2009). Forward primers were fluorescently labeled (Applied Biosystems). Primer sets used were *Ogo4* (Olsen et al. 1998), *Oke4* (Buchholz et al. 1999), *Oki23* (Smith et al. 1998), *Omy1001* and *Omy1011* (Spies et al. 2005), *Omy7* (Stephenson et al. 2009), *Oneu14* (Scribner et al. 1996), *One102* (Olsen et al 2000), *Ots100* (Nelson and Beacham 1999), *Ots3m* (Greig and Banks 1999), *Ots4* (Banks et al. 1999), *Ssa289* (McConnell et al. 1995), *Ssa407* and *Ssa408* (Cairney et al. 2000), *Omm1036* and *Omm1046* (Rexroad et al 2002).

Amplification (PCR) reactions consisted of 5 ul reactions containing 2.5 ul Qiagen Multiplex PCR Master Mix, five or six primer sets and water, added to 2ul of extract dried down in a 96 well plate. Cycling conditions included initial denaturation for 15 min at 95°C, followed by 28 cycles for 30 s at 94°C, 90 s at 51°C (Multiplex A) or 57°C (Multiplex B and Multiplex C), and 60 s at 72°C, followed by a final cycle for 30 min at 60°C. Multiplex A contained *Oki23*, *Oke4*, *Oneu14*, *Ssa289*, and *Ssa408*; Multiplex B contained *Ots4*, *Omy7*, *Ogo4*, *One102*, *Omm1046*, and *Ssa407*; Multiplex C contained *Ots100*, *Omy1011*, *Omy1001*, *Ots3m*, and *Omm1036*.

Amplification products were diluted with 10 ul DNA grade water and 1 ul of each dilution added to 10 ul of LIZ/formamide solution (30 ul LIZ600 to 1 ml formamide) in a 96 well half-skirted PCR plate compatible with an AB3730 genetic analyzer. A few samples from each plate were run on the AB3730 to test for the fluorescent strength of peaks. Adjustments were then made to sample dilution and volume, along with voltage and time settings for sample injection on the AB3730, to achieve optimum strength fluorescent peaks for the actual full plate run of 96 samples. Completed runs were analyzed automatically using Genemapper, followed by manual analysis of all peaks for verification. All homozygous results were checked for small allele dropout and large allele dropout. Peaks were also visually checked for conformity to expected profiles. Peaks were scored following the Stevan Phelps Allele Nomenclature (SPAN) convention (Stephenson et al. 2009). Lab error rates for the 13 standardized loci are <2% (Stephenson et al. 2009). Duplicate samples indicate lab error rates <1% for our study.

Statistical Analysis

The before-after analysis relies on the assumption that temporal genetic diversity is stable so that a detectable response can be attributed to the treatment. To test the temporal stability of the genetic diversity and variation, we used pair-wise comparisons between consecutive years. Therefore, pair-wise comparisons between the before-after samples were used to detect changes due to the instream treatments whereas pair-wise comparisons between consecutive years were used to test the frequency of statistical significance due to non-treatment related factors (such as finite sampling). Multiple tests were also used as much as possible to confirm the significance of the before-after comparisons detected at the sites.

Prior to statistical tests, full siblings were identified and removed from the data set using ML-RELATE (Kalinowski 2006). Exact tests of Hardy Weinberg Equilibrium and linkage disequilibrium were performed using GENEPOP version 4.0.10. Expected heterozygosity was calculated using GENEPOP version 4.0.10 (Raymond and Rousset 1995). Unbiased estimates of allelic richness and private alleles were calculated using HP-RARE (Kalinowski 2005). Exact tests for Fst were performed using ARLEQUIN v3.5 (Excoffier and Lischer 2010). All comparisons were adjusted for multiple comparisons using a Bonferroni correction (Rice 1989).

The proportion of hatchery admixture was estimated for each *O. mykiss* collected at each site and year in the sample with known hatchery steelhead from Wells Hatchery (n=99) using STRUCTURE version 2.3.3 (Pritchard et al. 2000). The two hatchery brood years were not statistically different and were combined for our analysis. STRUCTURE is a Bayesian based model that clusters individuals according to allelic frequencies minimizing Hardy Weinberg and linkage disequilibrium. The model allows for admixture between population groups. The admixture model was run in STRUCTURE using 10,000 iterations for burn in and 100,000 iterations using a Markov Chain Monte Carlo resampling algorithm as described in Prichard et al. (2000). All other settings were run using default values. The percent hatchery admixture for each individual was averaged for each sample collection at each site.

Results

Difficulties running the weir during high springtime stream flows resulted in inconsistencies between capture efficiencies and counts across the years of our study. Fluvial *O. mykiss* were particularly numerous during 2006 with nearly three times the number of adult migrants than the other years of our study (Fig. 3). Over the 4 years of our study, 34 individual fluvial rainbow trout >200 mm were documented during the spawning run in Beaver Creek. Males were the largest proportion (67%) of this life history type; females and unknown determinations were 6% and 18%, respectively. The fluvial *O. mykiss* were documented entering Beaver Creek up to three consecutive years during our study with 32% of the individuals entering the creek multiple years.

Capture efficiency at the fish trap was high for adults during 2005 and 2006 with only two individuals in 2005 and one individual in 2006 known to be missed in our sample. However, the weir was not run for the entire spawning seasons during 2007 and 2008 reducing the ability to count the wild anadromous *O. mykiss* entering the stream during these years (Fig. 3). Numerous hatchery *O. mykiss* were read at the Beaver Creek interrogation stations during these years, and the counts based on PIT tags would be biased toward hatchery trout.

Data from PIT tag interrogations indicated that adult *O. mykiss* migrated further upstream in Beaver Creek during the latter two years of the study (Fig. 4). At the end of our study, adult *O. mykiss* were still expanding into the upper basin. Downstream movements of PIT tags from parr in Beaver Creek indicate an increase in outmigration during these years in the upper basin. However, PIT tag outmigration from the middle reach (UBR1) remained relatively constant indicating that juvenile *O. mykiss* were expressing an anadromous life history from this reach prior to barrier treatment (Fig. 5). Between 2007 and 2011, 38 adult *O. mykiss* that were tagged as parr in Beaver Creek were detected migrating upstream. Most (68%) of these adults were last detected on the Columbia River or at the PIT tag interrogation site at the mouth of the Methow River. Eight adults (21%) were detected in Beaver Creek (n=1 2007, n=3 2008, n=4 2009) and 4 (33%) were detected in other tributaries (Twisp and upper Methow rivers). These returns indicate that a local population of anadromous *O. mykiss* was established and successfully homing back to their natal stream. One-third of these adults were detected in other natal streams in the Methow Basin.

The total number of alleles detected at each locus ranged from 7 to 28 with the average allelic richness ranging from 4.9 to 7.2 by site and collection date (Table 1). Expected heterozygosity and average allelic richness were similar to values documented for *O. mykiss* in other studies (Heath et al. 2002; Narum et al. 2004; Narum et al. 2006; Narum et al. 2008; Nielsen et al. 2009). Tests of Hardy Weinberg Equilibrium and linkage disequilibrium did not detect significant departures in the juvenile samples from the sites on Beaver Creek. Tests on the Wells Hatchery samples did not detect any significant departures from Hardy Weinberg Equilibrium but did detect linkage disequilibrium at 6 pairs of loci. There was no discernable pattern to these pairs of loci.

The genetic diversity parameters indicated some changes in the before-after comparisons with the temporal tests remaining stable for expected heterozygosity and allelic richness. Private alleles did vary across the comparisons (Table 1). The proportion of hatchery admixture showed confounding results with some sites increasing and some decreasing before-after the barrier removal. The comparisons of proportion of hatchery admixture among consecutive years were consistent except for the South Fork Beaver Creek (SFB) comparison. The campground site downstream from the mouth of the South Fork Beaver Creek showed an increase of proportion of hatchery admixture when comparing the 2005 to 2009 samples. Pair-wise Wilcoxan rank tests before and after comparisons and temporal comparisons of the proportion of hatchery admixture were not significant ($p>0.05$) except for the comparison between 2005 and 2008 SFB site ($p=0.02$).

Comparisons of genetic differentiation (Fst and allele frequency) showed significant differences at the two most downstream sites in the basin (Table 1). Both of these measures show significant differences indicating consistency across these measurements and supporting the conclusion that population genetics changed at these sites after barrier removal. Interestingly, the site downstream from the dams showed significant change even though it was accessible prior to the barrier removal treatments. The genetic differentiation tests at UBR4 were significant comparing 2004 and 2008, but not significant for the comparison between 2004 and 2009. It is possible that this significance could be a result of finite sampling or non-random mating or tissue collections. All of the temporal tests on the consecutive years did not show any significant tests for comparisons of Fst or allele frequencies (Table 1).

Discussion

Adult *O. mykiss* entered Beaver Creek during the first spawning season after barrier removal. Hatchery *O. mykiss* were a small proportion of these colonizing adults despite high abundances from releases by local fishery management programs. Anadromous parr tagged in Beaver Creek returned to the study area as adults in 2007 indicating that an anadromous population was established in the newly opened habitat. Comparisons of population genetic parameters before and after barrier treatment indicate significant changes in the two downstream monitoring sites in the basin (DS Dams and UBR1). The other sites did not show significant changes. Hatchery admixture was not significantly different in the before and after comparisons.

Temporal tests of the population genetic parameters showed no significant differences between pair-wise comparisons over consecutive years.

Adult anadromous *O. mykiss* did not increase during the first 4 years after barrier removal. Counts of wild and hatchery anadromous *O. mykiss* declined from 2005 to 2007 and then increased slightly. This followed the trend of adult counts into Wells Dam. Fluvial rainbow trout were a variable portion of the run and inter-breed with the anadromous *O. mykiss* (Weigel et al. *in review*). Although Anderson et al. (2010) found rapid colonization and steadily increasing abundances of coho salmon (*O. kisutch*) during the first 3 years after passage was restored at a dam, Demarias et al. (1993) found that re-colonization occurred much slower in the Virgin River chub (*Gila seminuda*) after an accidental release of rotenone, a fish poison. After 29 months, the population genetic attributes of the Virgin River chub had returned to the pre-poison conditions at the site closer to the unaffected (source) population (30 km), but was significantly different at a more distant site (>60 km away) indicating that this population was still disconnected. The rate of colonization is mediated by the abundance, distance and connectivity to source populations; therefore, different species and locations may vary in response to connectivity projects or disturbance events.

Few hatchery *O. mykiss* entered Beaver Creek despite high proportions of hatchery trout in the returns to the basin. Leider (1989) also found different proportions of hatchery *O. mykiss* between a hatchery counting site lower in the basin and a natal tributary. Hatchery fish may return to release locations or the hatchery site near the release location. In addition, other survival differences may affect the proportion of hatchery fish between the ladder at Wells Dam and the natal tributaries, such as selective harvest. Hatchery admixture did not significantly change in our before-after pair-wise comparisons. In addition, only two juvenile parr from

Beaver Creek were found to be spawned by a hatchery *O. mykiss* indicating very low reproductive contribution from this population (Weigel et al. *in review*).

Several parr tagged in Beaver Creek returned as adults in 2007 through 2011 indicating that an anadromous population established in the newly opened habitat. Some straying of these returning adult *O. mykiss* occurred during the study and 66% of these adults returned to the natal area. All the strays were detected in tributaries upstream from Beaver Creek. *O. mykiss* were found to stray into tributaries upstream from the natal tributary after the volcanic eruption on Mt. St. Helens, WA (Leider 1989). Additional adult *O. mykiss* tagged as parr in Beaver Creek were last detected migrating upstream in the Columbia River or the mouth of the Methow River. These adults were not detected again entering a natal tributary, and the fate of these adults is unknown. These trout either died, entered another natal stream undetected or returned to Beaver Creek downstream from the lowest tag interrogator. The adult *O. mykiss* from Beaver Creek had a substantially higher rate of straying (33%) than documented in other studies (7.7%) (Hendry et al. 2004).

The temporal stability of the population genetic measures is important to identify when attempting to detect a treatment effect. Population genetic measures can vary due to genetic drift from finite population sizes (Allendorf and Luikart 2007). Therefore, some tests could show significant differences and be unrelated to the treatment. Similar to other studies, our populations were temporally stable over short term comparisons. Similar tests ranging from collections <1 to 5 years apart found that only 1 out of 21 comparisons was significantly different (Heath et al. 2002, Narum et al. 2004, Narum et al. 2006, Nielsen et al. 2009). Therefore, we expect a less than 5% rate of significant temporal tests due to random or unmeasured effects.

O. mykiss from the two most downstream sites showed significant differences in allele frequency and Fst values, but not in proportion of hatchery admixture. We did not expect to see a change in the site downstream from the dams because this site was accessible to *O. mykiss* prior to the barrier treatments. Interestingly, there was also a reduction in the proportion of hatchery admixture at this site after barrier removal, another unexpected result. This shift in genetic parameters may be due to individual trout moving downstream from upstream sites for rearing or possibly due to the mixing of the anadromous population with the resident populations that were residing upstream from the diversion dams. Hatchery *O. mykiss* did not appear to substantially contribute to the colonization of the study area; therefore, this reduction in hatchery admixture could result from the higher contribution of the wild *O. mykiss*. The first site upstream from the diversion dam treatments (UBR1) had the greatest shift in Fst and allele frequencies which were significantly different before and after treatment. This site had only a slight, not significant increase in the proportion of hatchery admixture indicating little hatchery influence at this site.

The sites further upstream did not show changes in population genetics when comparing before and after treatment samples. Tag data indicate that few spawners migrated to these upper reaches of the basin during the first 4 years after barrier removal. Although outmigration increased from tags released at these sites during the study indicating an increase in anadromy, removal of the related individuals from the analysis will require more adults to spawn in these reaches of stream before genetic response will be detectable. The UBR4 site showed a significant change in Fst and allele frequencies when comparing the 2004 to 2008 samples, but this comparison was not significant when comparing the 2004 to 2009 samples. Since the pair-wise comparisons were not similar across the different years, we considered that the significant comparison did not indicate clear genetic changes due to the treatment. Similarly, the SFB site had an increase in allelic richness and private alleles when comparing the 2005 to 2008 samples, but not when comparing the 2005 to 2009 samples. These shifts in population genetic measures could be the result of genetic drift from finite population size of breeders, non-random mating, finite sampling, or result from a few new migrants in 2008 that did not migrate into this area in 2009.

Successful colonization requires that source populations are available that can provide colonizers for the newly opened habitat; connectivity between the source population(s) and the newly opened habitat and adequate habitat conditions to establish and support the colonizing species. The barrier removal resulted in connectivity in Beaver Creek allowing individuals to access the creek from other (source) populations. Adults that entered Beaver Creek successfully reproduced (Weigel et al. *in review*) and anadromous *O. mykiss* established a population further upstream in the basin. The sites in the lower reaches of Beaver Creek had significant changes in genetic differentiation when comparing before and after the barrier removal. Colonization and expansion of anadromous *O. mykiss* was a slower process than expected with adult anadromous *O. mykiss* expanding into the upper basin sites during the later years of the study.

Acknowledgements

Our project was possible with the support of numerous individuals and agencies. Funding and materials were provided by the U. S. Bureau of Reclamation. We are grateful to the local landowners, G. Ott and V. Stokes, who allowed access to sites on Beaver Creek that made this study possible. M. Newsom provided valuable scientific direction to the project. G. Knott and M. Notaro provided support with local coordination and permitting. B. Fisher, W. Tibbits and N. Glasser provided assisted in data collection and operation and maintenance of the weir and PIT tag readers. J. Faler conducted the tissue extraction and microsatellite analysis.

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Table 1. Genetic variation for pair-wise before-after treatment comparisons and temporal tests on consecutive years for sites in Beaver Creek sampled between 2004 and 2009. Sites are listed from the most downstream to the most upstream. Repeated pair wise tests were done to test repeatability of results. Parameter include: sample size (n), expected heterozygosity (H), average allelic richness (AR), private alleles (PA) and average proportion of hatchery admixture (%H), population differentiation (Fst) and allele frequency exact test (Pval).

	Before						**After**							
Site	year	n	H	AR	PA	%H	Year	n	H	AR	PA	%H	Fst	Pval
Downstream dam	2005	28	0.80	7.1	0.42	40.0	2009	23	0.81	7.2	0.35	35.6	0.014*	0.001*
UBR1	2004	19	0.78	6.4	0.26	45.2	2008	28	0.82	7.2	0.22	47.6	0.021*	<0.001*
UBR1	2004	19	0.78	6.4	0.26	45.2	2009	26	0.82	7.0	0.29	47.0	0.027*	<0.001*
CMP	2005	36	0.76	6.3	0.04	6.0	2009	21	0.78	6.3	0.06	12.6	0.002	0.047
UBR4	2004	15	0.70	4.9	0.03	6.3	2008	28	0.69	5.2	0.05	3.2	0.011*	0.009*
UBR4	2004	15	0.70	4.9	0.03	6.3	2009	23	0.68	5.3	0.03	5.0	-0.002	0.558
SFB	2005	28	0.72	5.5	0.03	1.8	2008	33	0.77	6.0	0.09	8.3	0.004	0.121
SFB	2005	28	0.72	5.5	0.03	1.8	2009	21	0.73	5.5	0.04	4.0	0.002	0.276
Temporal tests														
UBR1	2008	28	0.82	7.2	0.22	47.6	2009	26	0.82	7.0	0.29	47.0	-0.003	0.253
UBR2	2008	29	0.80	6.7	0.11	9.8	2009	22	0.80	6.6	0.18	9.0	-0.004	0.880
UBR4	2008	28	0.69	5.2	0.05	3.2	2009	23	0.68	5.3	0.03	5.0	<-0.001	0.147
SFB	2008	33	0.77	6.0	0.09	8.3	2009	21	0.73	5.5	0.04	4.0	0.005	0.568

* indicates statistical significance after Bonferroni correction

Figure Legends

Figure 1. Study location and sampling sites in Beaver Creek, Methow Basin, Washington.

Figure 2. Counts of wild and hatchery adult *O. mykiss* returns to Wells Dam, Columbia River, Washington (1999-2010). Data provided by Washington Department of Fisheries and Wildlife.

Figure 3. Adult *O. mykiss* counts into Beaver Creek 2005-2008. Counts include *O. mykiss* captured at the weir by population and life history (hatchery (H in weir), wild (W anad in weir) and fluvial (fluv in weir)) and tagged trout read at interrogation stations in Beaver Creek and not captured at weir (hatchery (anad tag) and fluvial (fluv tag)).

Figure 4. Number of adult *O. mykiss* trout counted at tag interrogation stations located at rkm 4 and rkm 12 migrating upstream during spawning season in Beaver Creek 2005-2008.

Figure 5. Number of parr outmigrants recorded migrating downstream past the tag interrogation stations in Beaver Creek. Parr were tagged at sites located upstream of the interrogation stations in the middle reach of Beaver Creek (UBR1) and upper Beaver Creek (UBR2, SFB, CMP and UBR4). The interrogation stations were installed during the summer and fall 2004. Therefore, the counts for 2004 are not complete enumeration of annual parr outmigrants.

Figure 6. Output from STRUCTURE showing population admixture for the lowest 3 monitoring sites in Beaver Creek. The Wells Hatchery steelhead were used as a reference for the hatchery population (HxH crosses, brood years 2005 and 2006). Hatchery samples were provided by WDFW.

Figure 7. Output from STRUCTURE showing population admixture for the upper 3 monitoring sites in Beaver Creek. The Wells Hatchery steelhead were used as a reference for the hatchery population (HxH crosses, brood years 2005 and 2006). Hatchery samples were provided by WDFW.

Figure 1.

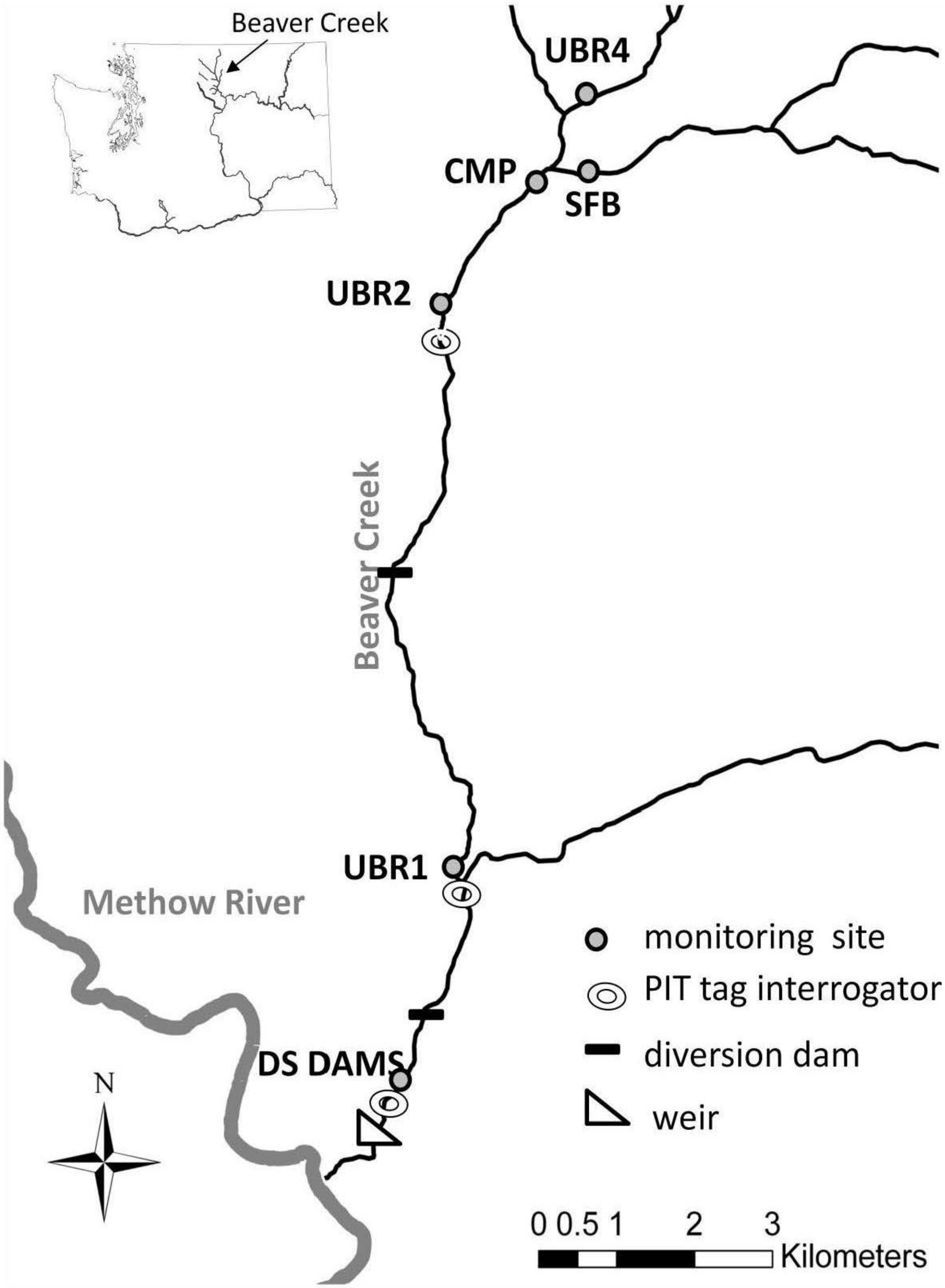
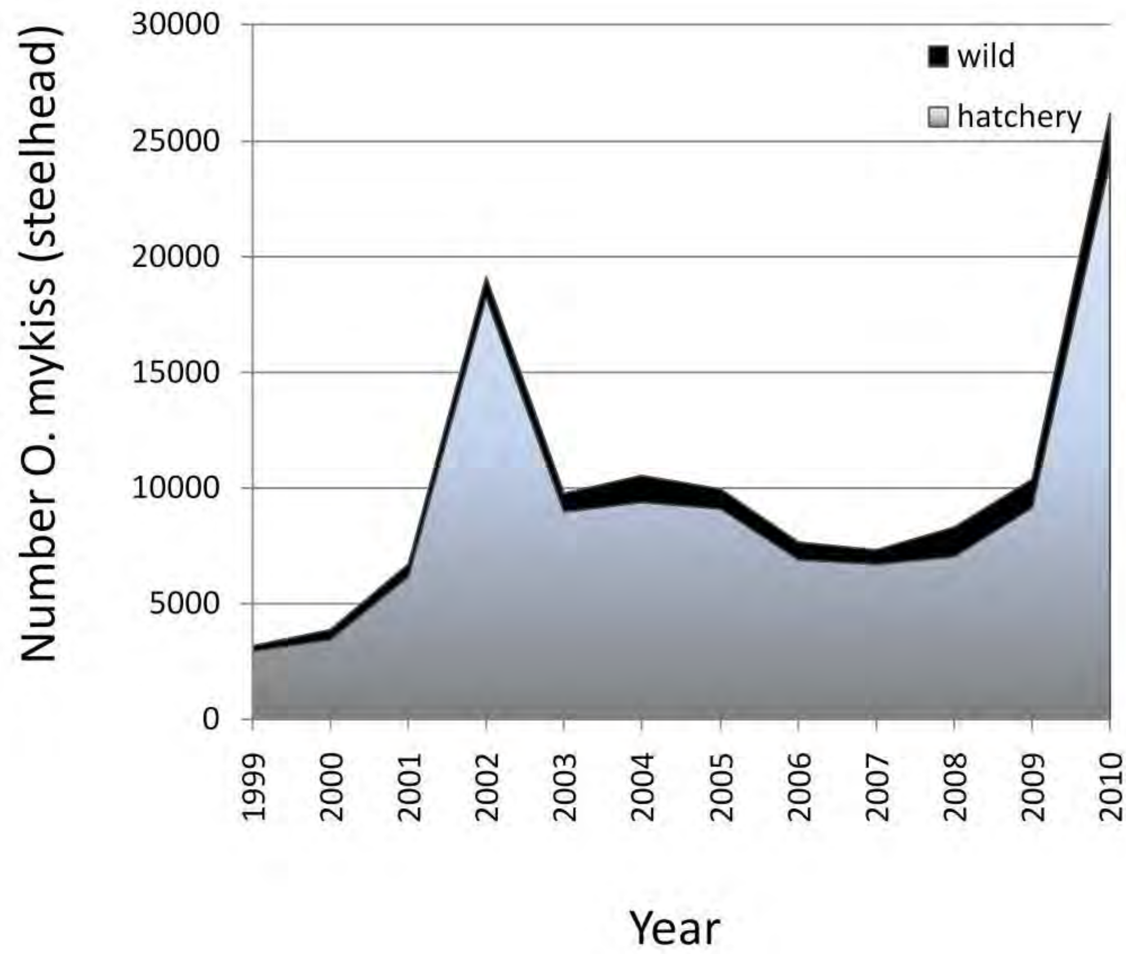

Beaver Creek
UBR4
CMP
SFB
UBR2
Beaver Creek
UBR1
Methow River
DS DAMS
N
monitoring site
PIT tag interrogator
diversion dam
weir
0 0.5 1 2 3
Kilometers

Figure 2.



wild
hatchery
Number O. mykiss (steelhead)
30000
25000
20000
15000
10000
5000
0
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Year

Figure 3.

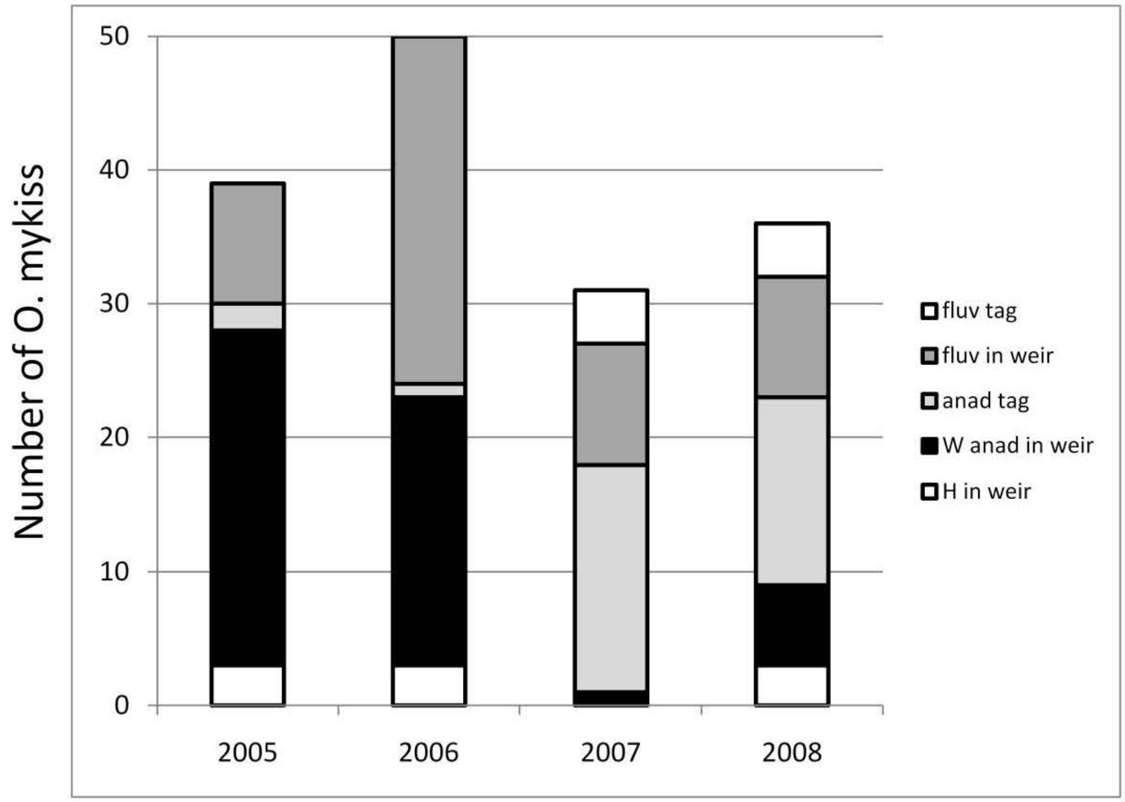

50
40
30
20
10
0
Number of O. mykiss
2005
2006
2007
2008
fluv tag
fluv in weir
anad tag
W anad in weir
H in weir

Figure 4.

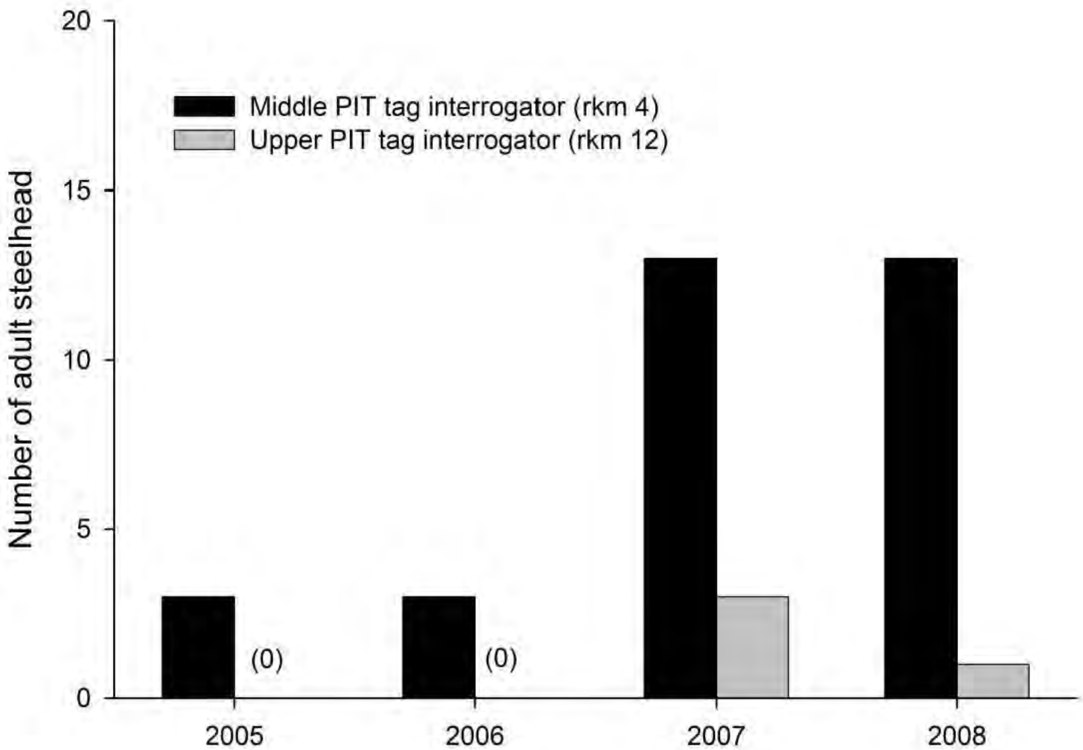

Middle PIT tag interrogator (rkm 4)
Upper PIT tag interrogator (rkm 12)
Number of adult steelhead
0
5
10
15
20
(0)
(0)
2005
2006
2007
2008

Figure 5.

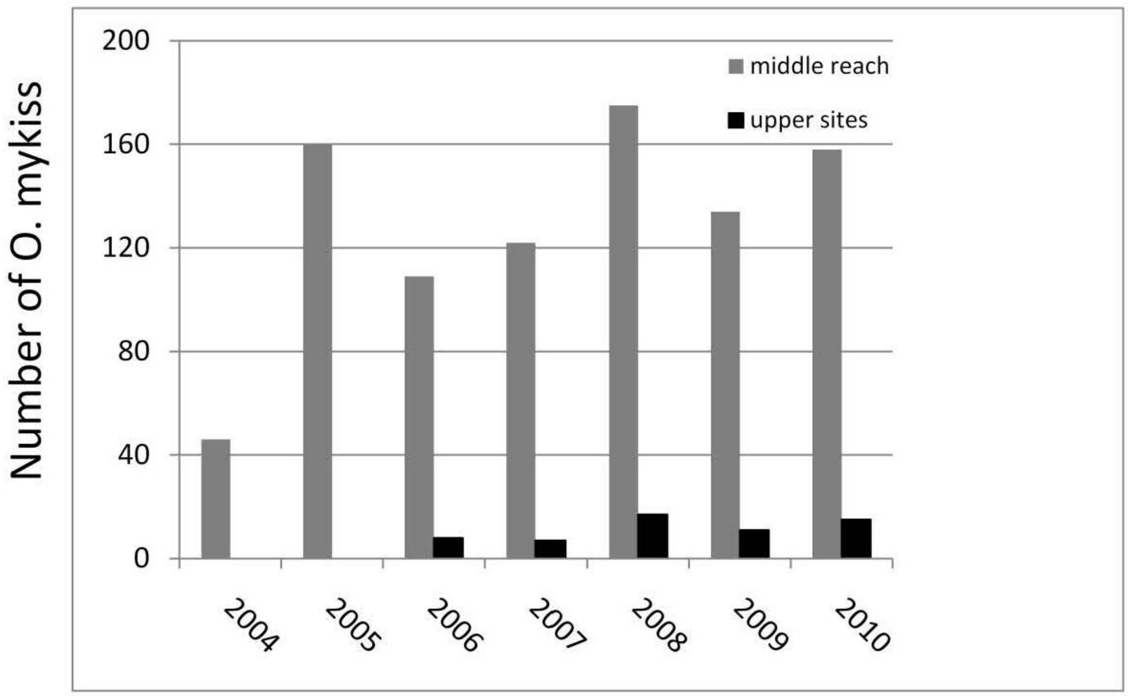

Number of O. mykiss
200
160
120
80
40
0
middle reach
upper sites
2004
2005
2006
2007
2008
2009
2010

Figure 6.

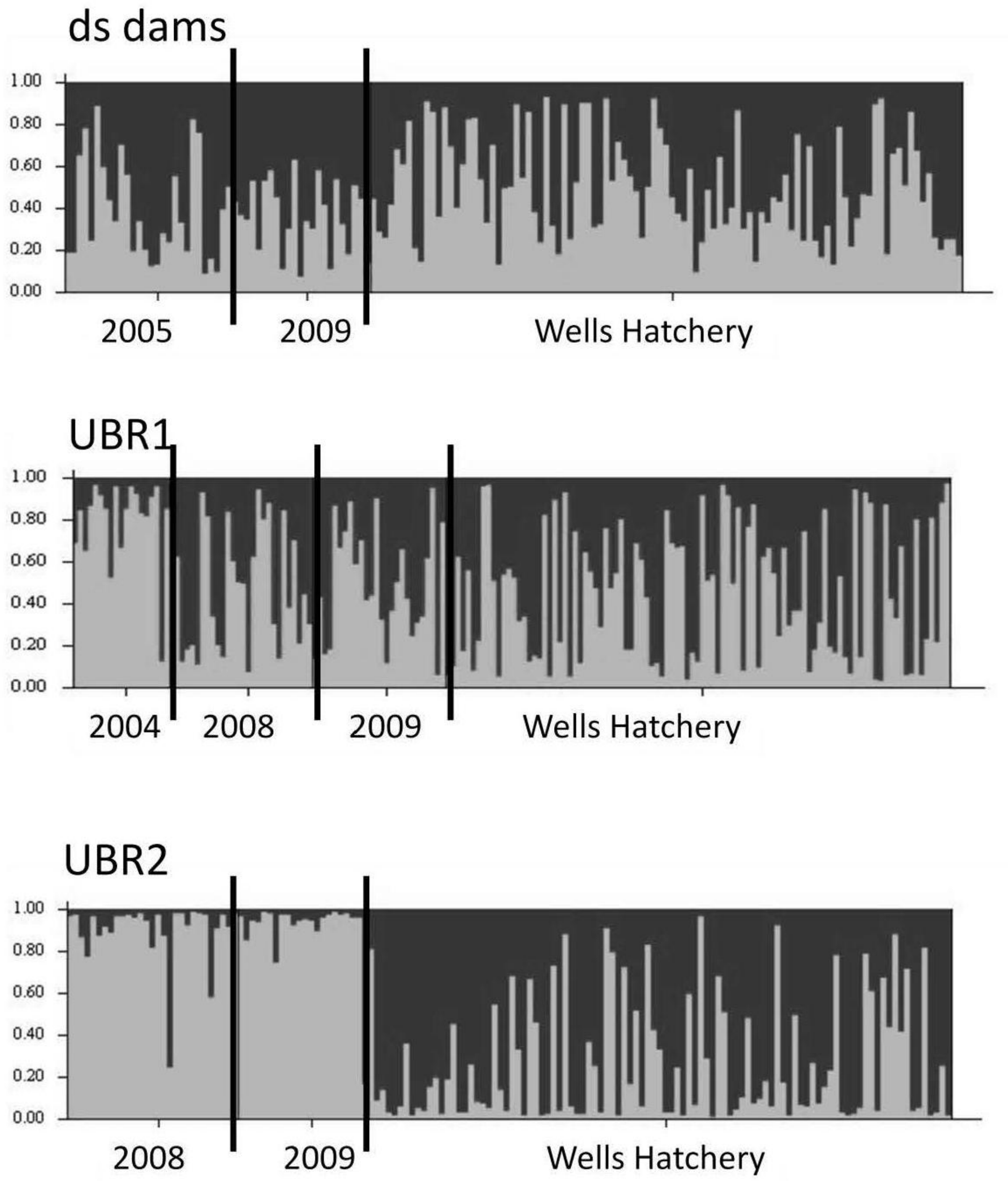
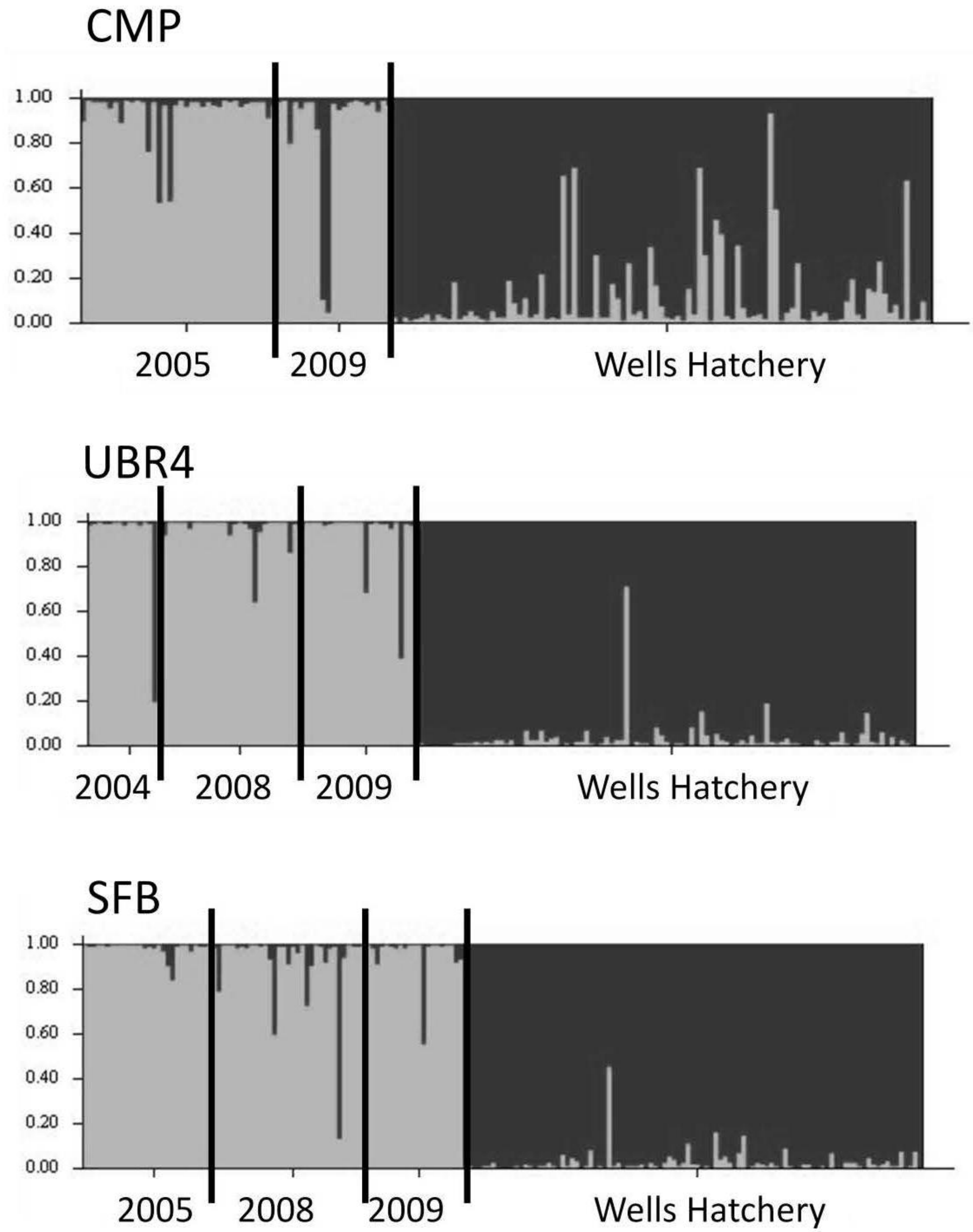

ds dams
1.00
0.80
0.60
0.40
0.20
0.00
2005
2009
Wells Hatchery
UBR1
1.00
0.80
0.60
0.40
0.20
0.00
2004
2008
2009
Wells Hatchery
UBR2
1.00
0.80
0.60
0.40
0.20
0.00
2008
2009
Wells Hatchery

Figure 7.


CMP
1.00
0.80
0.60
0.40
0.20
0.00
2005
2009
Wells Hatchery
UBR4
1.00
0.80
0.60
0.40
0.20
0.00
2004
2008
2009
Wells Hatchery
SFB
1.00
0.80
0.60
0.40
0.20
0.00
2005
2008
2009
Wells Hatchery

APPENDIX D

Elbow Coulee Studies

* Funded in part or in whole by Reclamation to help meet the FCRPS BiOp RME Strategies

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D-1 **More Fish Use Reconnected Side Channel near Elbow Coulee**

D-2 **Elbow Coulee Floodplain Reconnection and Side Channel Restoration Project – 2008-2009 Monitoring Report**

D-3 **Elbow Coulee Floodplain Reconnection and Side Channel Restoration Project – 2010 Post-Project Assessment Report**

D-4 **Elbow Coulee Side Channel – 2011 Update**

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More Fish Use Reconnected Side Channel near Elbow Coulee

Methow River, WA January, 2012

Introduction

More than 50 years ago, a portion of the floodplain and side channel near Elbow Coulee was cut-off from the main-stem Twisp River by a levee **(Figure 1)**. In September 2008, a project was initiated to reestablish connection to the river by breaching the levee. The Elbow Coulee Side Channel Restoration Project was implemented to meet the following objectives: 1) re-establish a side channel to the Twisp River at RM 6.6; 2) increase habitat complexity and large woody debris recruitment potential; 3) reduce stream energy to increase the potential for the accumulation of sediment and wood in the Twisp River; and 4) increase rearing habitat for native juvenile salmonids. A breach was excavated in the existing levee at the upstream entrance to the disconnected side channel **(Photo 1)**. A sill constructed at the breach functions as a grade control structure and limits flow entering the side channel. The sill was designed to activate the side channel when flows in the Twisp River reached 200-400 c.f.s., representing a 1.5 – 2 year recurrence interval discharge **(Photo 2).** Monitoring results obtained since post-construction in 2008 and through 2011 indicate that all four objectives have been met and that the project provides habitat for spring Chinook salmon, steelhead, and potentially bull trout:

- High flows activated the side channel each year
- Young-of-the-year spring Chinook and steelhead observed each year using the side channel
- More fish are using the side channel than before
- Water temperatures conducive for fish rearing.

This report summarizes the monitoring and evaluation of the project as presented by Crandall (2009, 2010, and 2011).

Project at a Glance

Formal Project Name: Elbow Coulee Floodplain Reconnection & Side Channel Restoration	
Project Type: Complexity – side channel reconnection	
Project Sponsor: Methow Salmon Recovery Foundation (MSRF), 509-422-0300	
Project Design: Bureau of Reclamation	
Landowner(s): Private, Washington Department of Fish and Wildlife, and US Forest Service	
Partners: US Forest Service (Technical Assistance and Permitting), Washington Department of Fish and Wildlife (Project Development and Construction Oversight), and Bureau of Reclamation (Technical Assistance and Design)	**Reclamation Development Costs:** $281,220
Funding Source(s): Bonneville Power Administration	**Implementation Cost:** $9,251

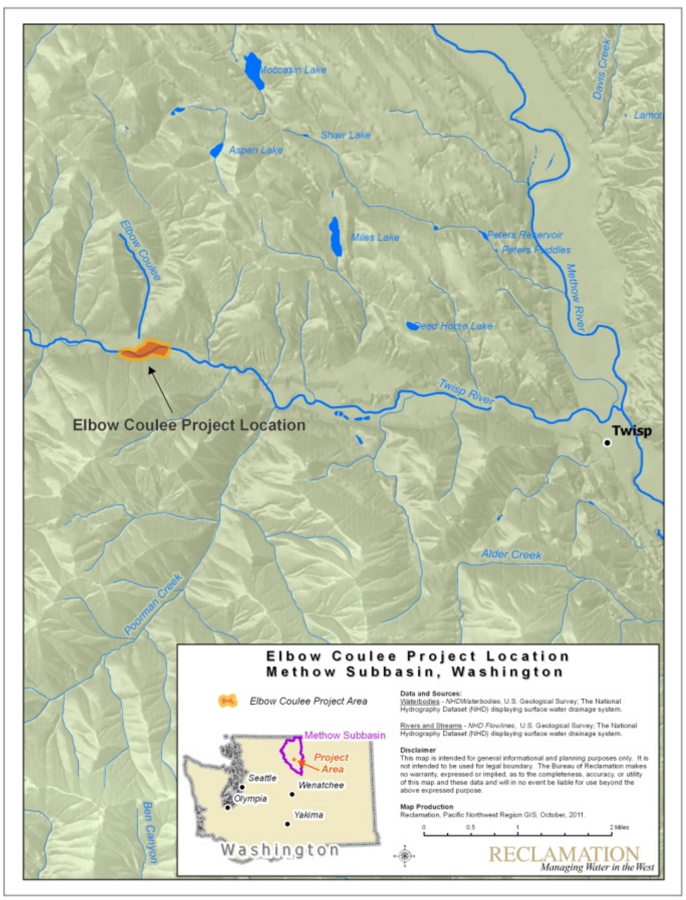


Figure 1. Location map for the Elbow Coulee Floodplain and Side Channel Reconnection Project.

 1)  2)

Photo 1. Levee at river left along Twisp River conceals the side channel with extensive floodplain rearing habitat. Photograph was taken in summer 2008 looking east.

Photo 2. Disconnected side channel showing numerous downed trees and woody vegetation. Photograph was taken in 2006 looking down-gradient viewing northeast.

Methods for Monitoring and Evaluation

Monitoring and evaluation of the reconnected side channel and associated floodplain is necessary to measure project success at meeting goals and forms the basis for adaptive management. Monitoring consists of both quantitative measurements and visual examinations of side channel form and function. Monitoring is being conducted to evaluate:

1) Response of the side channel geomorphic form and function.
2) Response of side channel discharge, water temperature, and biological community.
3) Identify steps needed (if any) to adaptively manage the project to maximize project success.

Prior to construction in 2008, monitoring goals in the side channel were focused initially around investigating the physical and biological aspects of the side channel. From this, a baseline dataset was developed to compare with future monitoring. These efforts are purposely aligned to the regional monitoring framework for the Upper Columbia River (Hillman, 2006).

Annual monitoring of the project is predominantly focused on flow, temperature, and fish.

- Flow – generally from late November through May including a combination of flow estimates, staff gauge readings, water level monitoring and visual observations.
- Temperature – continuous year-round using accuracy-checked electronic submersible data loggers.
- Fish – population surveys via electrofishing, visual (snorkel and bank) surveys, and pit tagging.

Results, Interpretations, and Trends

A portion of the side channel at Elbow Coulee received perennial groundwater and maintained a downstream connection to the Twisp River prior to project implementation. The levee that blocked flow access to the side channel was breached at the upstream end and opened to the Twisp River in the fall of 2008. The side channel was activated by high flows for the first time in over 50 years. Three years of monitoring data and observation have documented that the side channel continues to activate each year during high water and has been functioning in close accordance to the goals of the restoration actions. Since construction, juvenile spring Chinook salmon and steelhead trout have been observed in the side channel following nine activation events from the Twisp River spanning 284 days over a three-year period.

The perennial nature of groundwater inputs provide at least 700 linear feet of rearing habitat for fish including spring Chinook salmon and steelhead, along the entire length of the baseflow wetted channel (Crandall, 2009) **(Photo 3)**. The perennial groundwater provides year-round downstream connectivity to the Twisp River and monitoring results indicate juvenile fish are using the side channel for rearing.

Physical and geomorphic form was measured in November 2008 using Forest Service stream habitat survey protocols focusing upon channel type, substrate, large wood, and longitudinal profile. The side channel is primarily dominated by shallow riffles at about 60% and pools at 12% that provide deeper habitat. Further, eleven channel cross-sections were surveyed in November 2008 and photographs taken at each point. Plans are to repeat these surveys in 5 years or as significant flow events occur (e.g., greater than 10 year flood events).


3)

Photo 3. Before the project, this previously groundwater fed side channel had a terminal connection to the Twisp River. A levee was breached at the upstream end of the Elbow Coulee side channel along the left bank of the Twisp River in Fall 2008. A monitoring program was soon initiated in the side channel, which received its first flows from the Twisp River in 2009 during the spring freshet. The photograph was taken in summer 2008 looking northeast down gradient.

Flow

The snowmelt runoff in the Twisp River in 2011 was the highest since the project was completed. Peak discharge in the Twisp River exceeded 2,400 c.f.s., which represents an approximately 2.5-year recurrence interval flood. During these peak flows >20 c.f.s. was recorded flowing through the side channel (Crandall, 2011; unpublished data). Due to the high-, and extended, runoff, the side channel was activated by Twisp River flows for over 115 continual days in 2011.

Twisp River flows greater than approximately 580 c.f.s. are sufficient to crest the rock sill in the breach and fish would have uninhibited passage into the upstream end of the side channel (Crandall, 2009) **(Photos 4 – 5).** Once in the side channel, fish would have the ability to move downstream within the side channel and also back into the Twisp River at the terminus of the side channel. Thus, flows in excess of 600 c.f.s. are sufficient to allow passage for all life stages of fish. Due to the extended length of activation this last year, fine sediment and smaller particles were flushed out of the breach and it is expected to activate at a lower discharge (Crandall, 2011, unpublished communication). This will be confirmed in 2012 during the winter/spring flows. This adjustment is a natural outcome of a system allowed to freely adjust and settle out.


4)


5)

Photo 4. View looking west and upstream of the side channel confluence with the Twisp River and the reconstructed inlet of the side channel. The view shows side channel activation during high water May 2010.

Photo 5. The same event as Photo 4 downstream view of the activated side channel looking northeast during high water spring 2010.

Temperature

Juvenile salmonids generally enter the side channel during high flow associated with spring runoff, yet can remain for extended periods of time due to perennial groundwater feeding the side channel. The water temperatures in the side channel are both warmer in winter and cooler in summer compared to the adjacent Twisp River (Crandall 2009 and unpublished data) which may provide rearing fish with a thermally beneficial location for growth and survival.

Fish

In late 2008, 42 fish representing three species were captured and identified during an electrofishing survey **(Figure 2).** Fish were captured along the entire length of the wetted channel and were most commonly observed in the deeper portions of the channel in pools (Crandall, 2009) **(Photo 6)**. A subsequent electrofishing survey in late 2011 recorded an almost three-fold increase from 2008 in fish abundance and a greater diversity of fish species present in the side channel.

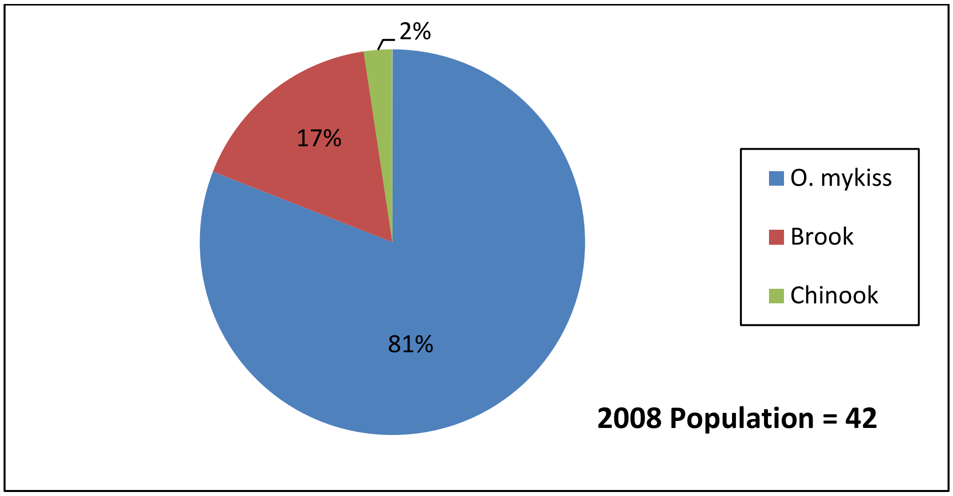
While rearing-sized fish were observed in the side channel prior to re-connection, the presence of young-of-the-year fish, including ESA listed salmonids, in the uppermost pool in the side channel is strong evidence that these fish gained access to the side channel through the newly constructed breach **(Photos 7 – 8).** Although it is plausible that 40 mm salmonids could have gained access to and entered the side channel from the bottom, the presence of larval sculpin (<20mm) that lack the swimming ability to move upstream through the side channel, is evidence that fish are entering the side channel through the newly created breach. Thus, it was concluded that fish gained access to the side channel during the first activation event post-emergence and resided in the channel (Crandall, 2009). Based on observations, the period of fish residency is estimated at several weeks to months and possibly longer for fish that select to remain in the groundwater influenced portion of the channel. Future monitoring will focus on determining whether undesired stranding is occurring and whether the channel may begin to prematurely fill in with fine sediment and detritus.

In 2011, beaver constructed two dams just downstream of the flow monitoring site in the side channel **(Photos 9 – 10).** While the ponds that resulted from this activity disrupted the continuous flow monitoring instrumentation by flooding the area, listed fish species were observed using the ponds almost immediately (Molesworth, USBR, pers. comm.). This change in habitat type has increased habitat complexity within the channel through increased pool habitat, wetted width and large woody debris.

6)

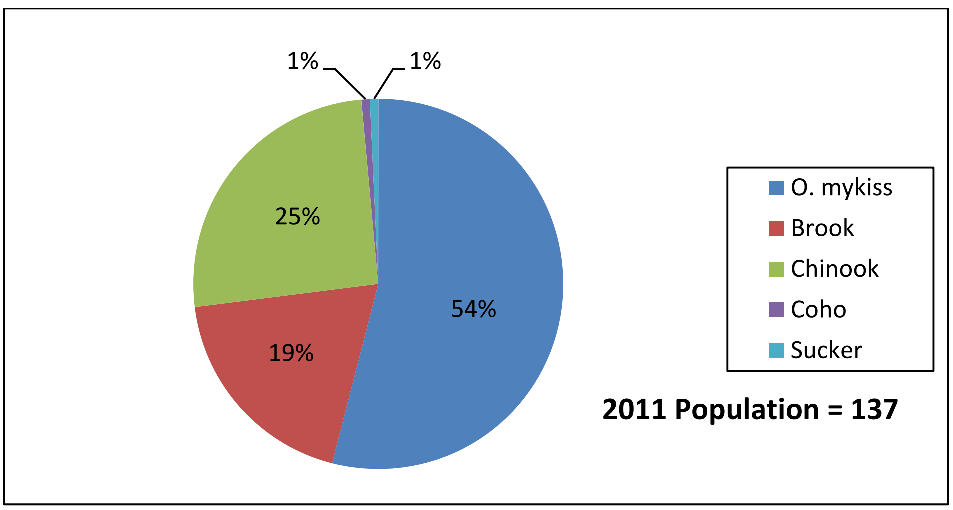
Photo 6. Endangered spring Chinook salmon, *Oncorhynchus tshawytscha*, in the Elbow Coulee side channel during the first post-construction spring channel activation event, June 2009.

More Fish Use Reconnected Side Channel near Elbow Coulee



2.a)

Figure 2.a. Elbow Coulee side channel fish species composition data for **2008**. Forty-two fish representing three species were sampled. Rainbow trout/steelhead dominated the catch representing 81% of the total. While present, ESA-listed spring Chinook were represented by only one individual. Non-native brook trout comprised 17% of the catch.



2.b)

Figure 2.b. Elbow Coulee side channel fish species composition data for **2011**. There was a three-fold increase in fish abundance in the side channel after three years of flow activation via the Twisp River when compared to 2008. Species richness also increased with the addition of coho salmon and bridgelip sucker. ESA-listed abundance increased noticeably. Spring Chinook salmon abundance increased from 1 to 48 and rainbow trout/steelhead increased from 34 to 74.

 7)  8)

Photo 7. A rearing wild young-of-the-year rainbow/steelhead trout collected from the side channel during May 2010.

Photo 8. A rearing wild spring Chinook parr, obtained from the side channel during May 2010.

 9)

Photo 9. Pond habitat in July 2011 on the activated side channel created by a beaver dam construction just downstream of the flow monitoring site established in early 2009. Note that photo location is identical to Photo 3.

10)

Photo 10. Beaver dams built in 2010 resulted in two ponds within the side channel that were subsequently inhabited and used for rearing by listed fish species.

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ELBOW COULEE FLOODPLAIN RECONNECTION AND SIDE CHANNEL RESTORATION PROJECT

2008-2009 Monitoring Report

John Crandall, Aquatic Ecologist, Confluence Aquatics

December 2009

Endangered spring Chinook salmon, *Oncorhynchus tshawytscha*, in the Elbow Coulee primary side channel during the first post-restoration spring channel activation event, 15 June 2009.

1. Executive Summary

In September 2008, the Elbow Coulee Floodplain Reconnection and Side Channel Restoration Project was implemented in order to: 1) re-establish a primary side channel to the Twisp River at RM 6.6; 2) increase habitat complexity and large woody debris recruitment potential; and 3) increase habitat for native fish, especially rearing-age salmonids. Specifically, a rock breach was constructed in an existing dike at the upper entrance to the primary side channel (Figure 1). The sill (breach) functions as a grade control structure and permits flow to enter the side channel. The sill was designed to activate the side channel when flows in the Twisp River (based on USGS gauge #12448998 data) reached 200-400 c.f.s., which represents a 1.5 – 2 year flow event (i.e. bankfull flow).

Post-project monitoring of the restored side channel and associated floodplain is necessary to gauge project success at meeting goals and to form the basis of adaptive management. Monitoring will consist of both quantitative and visual examinations of side channel form and function. Specifically, monitoring was conducted to assess the: 1) response of the primary side channel geomorphic configuration to restoration activities designed to create long-term habitat benefits; 2) Response of physical characteristics (primarily discharge and water temperature) and the biological community to habitat restoration and the newly re-established aquatic habitats within the primary side channel; and 3) identify steps needed to adaptively manage the project in order to maximize project success.

Figure 1. Elbow Coulee primary side channel breach with the Twisp River in the background, 7 July 2009.

Key findings of the 2008-2009 monitoring effort include the following:

- The primary side channel was activated when Twisp River discharge approached 300 c.f.s., but flows in excess of 575 c.f.s. may be required for unimpeded fish passage through the breach.
- The side channel was activated on four occasions for a total of 107 days with the longest occurring during spring runoff when the channel was active for 78 consecutive days.

- Endangered spring chinook salmon and threatened steelhead trout were observed in the side channel and some of these fish entered through the restored breach.
- Fish use, primarily rearing, of the side channel is year-round and is facilitated by groundwater flow that provides passage to the Twisp River at the downstream end of the side channel.
- Water temperature in the side channel was both warmer in winter and cooler in summer than the adjacent Twisp River. This may provide salmonids with a thermally beneficial environment.

2. 2008-2009 Monitoring Results

2.1 Physical Habitat

A stream habitat survey was conducted in the primary side channel on 20-21 November 2008. This survey used the USFS Level 2 Stream Inventory protocol (USFS 2006) to obtain channel type, substrate, large wood, and longitudinal profile data. Generally, surveys of this nature proceed in an upstream direction, but as the location of the downstream terminus of the channel is determined by discharge in the Twisp River, it was determined that beginning the survey upstream would increase repeatability of subsequent surveys.

Stream habitat in the side channel was dominated by riffles which accounted for half of the total habitat units and nearly 60% of the total side channel length (Table 1). Pools were the second most common habitat type and accounted for only slightly over 12% of the total channel length. The channel was dry in two locations (in the vicinity of construction activities upstream of groundwater influence) covering approximately one-quarter of the channel. Runs and marsh habitat combined accounted for <7% of the channel habitat.

Table 1.Units and length of Elbow Coulee Primary Side Channel habitat types based on USFS Level 2 Stream Inventory, November 2008.

Habitat Type	Number of units	Length (feet)	% of Total
Pool	4	119	12.3
Riffle	9	574	59.6
Run	2	40	4.2
Marsh	1	25	2.6
Dry Channel	2	205	21.3
TOTAL	**18**	**963**	**100**

Longitudinal profile data are presented in Figure 2. In total, 120 depth measurements were collected along the thalweg and depth generally varied between 0.3’ and 0.6’. The mean depth was 0.43’ and the deepest point measured was 1.2’ in a pool near the downstream end of the channel. During this survey (representing base flow conditions) residual depth for the pools varied between 0.5’ and 1’. Mean channel width was 6.3’ and varied between a minimum of 1.5’ and a maximum of 12.5’.

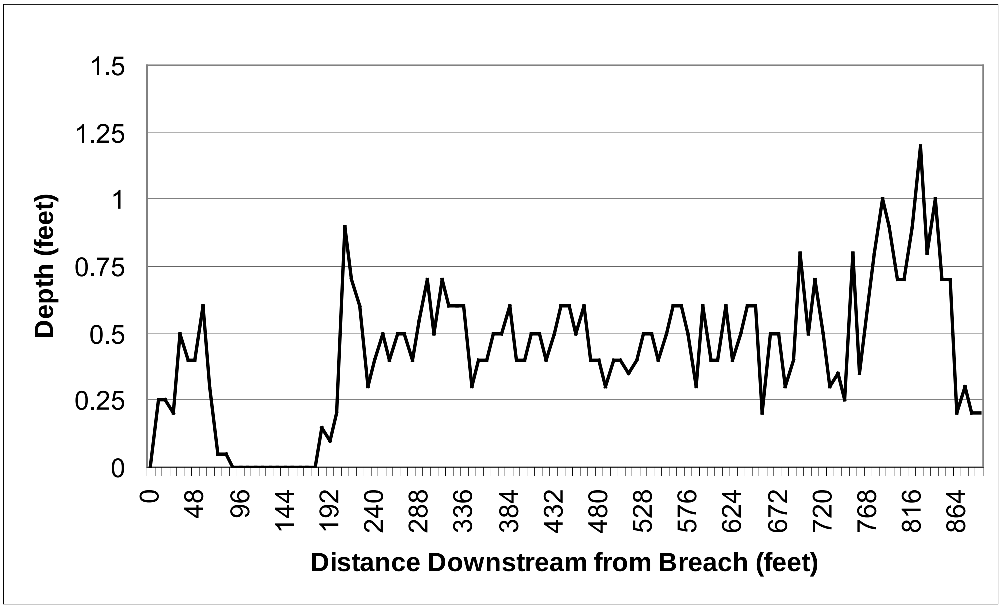

Figure 2. Elbow Coulee Primary Side Channel Longitudinal Profile, 21 November 2008.

Substrate measurements were taken at 25% intervals at cross sectional transects (five at each). Substrate in the channel was dominated by small particles of silt and detritus which were present at nearly 75% of the sampling locations. These particles were commonly associated with pools and lower gradient runs and were especially prominent in the previously dry reach upstream from the groundwater source. The remaining 25% of substrate was comprised of gravels and cobbles associated with the sparse higher gradient sections and at the return drop into the Twisp River. Boulders were only encountered at the uppermost transect across the breach. During this survey, and in subsequent casual observations, it was noted that a 3-12” thick layer of fines overlaid cobble in many locations in the channel and it is noted that these could become exposed after a large flow event through the side channel.

Large wood was present in the side channel (within the bankfull channel) in over half (55%) of the habitat units (10 of 18 units). Wood was dominated by small logs (>6”-12” diameter, >20’ long) which accounted for 27 of the 30 pieces counted (90%). Medium sized wood (>12”- 20” diameter, 35’ long) comprised the remaining 10%. No large logs (>20” diameter) were observed. The majority of the wood was present in the lower half of the channel downstream of the AquaRod deployment site and no wood was present in the upper 200’ of channel that was disturbed during construction.

2.2. Channel Cross Sections

Twelve channel cross sectional profiles were surveyed during 19-21 November 2009. Cross sections were spaced at equal intervals beginning at the upstream entrance sill (breach) to the side channel and moving downstream to the return to the Twisp River (Appendix A). The survey used the EMAP channel survey protocol (Peck et al. 2001) to establish transect locations. However, this survey added an extra transect in the upper section in order to gain more detail of the channel in the construction zone where the channel is not fully defined. Over the length of the channel, cross sections were spaced 88’ apart and photographs were taken at each.

The channel at the breach (XS 1) was dry at the time of the survey and is several feet higher than the channel immediately downstream. The bankfull area in the vicinity cross sections 2 and 3 is relatively wide and the channel in this reach is not very well defined as it was subject to construction impacts. When wetted, the channel flows within a defined channel, but topographically the area is relatively flat and the channel width increases significantly, and expanding into several braided channels, with small increase in discharge. Downstream of cross section 3, the channel gains perennial groundwater and flows within a narrower, yet well defined, bankfull channel. This channel form maintains integrity downstream into the area just upstream of cross section 10, at which point the channel widens until it rejoins the Twisp River downstream of cross section 12. In this reach, the channel is broad at higher discharge, but is difficult to determine because of adjacent, and extensive, emergent vegetation and sediment through which the water flows. The narrowest bankfull channel width area is in the vicinity of cross section 5.

The wetted channel during the survey (completed during groundwater-derived base flow) generally varied from 2’-7’. The widest wetted cross section was at cross section 8 which was over 30’ wide. However, a small hummock braided the channel at this location, thus the entire channel was not wetted.

<u>2.3 Discharge</u>

Discharge characteristics in the primary side channel were monitored through a combination of staff gauge readings, flow estimates, water level monitoring and visual observations. Flow measurements during the first season of monitoring were focused around capturing the period when the side channel was activated by flows entering from the Twisp River. Groundwater input into the channel was assumed to be relatively constant, thus less effort was directed at obtaining flow measurements during the periods when the channel was dominated by groundwater. However, monitoring data obtained in 2009 indicates that more attention is needed to investigate baseflow regime in the side channel and this will be included in future monitoring efforts.

Ten discharge estimates were made in the side channel at the staff gauge and AquaRod deployment pool between 2 December 2008 and 16 June 2009 which led to the development of a rating curve (Figure 3).As expected, flow in the side channel increased with increased depth measured at the staff gauge. A peak discharge of 13.89 c.f.s. was recorded in the side channel on 30 May 2009 that corresponded with a Twisp River flow of 1610 c.f.s. at the downstream USGS gauge (#12448998). The spring runoff in Twisp River peaked on the same day at a flow of 1790-1830 c.f.s, so this discharge measurement in the side channel likely underestimates, to a small degree) the peak flow that actually moved through (albeit only a few hours) the side channel in 2009. Only one discharge measurement was collected at baseflow (no Twisp River input) and resulted in a flow of 0.24 c.f.s. This could be considered primarily groundwater sourced as the Twisp River flow at this point in time was flowing at 123 c.f.s. and not entering the side channel.

The relationship between discharge in the side channel and Twisp River is displayed in Figure 4. The gauge reading of 0.32’ represents the baseflow condition with no direct input of Twisp River (flowing at 123 c.f.s.) water into the side channel.

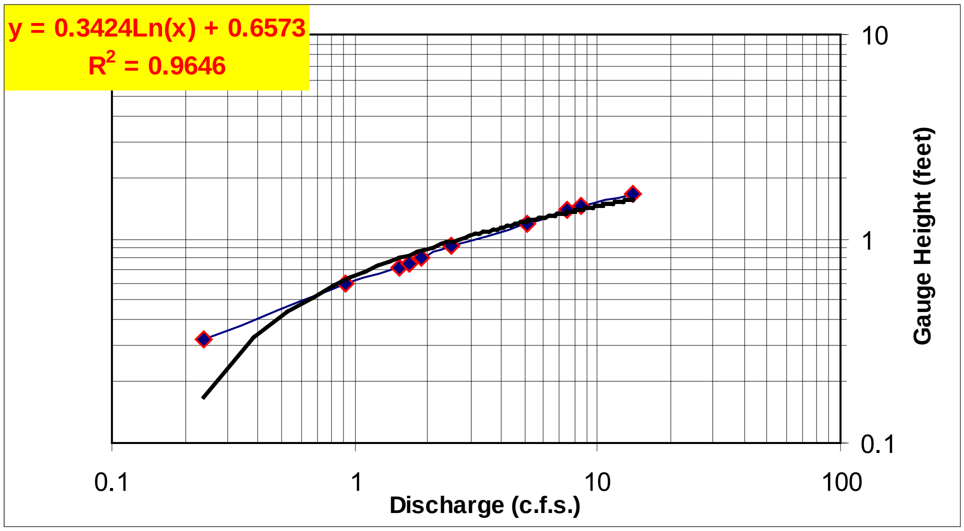

Figure 3. Rating curve for Elbow Coulee primary side channel staff gauge based on ten discharge measurements obtained between 12/08-6/09.

Visual observations at the breach confirmed no visible flow from the Twisp River was entering the side channel at the time and the upper 200’ of channel was dry. All other data were derived during visually confirmed hydrologic connectivity between the Twisp River and the side channel, and, based on these data, discharge in the side channel increases relatively gradually when the Twisp River is flowing between 630-900 c.f.s. Flow in the side channel increased sharply when flow in the Twisp River approached and exceeded 1000 c.f.s. Based on these data, and additional visual observations, it appears that 1000 c.f.s. flowing in the Twisp River corresponds to a bankfull flow in the existing, un-restored portion of the side channel. It is noted, however, that more data and observations are needed to fully support this assertion and more fully develop a relationship between ground and surface water flow in the side channel.

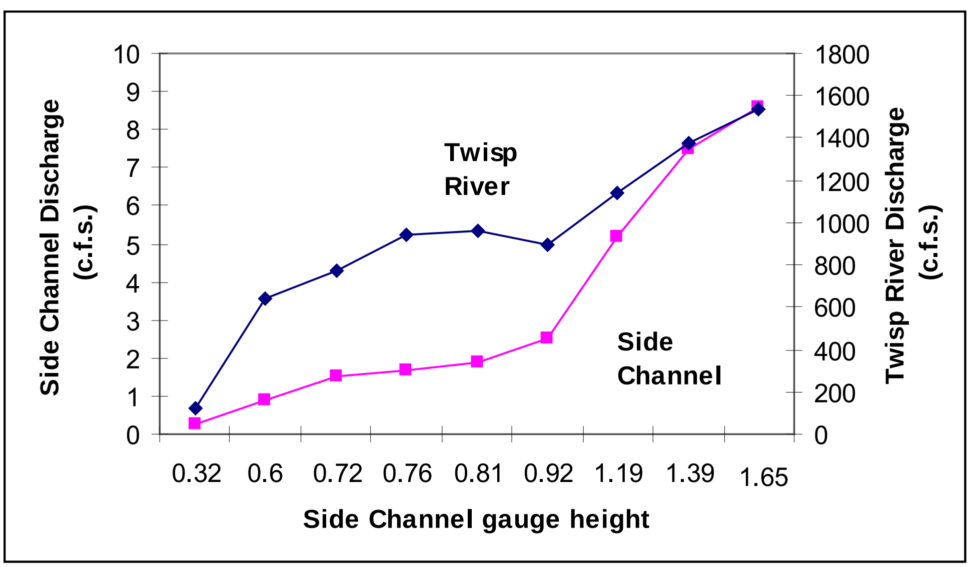

Figure 4. Discharge relationship between Elbow Coulee primary side channel and Twisp River (at USGS gauge #12448998) based on side channel staff gauge readings, 12/08-6/09.

The time period of side channel activation was examined through flow patterns in the Twisp River (Figure 5), side channel water level measurements (figure 6) and visual observations. The primary side channel was engineered to activate when discharge in the Twisp River was between 200-400 c.f.s. (USBR 2008). Based on visual observations on several dates in 2009, flow began to seep through the breach when discharge in the Twisp River reached 250-275 c.f.s. and flow in the side channel became noticeable in the restored (upper) portion of the channel when flows reached about 300 c.f.s. Although at this discharge flow is moving through the breach rather than over it, 300 c.f.s. appears to be the approximate discharge required to activate the side channel.

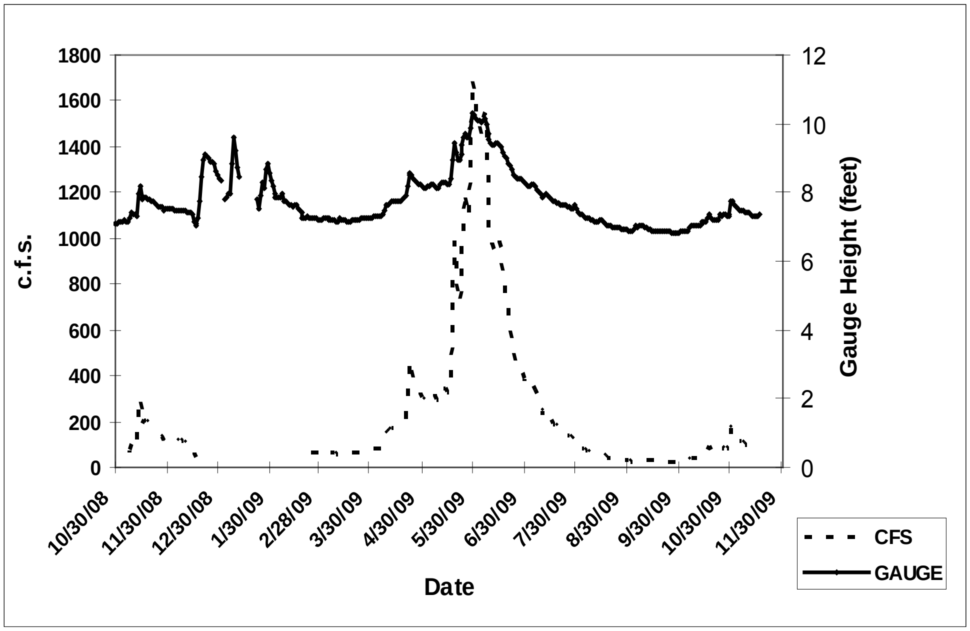

Figure 5. Twisp River discharge and gauge height at USGS station #12448998, 10/08-11/09. Icing of monitoring instruments occurs during winter at this station and is responsible for data gaps in December and January.

On 21 May 2009, flow over the “sill rock” in the breach cut, considered to be the base elevation post-construction, was observed and measured at 1.5 mm deep. The Twisp River discharge at this point in time was 637 c.f.s., thus it is estimated that a flow of approximately 580-600 c.f.s. in the Twisp River is sufficient to crest the sill rock. This flow also appears to correspond to the point on the line in Figure 4 (between 0.92 and 1.19 side channel gauge height) where flow increases significantly in the side channel. Maximum water depth above the sill rock was measured at 1.1’ on 30 May 2009 which coincides with peak spring flow in the Twisp River in 2009.

Water level in the side channel was measured hourly at the upper staff gauge pool with an AM&C AquaRod water level monitor between 30 September 2008 and 16 November 2009 (and is currently on-going). These data indicate that four flow events in the side channel occurred during the monitoring period (figure 6). [Note: A fifth, and short duration (<8 hours), event was recorded on 22 October 2008, but it is believed that this is a result of an AquaRod recording error as the Twisp River was flowing <100 c.f.s.]. AquaRod water level data is generally supported by both USGS gauge data (for flows >300c.f.s. which activate the side channel) and visual observations. However, during the two winter flow events ice was noted as affecting the USGS gauge and thus there is some disagreement between specific discharge data from the

USGS gauge and AquaRod measurements. In these two instances, it is thought that the AquaRod was measuring water level accurately and that the rises in water level associated with side channel activation did occur.

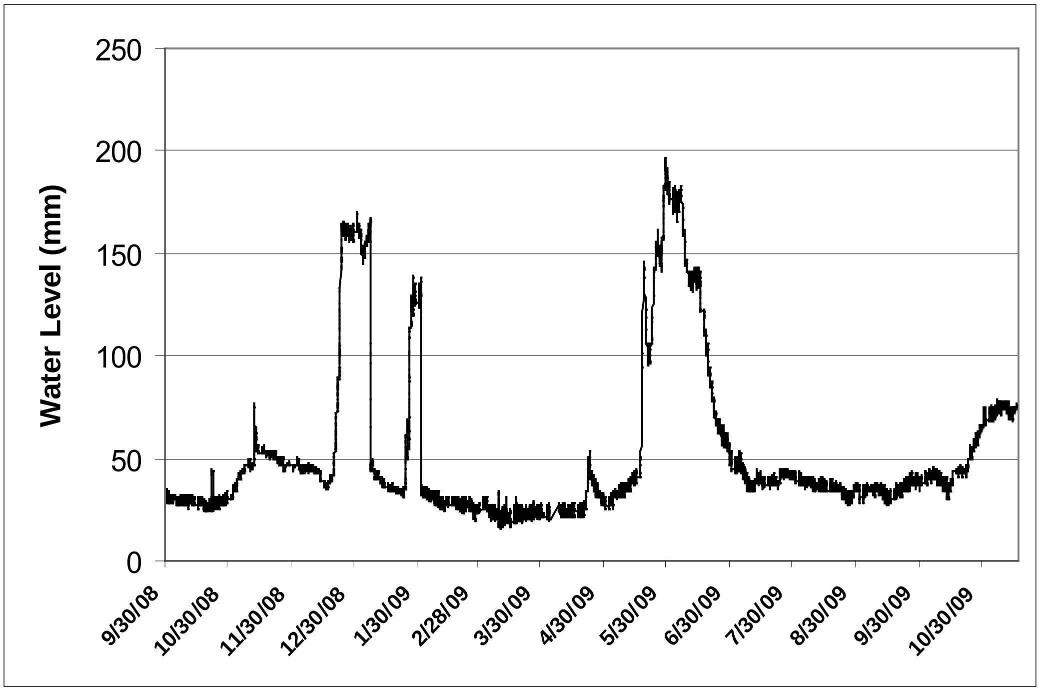

Figure 6. Water level in the Elbow Coulee primary side channel, 9/08-11/09.

The first side channel activation post-construction was brief and occurred between 12-13 November 2008 (Table 2) and peak Twisp River discharge during this period was 536 c.f.s. The next two events occurred during the winter and were both of longer duration and of higher discharge than the first (Table 2) with Twisp River flows of up to 650 c.f.s. recorded. Yet, during both of these events discharge in the side channel was less than 2 c.f.s. It is noted, however, that the Twisp River gauge was affected by ice during these events and may not be a fully accurate representation of flow patterns in the river.

Table 2. Flow activation schedule for Elbow Coulee Primary Side Channel, 10/08-11/09.

Date Activated	Date Deactivated	Peak Twisp Flow	# days active
11/12/08	11/13/08	536 c.f.s.	2
12/20/08	1/7/09	758 c.f.s.	19
1/24/09	1/31/09	642 c.f.s.	8
4/21/09	7/7/09	1790 c.f.s.	78
TOTAL	n/a	n/a	**107**

Overall during the monitoring period, the side channel was activated by Twisp River flow for 107 days with the spring runoff event accounting for nearly 75% of this time. Spring side channel activation was designed to coincide with the steelhead spawning window in the Twisp River and these data indicate that in 2009 it was available habitat for migrating or spawning adult steelhead. For reference purposes only, if the 2008 hydrograph is taken into consideration, the side channel would have been activated (based on a discharge of 300 c.f.s. in the Twisp River, as the side channel had not been re-connected at this time) between 5 May and 12 July, a total of 69 days. This connection is 9 days fewer than what was observed, but it still coincides with adult steelhead migration and spawning in the Twisp River.

2.4 Water Temperature

Water temperature in the primary side channel and in the Twisp River adjacent to the side channel was continuously monitored on an hourly basis from 3 December 2008 to 16 November 2009 (and is presently on-going). To ensure data accuracy, temperature loggers (both Onset Temp Pro V2 and Onset Tidbits were used) were submitted to pre- and post-deployment accuracy checks (ODEQ, 200X). Unfortunately, the temperature logger deployed in the Twisp River was lost or stolen during the summer of 2009 and thus data are unavailable for that location after 9 April 2009.

Daily maximum, minimum and average water temperature data for the primary side channel are presented in figures 7 and 8, respectively. Generally, temperatures in both locations were coldest from December through March and the Twisp River remained near 0 °C for two months between mid-December through mid-February. During this period, the side channel was warmer and fluctuated between 2-5 °C. A noticeable increase in temperature occurred in both locations beginning around early April and this increase continued into September in the side channel. The side channel had a maximum temperature of 11.87 °C on 2 September and consistently averaged around 10°C for much of July, August and September. Unfortunately, summer temperature data are missing from the Twisp River location, but it is believed that summer maximums were significantly higher than in the side channel. This is supported by data from a temperature monitoring location in the Twisp River above Buttermilk Creek (approximately 5 RM upstream of Elbow Coulee) that experienced a maximum temperature of 17.63 °C on 28 July. Additionally, a monitoring site at the USGS stream gauge approximately 4 RM downstream of Elbow Coulee had a maximum temperature of 20.62 °C on 12 August which is nearly twice the maximum temperature recorded in the side channel. Beginning around early October, the side channel temperature began its seasonal decline to wintertime lows and this trend was likely occurring in the Twisp River as well.

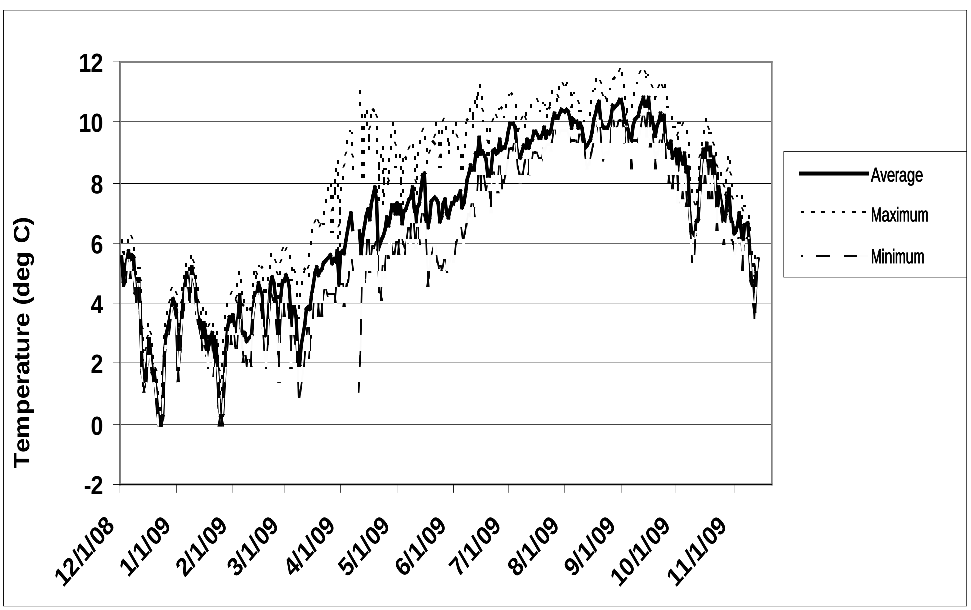

Figure 7. Maximum, minimum and average water temperature from the Elbow Coulee primary side channel, 12/08 – 11/09.

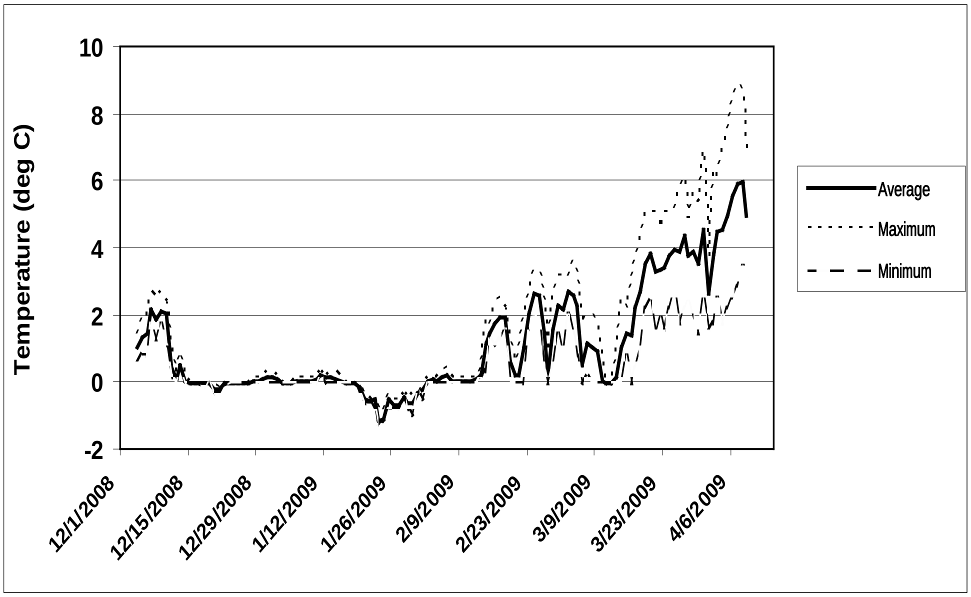

Figure 8. Maximum, minimum and average water temperature from the Twisp River adjacent to the Elbow Coulee side channel, 12/08 – 4/09.

A comparison of the 7 day average temperature between the primary side channel and adjacent Twisp River is made for the period that data was available from both locations (Figure 9). These data illustrate the difference in temperature regimes between the two locations during the cold portion of the year with the side channel commonly 2-4° C warmer than the adjacent Twisp River. As noted above, the Twisp River averaged near 0° C for nearly two months while the side channel average was consistently above 2° C during this period. Although the side channel is largely spring fed during this period of record, fluctuations in side channel average temperature were recorded and could be a response to changes in the ambient air temperature as well as flow entering the channel from the Twisp River which likely occurred on two occasions between 20 December and 31 January. These events may be responsible for the sharp decreases in average temperature observed during the first half of the run.

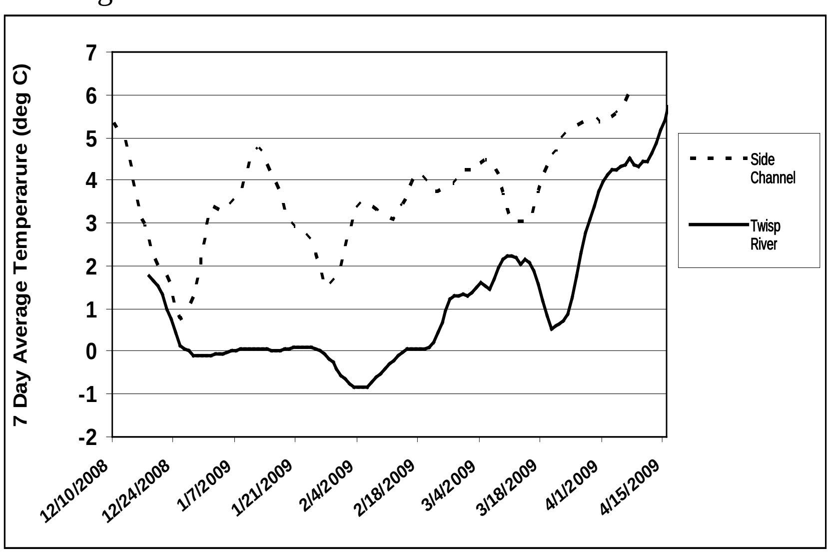

Figure 9. 7-day average temperature for the Elbow Coulee primary side channel and the adjacent Twisp River, 12/08-4/09.

Although data are unavailable for comparison, it is expected that beyond April the average in the Twisp River climbed to summertime highs that exceeded the side channel average by as much as 4-8° C. Additional data collection from both locations will likely confirm this occurrence on an annual basis.

2.5 Fish Surveys

A fish population survey, via electrofishing, was conducted in the primary side channel on 3 December 2008. Additional snorkel and visual surveys were conducted on four occasions in June and July 2009 when the restored upper channel reach was activated with flow from the Twisp River. The primary survey involved three-pass removal electrofishing of the entire groundwater-derived baseflow wetted channel that covers a distance of approximately 700'. A USGS crew assisted USBR in survey work and the majority of fish captured were PIT tagged for possible detection within the Methow subbasin.

In total, 41 fish representing three species were captured and identified during electrofishing (Table 2). Fish were captured along the entire length of the wetted channel and were most commonly observed in the deeper portions of the channel in pools. The species list could include a fourth member if any of the unidentified *Oncorhynchus* were *O. clarki lewisi* (cutthroat trout), yet this was not determined. When species and size (age) classes are combined, the three pass depletion lies within an estimated coefficient of variation of 25%. A more precise population estimate could have been obtained with a fourth pass, but logistical considerations during sampling prevented this from occurring.

Nearly half of the fish sampled were unidentified *Oncorhynchus* trout, most likely rainbow/steelhead trout. Including these fish with the positively identified *O. mykiss* would increase the percentage of this species to over 80% of the sample. *O. mykiss* (including unidentified trout) ranged in size from 37-150 mm in length. Based on their silver coloration and size (>140 mm), several of the *O. mykiss* were identified as steelhead smolt, so it is likely that the channel contained both resident and anadromous forms of this species. Several of these fish were PIT tagged and at least one of them moved downstream and was detected in the lower Twisp River in may 2009.

Table 2. Fish survey species data, Elbow Coulee Primary Side Channel, 3 December 2008.

Species	Pass 1	Pass 2	Pass 3	Total	%
Chinook salmon (*Oncorhynchus tshawytscha)*	1	0	0	1	2.4
Unidentified *Oncorhynchus* (<80mm)	11	5	2	18	43.9
Rainbow/steelhead trout (*Oncorhynchus mykiss*)	9	4	3	16	39.1
Brook trout (*Salvelinus fontinalis*)	3	2	1	6	14.6
TOTAL (N=41)	24	11	6	41	100

Brook trout were the second most abundant species encountered, with six fish ranging between 105-130 mm sampled during the three passes. At least three of these were ripe males who expressed milt during handling. One juvenile Chinook salmon (*Oncorhynchus tshawytscha*, length = 72 mm) was captured during sampling and, based on the location of documented spawning areas, this fish was likely an endangered spring Chinook salmon (figure 10).

Figure 10. Young-of-the-year Chinook salmon, *Oncorhynchus tshawytscha*, captured in the Elbow Coulee primary side channel, 3 December 2008.

The uppermost reach of the channel (~70 meters immediately downstream of the breach) was snorkeled on 15 June 2009 to determine fish presence in the newly established portion of the side channel. During this survey, 16 young-of-the-year Chinook salmon were observed and photographed. These fish were estimated to be between 40-65 mm in length. Additionally, one 130 mm *O. mykiss* was observed along with four larval *Cottus* sp. (Figure 11). After this survey, water in this reach of the side channel became too shallow and silty to snorkel effectively.

Figure 11. Larval *Cottus* sp. (approximately 25 mm) observed in the Elbow Coulee Primary Side Channel, 15 June 2009.

However, five subsequent visual surveys for fish presence occurred on 23, 26, 30 June and 2 and 9 July (flow through the breach and into the channel effectively ceased around 7 July, see results in section 2.4). Between 8 and 15 young-of-the-year Chinook and *O.mykiss* combined were observed in the channel during each of these visits, although their number decreased to only 5 fish on 9 July, just prior to cessation of input flow. These fish likely became stranded in the upstream pool in the channel, but this was not verified. It is likely that at least some fish moved downstream into the perennial section of the side channel prior to upstream disconnection. Temperatures during snorkeling and visual surveys ranged between 7-13° C.

<u>2.6 Photo Monitoring</u>

In total, 23 photopoints were established in the side channel. These photopoints cover a variety of habitat features and include all twelve channel cross section locations. Several photopoints are located around the breach and upper section where the channel is less well defined. Photos were taken at a variety of flow levels (figures 12 and 13) and all are documented in the photo journal for the site.

<u>3.0 Discussion</u>

The Elbow Coulee primary side channel was designed and engineered largely to re-establish connectivity between side channel floodplain habitat and the mainstem Twisp River in order to increase habitat complexity and provide habitat for ESA listed salmonids. Monitoring results obtained in 2008 and 2009 indicate that this goal has largely been met and it is likely that this project will provide habitat for spring chinook salmon, steelhead, and possibly bull trout for years to come. Indeed, the project was completed in the fall of 2008 and soon after the side channel was activated by flow from the Twisp River for the first time in over 50 years.

Prior to the first side channel activation event, discharge monitoring and visual observations over several years (J. Molesworth, USBR, personal communication) revealed that groundwater influence into the side channel was perennial with a discharge of approximately 0.24 c.f.s. Yet, water level data also indicate that groundwater influence in the side channel is not constant and may be influenced by seasonal factors such as irrigation operations, precipitation, riparian transpiration rates, soil dynamics, etc. Furthermore, groundwater discharge may be influenced by the location within the side channel, as it appears that groundwater may be infiltrating into the side channel along a continuum rather than from a single point source. Thus, more flow may exist near the terminus of the side channel as opposed to the upper staff gauge pool where flow measurements have been concentrated. Additional discharge measurements at multiple locations during groundwater only periods are needed to fully assess the groundwater patterns in the side channel as it is possible that the average annual groundwater discharge is significantly different from the 0.24 c.f.s. measured in 2008.

Importantly, the perennial nature of the side channel groundwater provides at least 700'of fish bearing habitat as witnessed by the collection of numerous fish, including spring Chinook salmon and steelhead, along the entire length of the baseflow wetted channel. The perennial groundwater provides year-round connectivity to the Twisp River and juvenile fish are certainly using the side channel for rearing. The side channel is dominated by shallow riffles, yet pools are providing deeper habitat throughout the wetted channel.

Figure 12. Elbow Coulee primary side channel near peak channel activation flow, 30 May 2009. Twisp River discharge at time of photo was 1720 c.f.s. Young-of-the-year Chinook salmon were observed in the pool in the middle of the photo two weeks later.

Figure 13. Elbow Coulee primary side channel nearly disconnected from the Twisp River, 7 July 2009. Twisp River discharge at time of photo was 303 c.f.s.

Brook trout were present in the side channel prior to any activation events, and it is believed that they have been using the side channel for many years. Brook trout have also been observed in the adjacent ponds which also have seasonal access to the Twisp River. Several of the brook trout captured were ripe males who were possibly attempting to spawn in the side channel. No redds were observed during the survey, but brook trout are known to spawn over the variety of substrates currently present in the side channel. The brook trout captured were large enough to be considered possible predators of young-of-the-year fish.

The side channel lies within a dense and complex riparian forest that is contributing a significant amount of wood to the stream channel. While this wood, derived primarily from willow and alder, is mostly <12" in diameter, it is responsible for the creation of several fish bearing pools and pockets and appears to be contributing to overall habitat complexity. Larger cottonwoods are present along the channel and an active beaver community has been observed working on several of these trees. It is assumed that over time some of these larger trees will make their way into the side channel where they would then have the possibility of recruitment into the Twisp River during a flood event.

Post-construction observations at the breach indicate that a Twisp River discharge of approximately 250-275 c.f.s. (measured at the USGS gauge 4 RM downstream) is sufficient to activate slight flow through the breach and flow begins to connect with the groundwater channel when flows reach approximately 300 c.f.s. All of this flow is through the breach and the exact flow where upstream connectivity becomes established for fish passage is not fully known (i.e. it is not known if fish can and will pass through the breach). Flows greater than approximately 580 c.f.s. are sufficient to crest the rock sill in the breach and fish would have uninhibited, albeit shallow, passage into the upstream end of the side channel at this flow. Once in the side channel, fish would have the ability to move downstream within the side channel and also back into the Twisp River at the terminus of the side channel. Thus, flow in excess of 600 c.f.s. should be sufficient to allow passage for all life stages of fish.

During the first year post-construction, the side channel was activated by the Twisp River on four occasions for a total of 107 days. Three of these were winter events of relatively low discharge and duration and, hence, significance related to influencing the dynamics of the side channel. Icing of instruments was, and will likely continue to be, a significant factor affecting the ability to continuously measure discharge in both the side channel and Twisp River and thus visual observation during suspected activation events is warranted. These winter events likely afforded little opportunity for fish passage.

The spring runoff activation event (based on 300 c.f.s. in the Twisp River) in 2009 lasted for 78 days and was entirely dependant (obviously) on the Twisp River hydrograph. Based on USGS gauge data, the 1790-1830 c.f.s. peak flow in 2009 was approximately a 1.5 year event (2 year event = 2,470 c.f.s.). Thus, the side channel was able to capture this flow for over 2 months. Based on USGS daily average flow since 1974, the side channel could be expected to be activated for 98 days during the "average" spring runoff period (again, based on 300 c.f.s.). While the side channel in 2009 was activated for 20 days less than this in 2009, this is not surprising given the magnitude of the hydrograph. It does not appear the flows observed in 2009 were sufficient to provide a significant amount of scouring in the side channel. If this is the case, then flows in excess of a two year event will likely be needed in order to flush the large amounts of fine sediment that have accumulated in the side channel.

Peak flow in the side channel was 13 c.f.s. during the spring runoff and discharge into the side channel increased sharply when Twisp River discharge exceeded ~575 c.f.s. As a result, habitat availability likely increased dramatically during this period, although only for a relatively short duration.

While rearing sized fish were observed in the side channel prior to re-connection, the presence of young-of-the-year fish, including ESA listed salmonids, in the uppermost pool in the side channel is strong evidence that these fish gained access to the side channel through the newly constricted breach. Although it is plausible that 40 mm salmonids could have swum up the side channel from the bottom, this explanation is untenable when considering the presence of larval sculpin that lack the swimming ability to move upstream through the side channel. Thus, it is concluded that fish, either volitionally or passively, gained access to the side channel during the first activation event post-emergence and resided in the channel until it became disconnected from the Twisp River at the upstream end. The period of this residency for these fish is estimated at several weeks to months and possibly longer for fish that select to remain in the groundwater influenced portion of the channel.

Rainbow trout/steelhead were the most numerous fish sampled in the groundwater (baseflow) channel, and although other species were present, including chinook salmon, it is likely that the restored side channel may provide the most benefits to this species. Yet, additional monitoring will be required to fully asses this.

The fate of the fish that entered the side channel is unknown. Based on numbers of fish observed at any one time (<20 from the uppermost pool) throughout channel activation during spring runoff, some likely moved downstream into the perennial portion of the channel and thus gained access to the perennial portion of the channel with access to the Twisp River. Five chinook and steelhead were observed in the uppermost pool during the period when activation was ceasing in early July and these fish likely became isolated in the top pool. Once isolated these fish probably did not survive and probably succumbed to predation, starvation or lethal high temperatures.

With the possible exception of brook trout, spawning habitat for salmonids is very limited in the side channel and it is unlikely that successful spawning will occur in the side channel in its present configuration. There is a high amount of fine silt throughout the channel, and although this material overlays potential spawning substrates (cobble and gravel) in some locations, it appears that a significant flow event would be required to transport this material off these substrates before some type of spawning potential develops in the side channel.

The temperature regime in the side channel appears to be one that would be favorable for fish use during many portions of the year. The side channel was both warmer in winter and cooler in summer when compared to the adjacent Twisp River. This difference was as much as 3-5 °C in winter and likely as much or more during summer. Juvenile fish rearing in the side channel may experience a thermal regime that favors growth, hence, survival.

Monitoring goals in this first year were focused around an initial investigation into the physical and biological aspects of the side channel through the development of a baseline dataset on which future monitoring can be based. These goals were largely met, yet additional monitoring will be necessary to develop a broad enough understanding of the functionality of the restored habitat in order to adaptively manage the project to increase functionality and overall effectiveness.

4.0 Monitoring Recommendations

1. Continue to monitor the side channel at a level similar to that in 2008-2009, including flow (discharge and water level), temperature, fish use, and photopoints. Repeat channel cross sections in five years or when a significant (>10-20 year flood) flow event occurs.

2. Investigate groundwater baseflow in the side channel through discharge measurements when the channel is not activated (summer-spring).

3. Develop a more specific sediment monitoring plan to investigate sediment dynamics. Methods could include additional pebble counts and/or scour and fill chains.

4. Check water temperature thermographs and water level monitors more frequently (i.e. every two months) to insure that they are present and functional.

5. Consider re-vegetation of primary side channel area influenced by construction activities. Although natural plant regeneration is likely, willow sprigs placed in uppermost reach of the side channel would have a high probability of survival without significant maintenance and could contribute cover and nutrient input sooner than plants germinating from other sources.

5.0 Literature Cited

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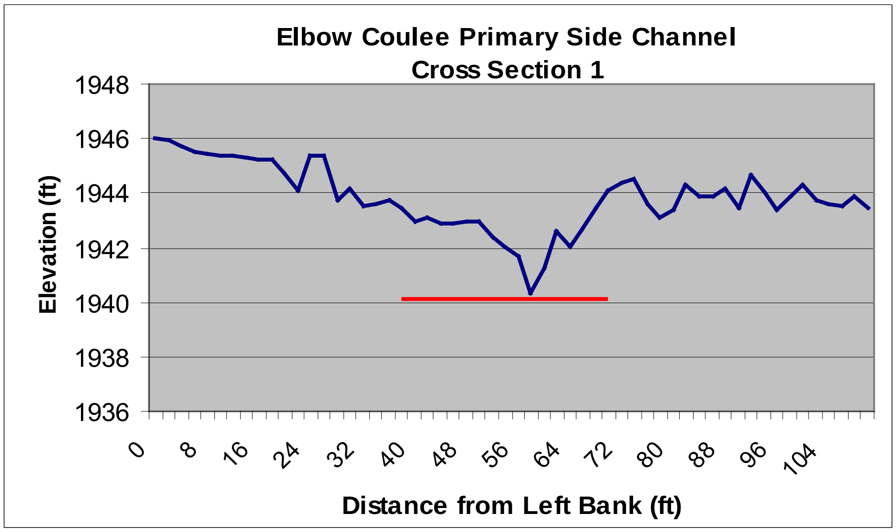
Peck, D. V., J. M. Lazorchak, and D. J. Klemm. 2001. Environmental monitoring and assessment program—surface waters: western pilot study field operations manual for wadeable streams. Draft Report. EPA/XXX/X-XX/XXX, U.S. Environmental Protection Agency, Washington.

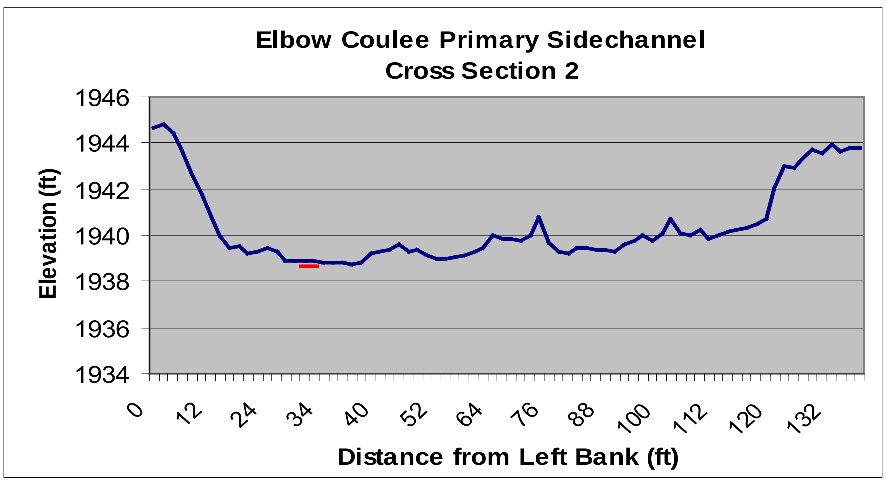
USBR. 2008. Elbow Floodplain Reconnection and Channel Restoration Project. Construction Narrative, March 2008 draft. 8 p.

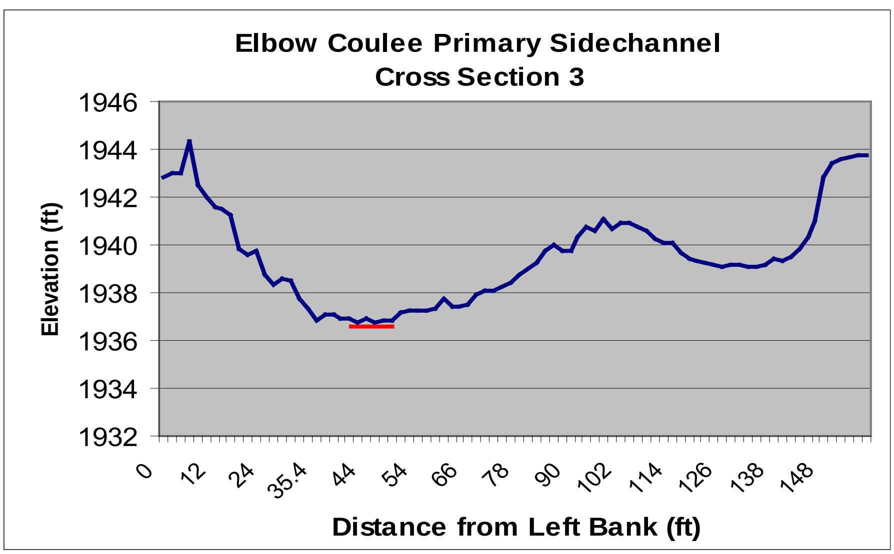
USFS. 2006. Stream Inventory Handbook, Level 2, Version 2.6. USFS Region 6.

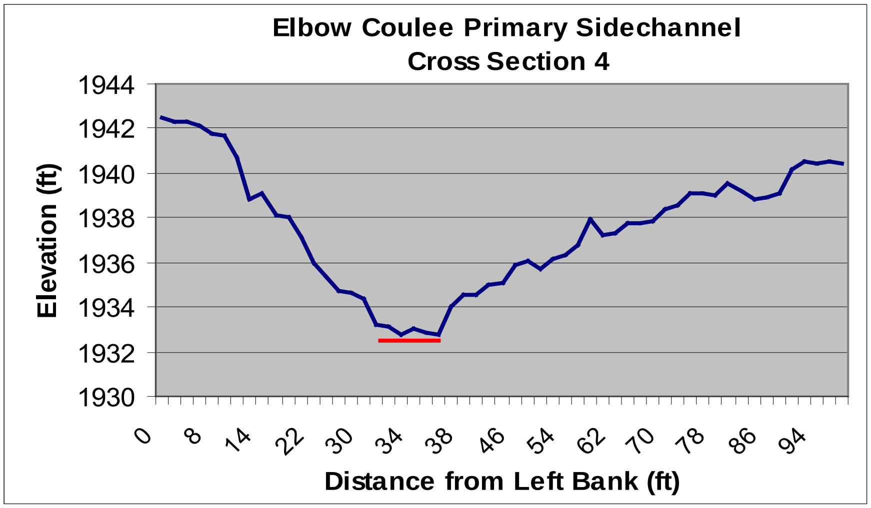
APPENDIX A. PRIMARY SIDE CHANNEL CROSS SECTIONS

(Note: Cross section 1 is upstream beach and subsequent sections are downstream. Sections move from left bank to right bank and red lines demark approximate wetted channel location during survey, with the exception of cross section 1 where the red line denotes the restored breach. Variations in scale are present in both X and Y-axes.)

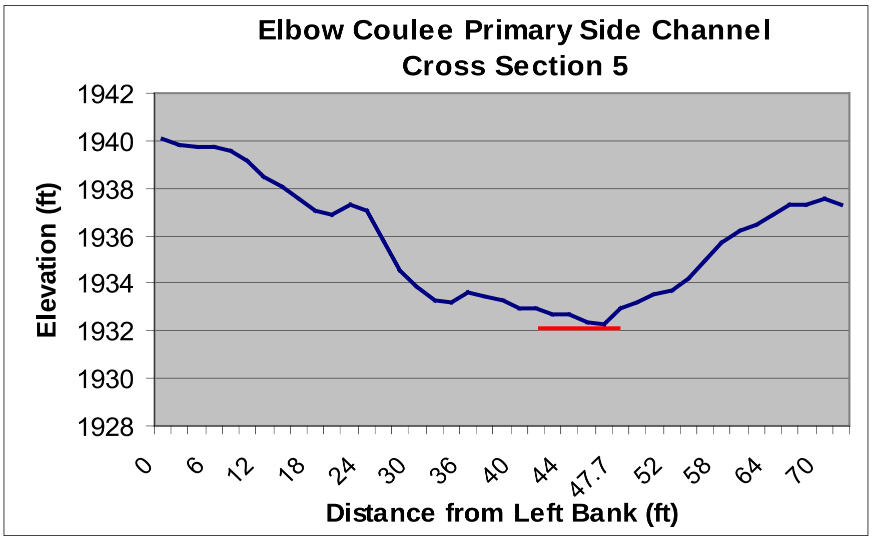




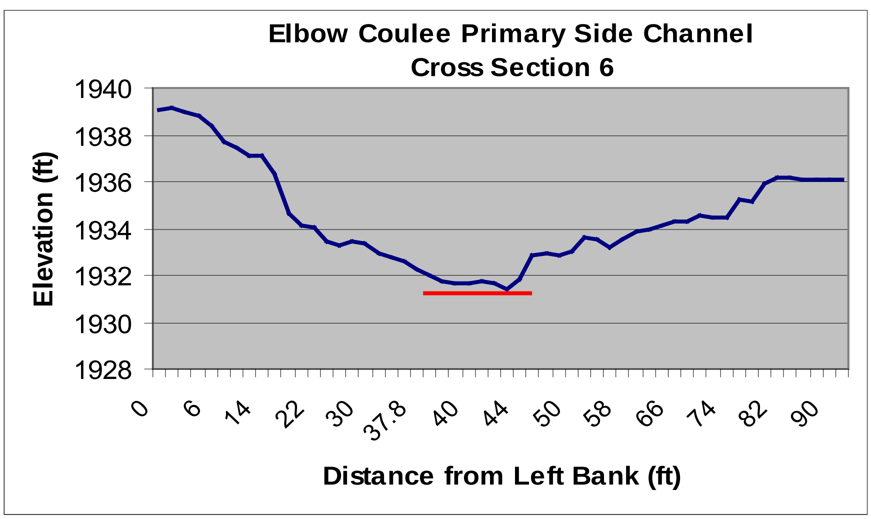




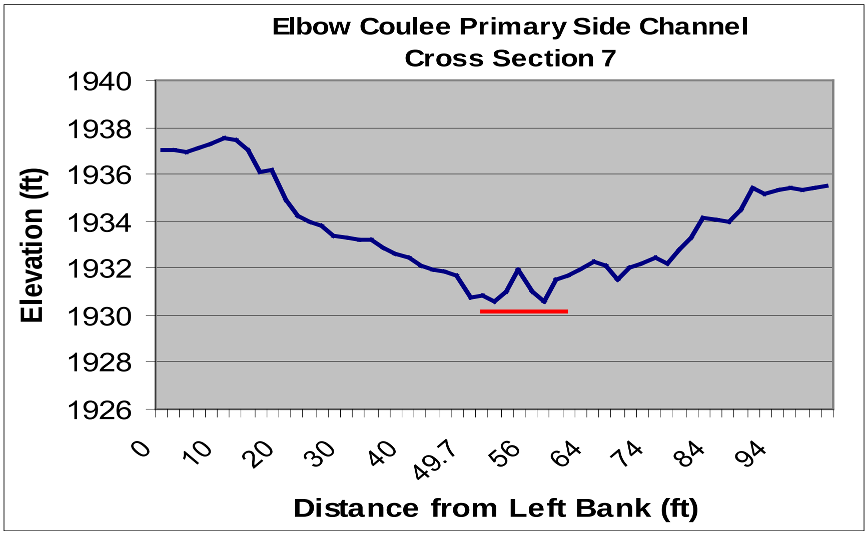
Elbow Coulee Primary Sidechannel
Cross Section 4
Elevation (ft)
1944
1942
1940
1938
1936
1934
1932
1930
0
8
14
22
30
34
38
46
54
62
70
78
86
94
Distance from Left Bank (ft)

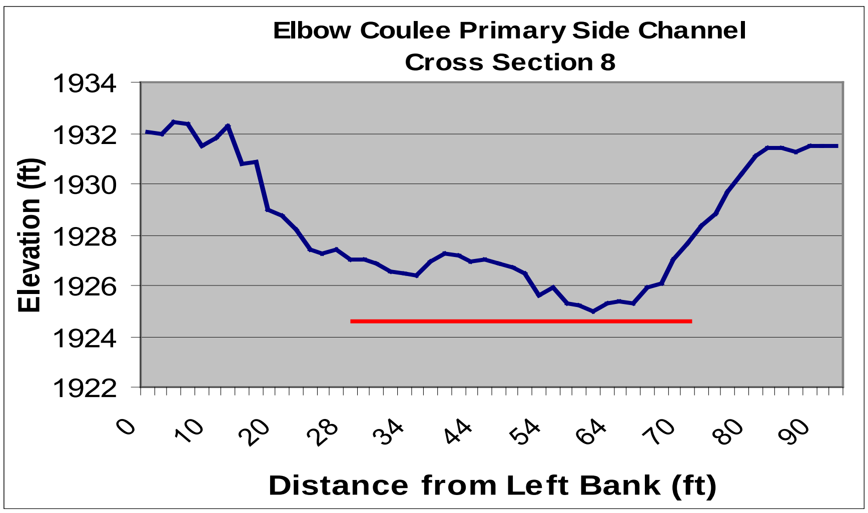


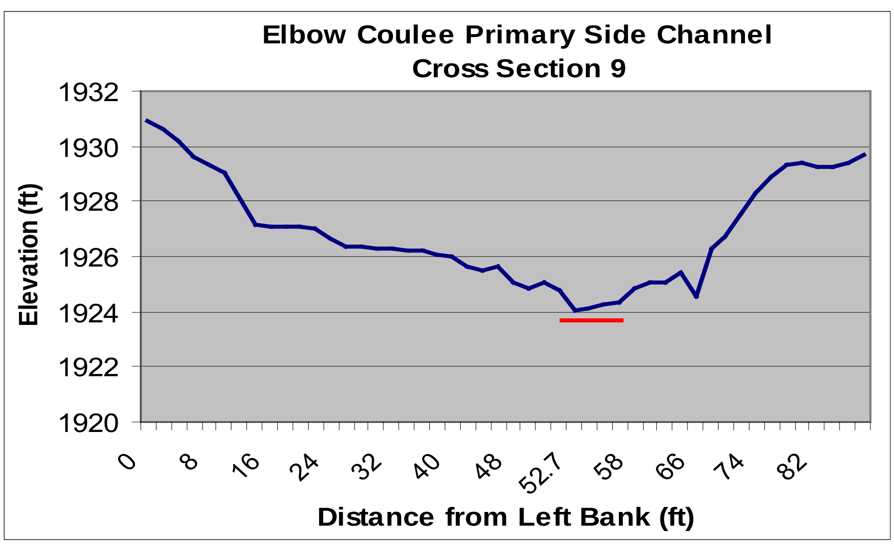
Elbow Coulee Primary Side Channel
Cross Section 5
Elevation (ft)
1942
1940
1938
1936
1934
1932
1930
1928
0
6
12
18
24
30
36
40
44
47.7
52
58
64
70
Distance from Left Bank (ft)

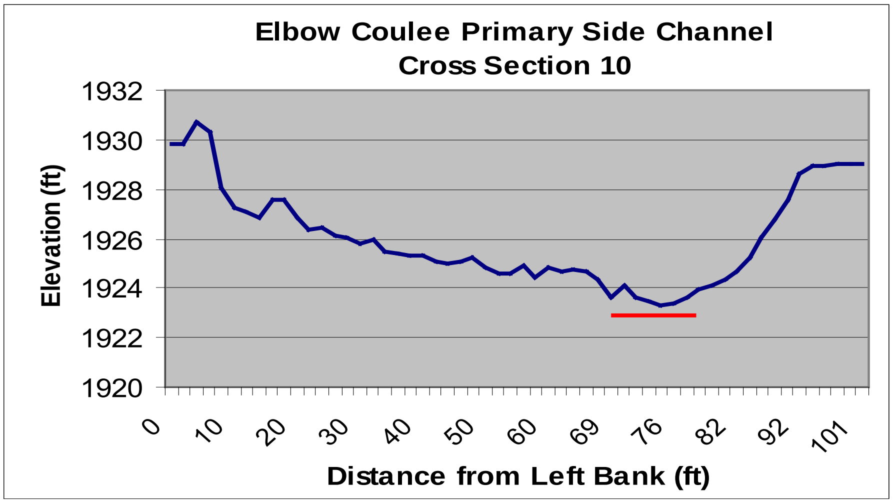


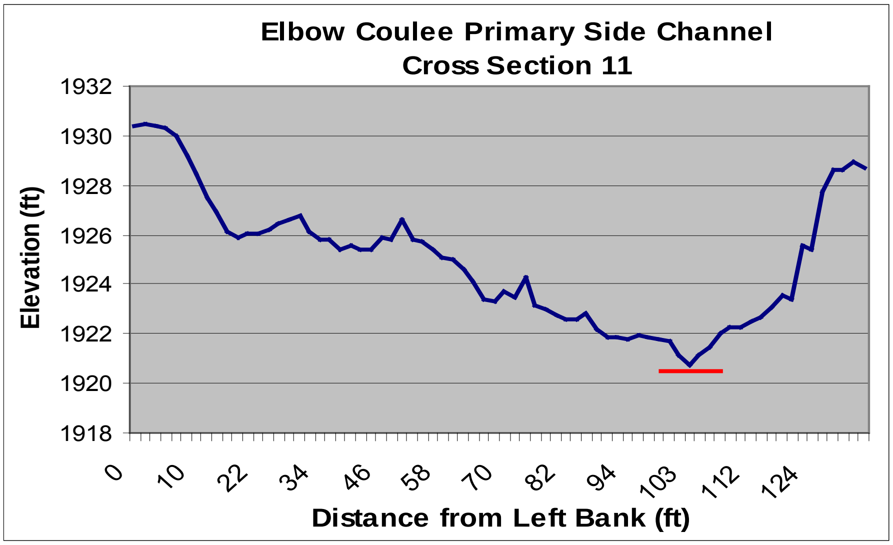
Elbow Coulee Primary Side Channel
Cross Section 6
Elevation (ft)
1940
1938
1936
1934
1932
1930
1928
0
6
14
22
30
37.8
40
44
50
58
66
74
82
90
Distance from Left Bank (ft)

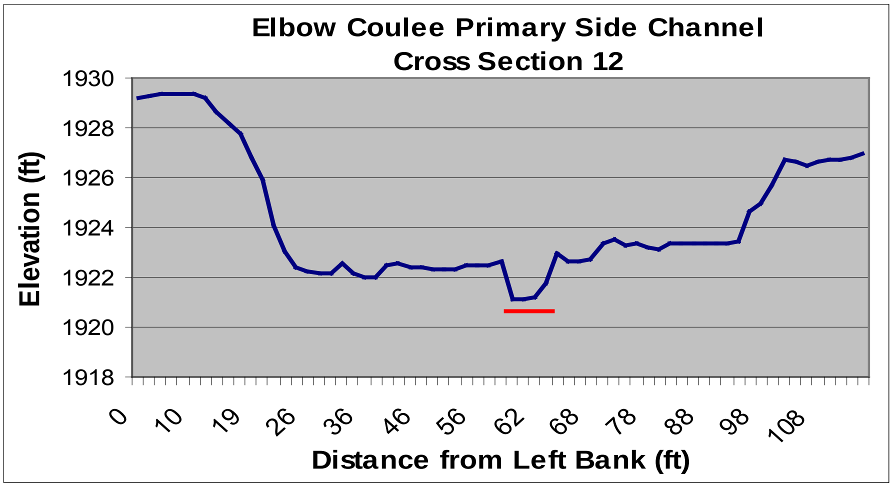

Elbow Coulee Primary Side Channel
Cross Section 7
Elevation (ft)
1940
1938
1936
1934
1932
1930
1928
1926
0
10
20
30
40
49.7
56
64
74
84
94
Distance from Left Bank (ft)


Elbow Coulee Primary Side Channel
Cross Section 8
Elevation (ft)
1934
1932
1930
1928
1926
1924
1922
0
10
20
28
34
44
54
64
70
80
90
Distance from Left Bank (ft)


Elbow Coulee Primary Side Channel
Cross Section 9
Elevation (ft)
1932
1930
1928
1926
1924
1922
1920
0
8
16
24
32
40
48
52.7
58
66
74
82
Distance from Left Bank (ft)


Elbow Coulee Primary Side Channel
Cross Section 10
Elevation (ft)
1932
1930
1928
1926
1924
1922
1920
0
10
20
30
40
50
60
69
76
82
92
101
Distance from Left Bank (ft)


Elbow Coulee Primary Side Channel
Cross Section 11
Elevation (ft)
1932
1930
1928
1926
1924
1922
1920
1918
0
10
22
34
46
58
70
82
94
103
112
124
Distance from Left Bank (ft)


Elbow Coulee Primary Side Channel
Cross Section 12
Elevation (ft)
1930
1928
1926
1924
1922
1920
1918
0
10
19
26
36
46
56
62
68
78
88
98
108
Distance from Left Bank (ft)

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ELBOW COULEE FLOODPLAIN RECONNECTION AND SIDE CHANNEL RESTORATION PROJECT

2010 Post-Project Assessment Report

Executive Summary

In September 2008, the Elbow Coulee Floodplain Reconnection and Side Channel Restoration Project was implemented in order to: 1) re-establish a primary side channel to the Twisp River at RM 6.6; 2) increase habitat complexity and large woody debris recruitment potential; 3) reduce stream energy to increase the potential for accumulation of sediment and wood in the Twisp River; and 4) increase habitat for native fish, especially rearing-age salmonids. Specifically, a rock breach was constructed in an existing dike at the upper entrance to the primary side channel (Figure 1). The sill (breach) functions as a grade control structure and permits flow to enter the side channel. The sill was designed to activate the side channel when flows in the Twisp River (based on USGS gauge #12448998 data) reached 200-400 c.f.s.

Post-project assessment of the restored side channel and associated floodplain is necessary to gauge project success at meeting goals and to form the basis of adaptive management. This assessment will consist of both quantitative and visual examinations of side channel form and function. Specifically, monitoring was conducted to assess the: 1) response of the primary side channel geomorphic configuration to restoration activities designed to create long-term habitat benefits; 2) response of physical characteristics (primarily discharge and water temperature) and the biological community to habitat restoration and the newly re-established aquatic habitats within the primary side channel; and 3) identify steps needed to adaptively manage the project in order to maximize project success.

Two years of monitoring was detailed in a 2008-2009 post-project assessment report (Crandall 2009). Overall, the project had functioned to allow rearing of juvenile spring Chinook salmon and steelhead both of which were target species. Both of these species were observed in the primary side channel in 2009. Additionally, the side channel was activated when discharge in the Twisp River was approximately 300 c.f.s., yet significant flow did not enter the channel until the sill rock was overtopped at a Twisp River flow of approximately 575 c.f.s.

Fall 2009- Spring 2010 Monitoring Summary

The primary side channel functioned very similar to what was observed through previous monitoring efforts and has been functioning in close accordance to the goals of the restoration actions undertaken at the site. For the second consecutive year post-construction, juvenile spring Chinook salmon were observed in the side channel following activation flows from the Twisp River. The monitoring described below is limited to the period from November 2009 through May 2010. Previous monitoring results are presented in Crandall (2009).

Flow Monitoring

Flow monitoring during this period focused on increasing the primary side channel discharge dataset to further define the staff gauge rating curve developed in 2008-2009. Additionally, water level in the primary side channel was recorded continuously with an electronic water level logger identical to that used in previous monitoring. This monitoring continues to elucidate the groundwater regime present in the side channel.

Discharge in the primary side channel was measured between > 0.1 and 10 cubic feet per second during the period 19 November 2009 to 30 May 2010 (Figure 1). Based on both flow monitoring and qualitative visual observations, it appears groundwater inflow into the upstream portion of the side channel is <0.1 c.f.s. There is a sharp increase in side channel flow when staff gauge height >1.0 which corresponds to flow from the Twisp River overtopping the rock sill in the breach. Below this gauge height, flow in the side channel ranges between 0.1 and 2 c.f.s.

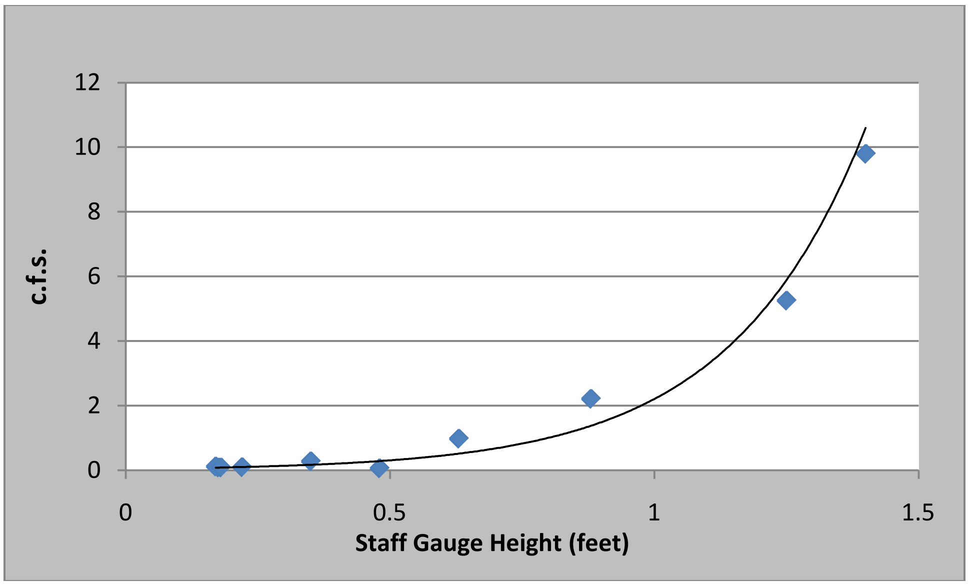

Figure 1. Flow curve based upon nine discharge measurements in the Elbow Coulee Primary Side Channel, November 2009- May 2010.

During the study period and based on a Twisp River flow of 300 c.f.s. required for side channel activation, the primary side channel was activated for 62 days across four separate activation events (Figure 2). Of these, 19 days occurred during two winter flow events in December 2009. The remaining 43 days were associated with high flows associated with the spring runoff.

Similar to 2008-2009 (Crandall 2009), water level in the side channel generally decreased during the winter-spring study period (Figure 2). The two winter flow activation events were captured by the water level monitoring, although the relationships between flow in the Twisp River and water levels, hence, flow, in the side channel, still require additional data collection and observation in order to develop a more complete understanding of the situation. Water level in the side channel rose during the activation events, but icing at both the location of the monitoring, as well as at the USGS Twisp River gauge site, may have confounded precise measurements. Furthermore, the groundwater dynamics influencing the side channel, which also account for its perennial nature, are not fully understood. Thus, the causative factors involved with decreases in water level when the channel is isolated from the Twisp River will require additional monitoring to clarify.

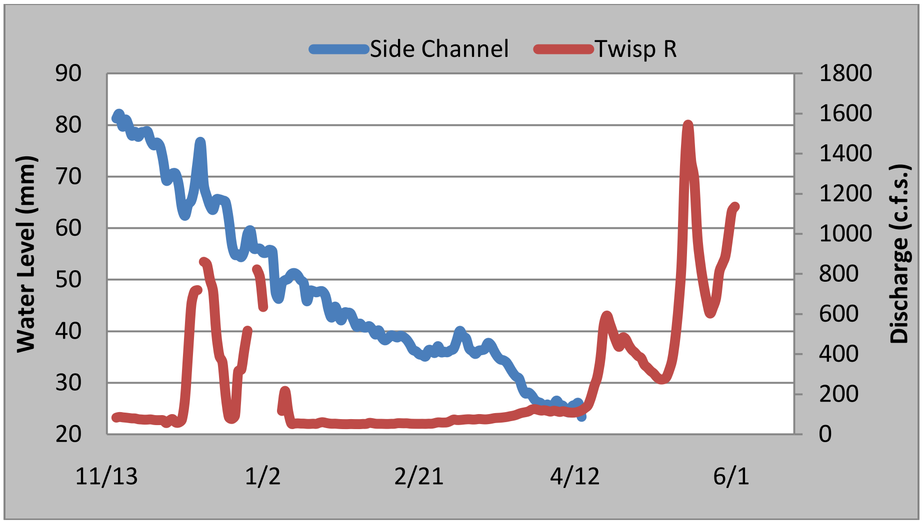

Figure 2. Water level in the Elbow Coulee Primary Side Channel and discharge in the Twisp River, November 2009-May 2010.

Temperature Monitoring

Water temperature monitoring was continuous during the period 26 November 2009 through 30 May 2010 in both the primary side channel and the adjacent reach of the Twisp River. However, due to field logistics, the dataset reported here ended on 21 March 2010. Temperature was recorded by accuracy-checked electronic submersible data loggers every 30 minutes.

Overall, and similar to 2009 (Crandall 2009), the temperature in the primary side channel was warmer during the winter when compared to the adjacent Twisp River (Figures 3 and 4). Temperature in the side channel ranged from 0.5 to 8 °C during the monitoring period. During this same period, the Twisp River ranged between -0.2 to 6 °C and spent over a month at temperatures >0.5 °C while the side channel was only this cold for a few days.

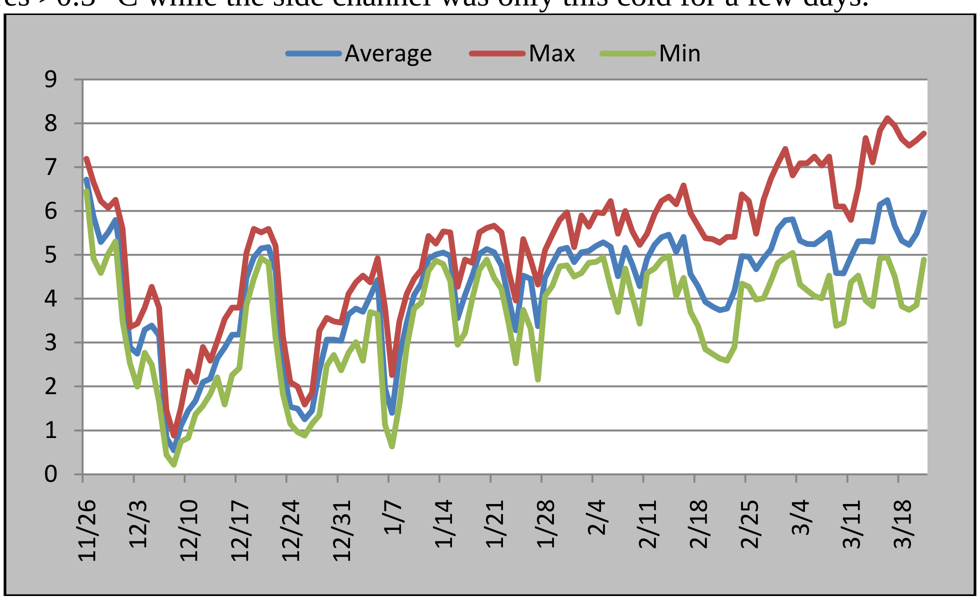

Figure 3. Daily Average, maximum and minimum water temperature, Elbow Coulee Primary Side Channel, 2009-2010.

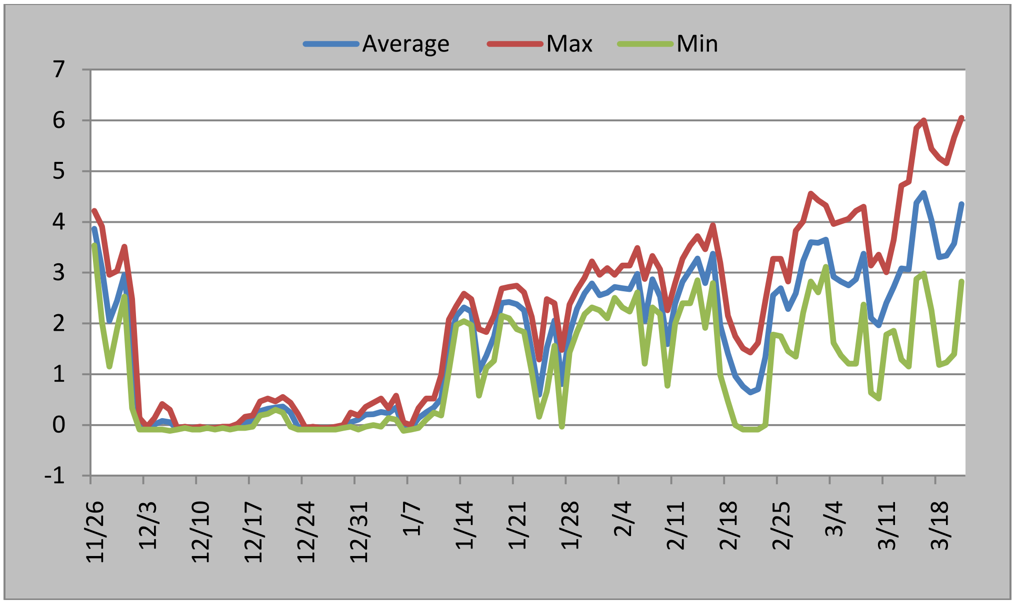

Figure 4. Daily average, maximum and minimum water temperature, Twisp River adjacent to the Elbow Coulee Primary Side Channel, 2009-2010.

Due to the generally consistent nature of groundwater temperatures, winter variations in water temperatures in the side channel are likely influenced by factors associated with air temperature, icing and snow cover in the area of the temperature logger.

Fish Monitoring

Fish monitoring during the study period was limited to visual observations. On 29 April 2010, one juvenile salmonid, likely an endangered spring Chinook salmon, was observed in the perennial portion of the side channel. On 28 May 2010, five young-of-the-year spring Chinook salmon (estimated length 40-45 mm) were observed just downstream of the breach in the upstream portion of the side channel. This was the same location that this species and life stage was observed in the channel in the spring of 2009. It is assumed that these fish were spawned in the Twisp River upstream of the side channel and entered the side channel through the breach when it became connected to the river.

Literature Cited

Crandall, John D. 2009. Elbow Coulee Floodplain Reconnection and Side Channel Restoration Project, 2008-2009 Post-Project Assessment. 22 p.

Elbow Coulee Side Channel – 2011 Update

In 2011, monitoring of the Elbow Coulee Side Channel Restoration Project documented that the restored side channel continued to provide perennial rearing habitat for ESA-listed spring Chinook salmon and steelhead (J. Crandall 2011, unpublished data). These fish species have been observed utilizing the side channel every year since its reconnection with the Twisp River was established in 2008.

Juvenile salmonids generally enter the side channel during high flow associated with spring runoff, yet can remain in the side channel for extended periods of time due to the perennial nature of the side channel. The water temperatures in the side channel are both warmer in winter and cooler in summer compared to the adjacent Twisp River (Crandall 2009 and unpublished data) which may provide rearing fish with a thermally beneficial location for growth and, hence, survival.

The snowmelt runoff in the Twisp River in 2011 was the highest since the project was completed. Peak discharge in the Twisp River exceeded 2,400 c.f.s. (USGS provisional data for gauge #12448998) which represents an approximately 2.5 year flow event. During these peak flows >20 c.f.s. was recorded flowing through the side channel (J. Crandall 2011, unpublished data). Due to the high, and extended, runoff, the side channel was activated by Twisp River flows for over 115 days in 2011 which was more than 30 days longer than any previous year.

In 2011, beaver completed the construction of two dams just downstream of the flow monitoring site in the side channel. While the ponds that resulted from this activity disrupted the continuous flow monitoring instrumentation by flooding the area, listed fish species were observed utilizing the ponds almost immediately (J. Molesworth, USBR, personal observation). This change in habitat type has increased habitat complexity within the channel - a primary goal of the project.

Elbow Coulee Side Channel photo captions (draft)

Note: Photos 1 and 2 were taken from the same location.

Photo 1 (File: Elbow Coulee_7.7.09_PP24)

BEFORE: The Elbow Coulee side channel project was completed in the fall of 2008 and the newly reconnected side channel received its first flow input from the Twisp River in 2009 during spring freshets.

Photo 2 (file: ElbowSC_PP24_7.19.11)

AFTER: Pond habitat created in the Elbow Coulee side channel in 2011 as a result of beaver dam construction just downstream of the flow monitoring site.

Photo 3 (file: elbow beaver activity 2011)

Beaver dam construction in the Elbow Coulee side channel began in 2010. Two ponds were created and subsequently inhabited by listed fish species.

Photo 4 (file: Chinook1_elbowCoulee_12.3.08, or I have others that could be used including groups of chinook or steelhead, let me know what works)

A wild endangered spring Chinook salmon parr rearing in the Elbow Coulee side channel.

APPENDIX E

Middle Methow M2 Studies

* Funded in part or in whole by Reclamation to help meet the FCRPS BiOp RME Strategies

E-1 Reclamation's Methow River Reach Evaluations

E-2 Reclamation's Middle Methow River Reach Assessment

E-3 Middle Methow Fish Sampling Surveys

E-4 Middle Methow River Fish Food Web Study

E-5 Planning Middle Methow Post-treatment Studies for the Period 2014-2016

Appendix E

Middle Methow IMW Studies

Appendix E1: Reclamation's Methow River Reach Evaluations

Information Source:

Methow Subbasin Geomorphic Assessment, Okanogan County, Washington, Bureau of Reclamation, Technical Services Center, Denver, CO; Pacific Northwest Regional Office, Boise, ID; and the Methow Field Station, Winthrop, WA, February 2008

The Methow IMW is designed to assess the habitat processes that affect fish populations across multiple space and time scales. Reclamation developed Reach-based Ecosysem Indicator (REI) river geomorphology studies to prioritize habitat improvement actions, particularly to benefit ESA-listed spring Chinook and steelhead, and to ensure that the actions do not damage human infrastructure. The REI prioritization approach is based on broadly accepted ecosystem principles. Reclamation coupled reach-based geomorphology studies with intense fish and fish habitat monitoring efforts in a large reach of the Middle Methow River basin (M2 Reach) to evaluate the relationships between habitat and fish and the effects of habitat improvement projects on fish production at this scale. Section 1 describes the general REI approach in the Methow River basin. Section 2 describes the REI study in the Middle Methow reach. Section 3 describes the detailed before treatment monitoring program for the Middle Methow Reach, 2008-2012. Section 4 briefly describes the planning effort to conduct post-treatment studies for the period 2014-2016. Finally Section 5 describes the overall Methow River survival analysis.

The *Methow Subbasin Geomorphic Assessment* describes a tributary reach-based approach for geomorphic assessments of nearly 80 river miles of the Methow River Subbasin. The approach describes a strategy that resource managers can use to sequence and prioritize opportunities for protecting and improving channel and floodplain connectivity and complexity in the Methow Subbasin.

The tributary reach-based approach is designed to focus on the geomorphic and hydraulic physical conditions that influence identification, prioritization, and development of habitat projects for implementation. Figure 1 shows the underlying structure of the approach: a dual hierarchical structure of ecosystems illustrating that processes and functions are capable of operating on multiple levels, ultimately forming nested, interdependent systems (or adaptive cycles) where a lower level of organization influences upper levels. The bio-physical attributes operate over multiple levels of organization. Corresponding scaling relationships are represented on the left by the biological realm (land cover and vegetation) and on the right by the physiography realm (geology, geomorphology, and topography). The third realm, climate is unrepresented.

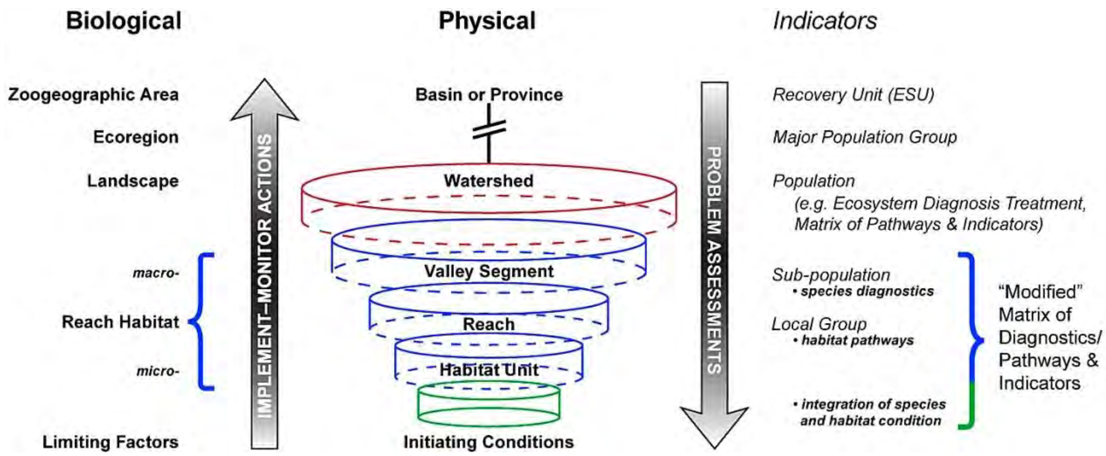

Figure 1. Biophysical levels of spatial organization typical of a nested hierarchical framework demonstrating in a cross-walk, the relationship of biotic (left) and physical (center) scaling relationships with that of relevant biotic and ecosystem indicators on the right.

The report addresses four river valley segments in the Methow Subbasin, located in Okanogan County, Washington (Figure 2 and Table 1). The Upper Methow, Middle Methow, Twisp, and Chewuch River valley segments were investigated concurrently to compare and prioritize potential habitat protection and improvement areas within the historic channel migration zone and floodplain of 23 delineated geomorphic reaches. The assessment was carried out by Reclamation with the technical assistance on fish habitat from the USFS through an interagency agreement funded by Reclamation.

Three floodplain types were identified that help group the 23 reaches based on the natural potential of channel habitat complexity:

- High complexity, with wide, unconfined floodplain
- Medium complexity, with narrower, moderately confined floodplain
- Low complexity, with narrow, confined floodplain

Although the level of complexity may vary, each of the three floodplain types has valuable habitat components that are essential to sustaining the variety of aquatic life stages and species within the Methow Subbasin ecosystem. Areas with higher rates of floodplain reworking and interaction between the channel, side channels, and riparian vegetation offer the most opportunity for providing habitat complexity

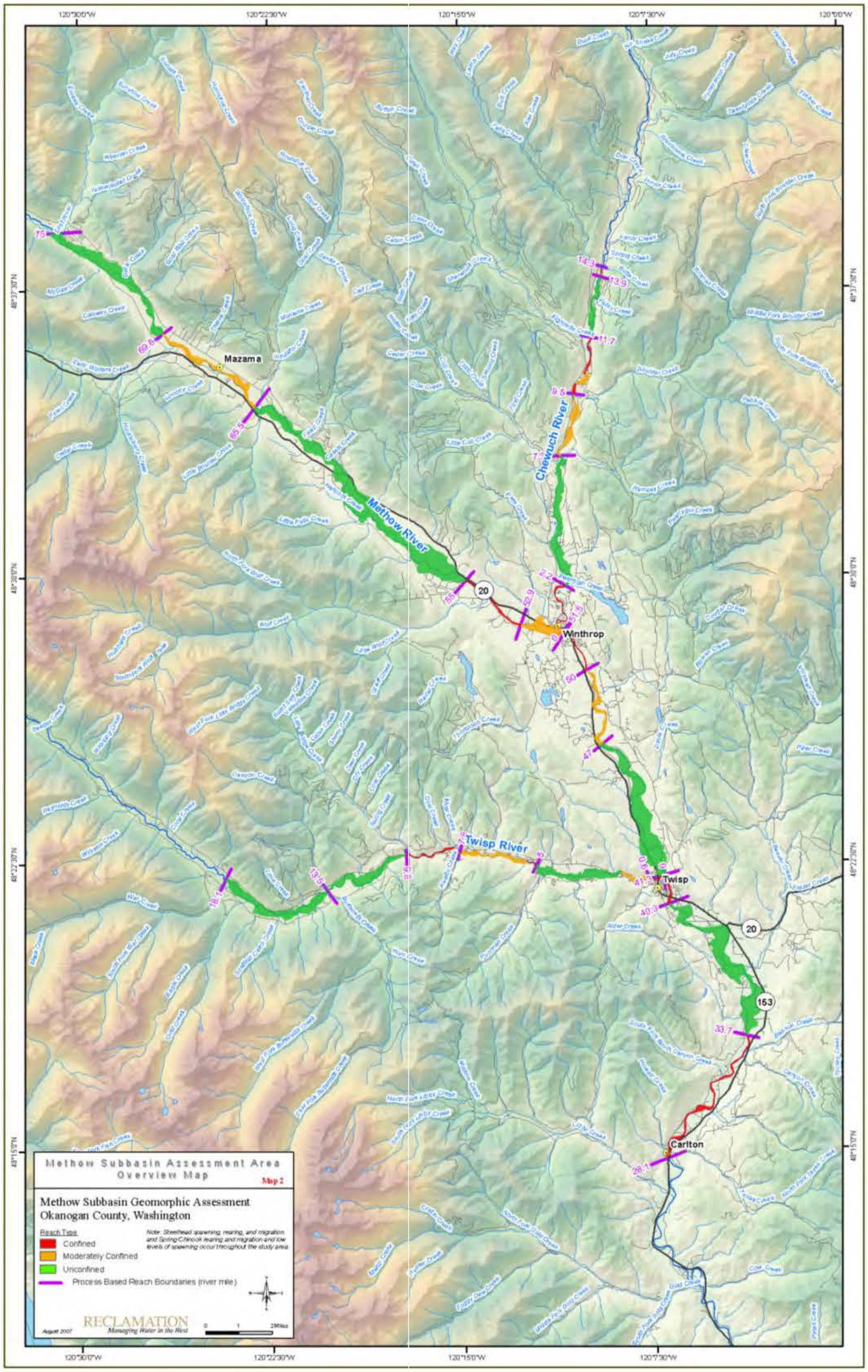

Figure 2. Geomorphic reach locations categorized by floodplain type. From Information source 1 above, figure 6, page 25.

Table 1. Assessment area within Methow Subbasin.

Valley/Stream Segment	Downstream Boundary	Upstream Boundary	River Mile (RM) Length
Upper Methow River	RM 51.5 (confluence with Chewuch River)	RM 75 (Lost River confluence)	23.5
Middle Methow River	RM 28.1 (near Carlton, WA)	RM 51.5 (confluence with Chewuch River)	23.4
Twisp River	RM 0	RM 18.1 (boundary of Forest Service Land and confluence with Eagle Creek)	18.1
Chewuch River	RM 0	RM 14.3 (boundary of Forest Service Land and confluence with Falls Creek)	14.3
TOTAL LENGTH			79.3

The 23 reaches in the four Methow Subbasin segments were characterized based on differences in geomorphic conditions and potential to provide habitat features associated with multiple fish life stages and species use, particularly complex habitat for ESA-listed spring Chinook and steelhead. One primary habitat objective is protecting and improving connectivity between the channel and floodplain and hence habitat units. Therefore unconfined and moderately confined reaches with wide floodplain areas were identified separately from naturally confined, single-thread channel reaches.

Approximately 78 percent of the 80-mile assessment area is composed of moderately confined and unconfined reaches (Figure 3). These reaches have measurable floodplain areas adjacent to the main channel that consist of islands, overbank flooding areas, side, and overflow channels. These floodplain areas contain opportunities for protecting and restoring habitat complexity in unconfined and

The “floodplain protection area” (column) documents the percent of the total floodplain and off-channel area that has no human features so there is no restoration action needed. These areas are for the most part presently functioning in terms of physical processes and vegetation, but in some cases are indirectly impacted by nearby human features in other floodplain restoration areas.

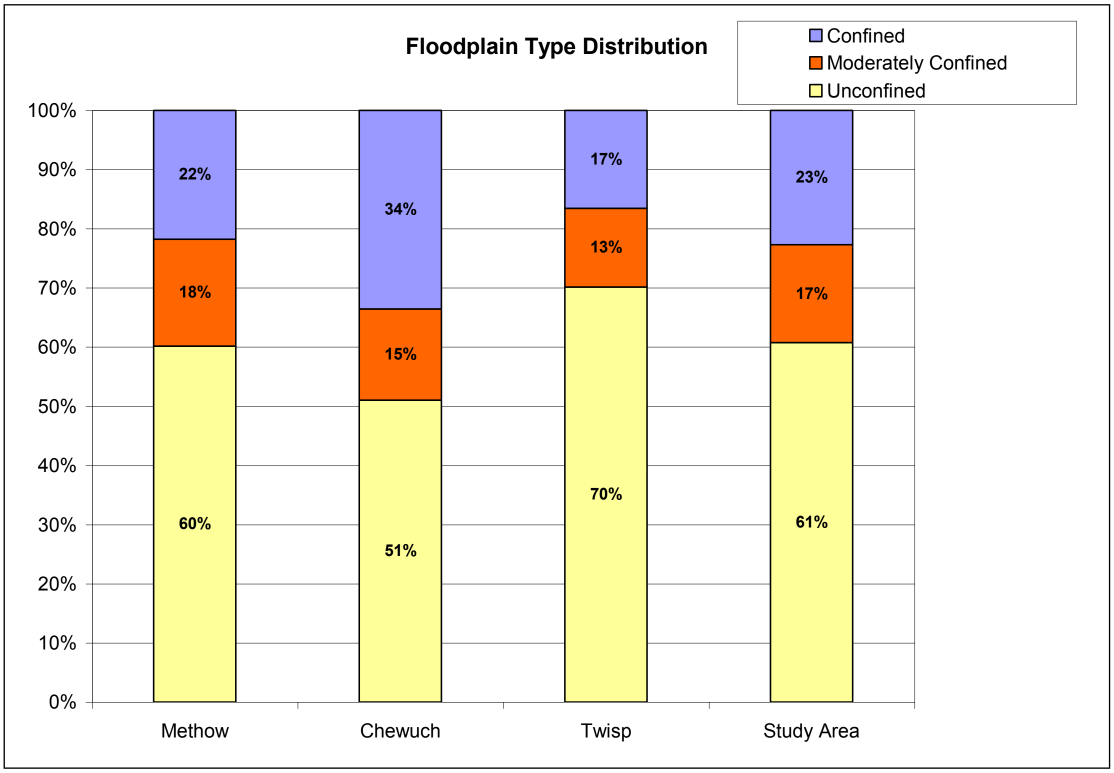

Figure 3. Distribution of reach types and floodplain availability within assessment area

Columns 6 and 7 document the length of well-defined side channels (from 2004 aerial photographs and 2006 LiDAR) that could provide off-channel habitat. The table is separated into channels with no human features blocking them off (protection areas) and channels that are presently cut off at either the upstream or downstream ends (or both) by levees, bridges, etc. (restoration areas). In some unconfined and moderately confined reaches, historical channels may have been filled or altered. This measured miles therefore represent a minimum number of potential channels that could provide off-channel habitat. More refined mapping at the reach analysis or project level stage with additional field verification should be done to validate the channel mapping.

Table 2. Summary of reach characteristics, from Table 4, Information Source 1, pg. 38.

Reach Name	Floodplain Type	Down-stream River Mile	Up-stream River Mile	Floodplain Protection Area (properly functioning with no human impacts) (% of total reach)	Length of Side Channels (miles)		Indicator of Disruption to Processes		Minimum Cleared Vegetation (% of total reach)
					Presently Accessible[1]	Presently Cut Off by Human Features	Disruption to Channel Migration and Floodplain Access[2]	% of Floodplain Boundary (terraces and glacial banks) that is Armored [3]	
M1	Confined	28.1	33.7	NA	0	0	0.13	27	11.1
M2	Unconfined	33.7	40.3	7%	0.9	8.2	0.66	23	24.4
M3	Confined	40.3	41.3	NA	0	0	0.06	61	5.3
M4	Unconfined	41.3	47	9%	1.2	7.0	0.80	17	37.0
M5	Moderately confined	47	50	26%	0.2	1.1	0.38	14	26.6
M6	Confined	50	51.5	NA	0	0	0.00	12	0.0
M7	Moderately confined	51.5	52.9	0%	0	1.4	1.89	4	40.9
M8	Confined	52.9	55	NA	0	0	0.01	40	10.6
M9	Unconfined	55	65.5	34%	11.4	9.7	0.54	10	13.2
M10	Moderately confined	65.5	69.6	56%	1.2	1.2	0.05	7	11.6
M11	Unconfined	69.6	75	38%	3.2	2.8	0.40	7	7.8
C1	Confined	0	2.2	NA			0.04	2	8.8
C2	Unconfined	2.2	7.3	32%	2.9	3.7	0.16	0	16.8
C3	Moderately confined	7.3	9.5	45%	0.9	0.6	0.45	0	24.6
C4	Confined	9.5	11.7	18%			0.12	6	12.7
C5	Unconfined	11.7	13.9	29%	0.2	0.6	0.14	0	2.1

Reach Name	Floodplain Type	Down-stream River Mile	Up-stream River Mile	Floodplain Protection Area (properly functioning with no human impacts) (% of total reach)	Length of Side Channels (miles)		Indicator of Disruption to Processes		Minimum Cleared Vegetation (% of total reach)
					Presently Accessible[1]	Presently Cut Off by Human Features	Disruption to Channel Migration and Floodplain Access[2]	% of Floodplain Boundary (terraces and glacial banks) that is Armored [3]	
C6	Confined	13.9	14.3	NA			0.00	0	0.0
T1	Confined	0	0.6	0%		0.2	0.64	33	87.2
T2	Unconfined	0.6	5	9%	0.7	4.9	0.98	3	38.9
T3	Moderately confined	5	7.8	45%	1.0	0.7	0.29	9	21.9
T4	Confined	7.8	9.8	18%		0.2	0.28	16	15.4
T5	Unconfined	9.8	13.5	14%	0.8	1.3	0.44	8	31.7
T6	Unconfined	13.5	18.1	61%	3.9	1.8	0.26	0	8.3

1/ Although presently accessible, the natural frequency of inundation may still be disrupted in some cases due to past human activities such as filling of channel entrances or altering the land surface for housing, infrastructure, or agriculture.

2/ Computed by taking the total length of human features located within the floodplain (low surface) divided by the total reach length.

3/ Computed by taking the total length of riprap and bank armoring located along the floodplain (low surface) boundary divided by the total length of the boundary.

Column 9 documents the boundary of the floodplain on terraces or high elevation glacial banks. The ratio was computed by dividing the total length of human features along the floodplain boundary (typically bank protection) by the total floodplain boundary length for each reach. The higher the number computed, the greater the boundary length impacted. The amount of floodplain boundaries protected ranges from none in some reaches to 61 percent in Reach M3.

Generally, the confined reaches have more bank protection. These reaches are generally bound by glacial terraces that would be expected to have minimal lateral bank erosion. It is believed that the majority of bank protection went in after the 1948 and 1972 floods, during which accelerated bank erosion may have occurred due to most of these areas being cleared of native vegetation. Glacial banks in this system contain large cobbles that often line the toe of the bank during erosion helping to protect from extensive lateral expansion due to river erosion. Although the lateral extent of bank erosion that could occur during floods is likely small, many houses and infrastructure are located in close proximity to the edge of the bank and cannot tolerate even localized bank erosion without incurring damage. Lateral bank erosion of these glacial banks has only been detected in a few sections of the 80-mile assessment area where no bank protection has been placed. The limited erosion measured from 1948 to 2004 also may result from the fact that the majority of banks with the potential to be eroded have already been armored with riprap.

As a rough indicator of disruption to channel migration and floodplain access, a second ratio was computed by dividing the total length of human features that disconnect the main channel from side channels or floodplain, or prevent lateral migration by the reach length (column 8). Reaches with higher values have more reduction in floodplain connectivity than reaches with lower values, which indicates the reaches with higher values may have more opportunity for improving habitat function.

The amount of floodplain area where vegetation has been cleared under the present setting (2006) is also documented in column 10. Reaches with larger values of vegetation clearing generally have more development potentially posing more challenging restoration strategies than areas with limited or no development. Areas of historic vegetation clearing are not well documented and were not incorporated into this computation. Therefore, this number represents a minimum area of floodplain clearing and does not include areas that were cleared in the past and currently in a regeneration stage.

Combining results from all columns in 2 gives a quick look at the current condition of each reach and restoration opportunities. Reaches that are unconfined and moderately confined generally have more disruption to channel and floodplain connectivity and habitat access than confined reaches. Reaches with a high percentage of protection areas (limited or no human impacts), good connectivity to side channels, healthy riparian buffer zones (little riprap), and limited vegetation clearing are the least impacted and vice versa for the most impacted.

Reaches M2, M4, M7, M9, C2, and T2 have at least 1 mile of potential off-channel habitat that could be reconnected. Of these reaches, M9, M10 and C2 have at least 30 percent of the reach that is noted as a protection area that could provide more connectivity of habitat availability at a reach scale. T6 has the highest percentage of functioning off-channel habitat presently available.

Despite impacts from human activities and features, the channel planform and bed elevations appear consistent in most locations with no detectable trends of channel bed incision or aggradation on a decadal scale. The river hydraulics and sediment sizes present along the channel bed within the study area are most notably dominated by geologic features that control the river bed slope and the lateral extent of the active channel and floodplain (width). The average sediment particle sizes measured in the bar and channel surface are gravel to cobble (40 to 140 mm) for all three rivers, with the larger sizes present in the reaches with steeper slopes. Except for a few steep, confined reaches, the bars and channels can be reworked at the more frequent 2- and 5-year flood peaks. This is one indicator that the energy in most reaches is not exceeding sediment supply, which combined with findings from historical channel analysis and field observations suggests there is limited tendency for continued incision.

At a more localized scale, human features and activities have impacted hydraulics, availability of LWD and riparian vegetation, and spawning-sized sediment availability that are critical to habitat quantity and quality. Hydraulic conditions have been most impacted by reducing flow access to off-channel areas at the entrance to side channels, and to some degree altering access to overbank flooding.

LWD levels are highest in unconfined reaches, but are believed to be lower than natural conditions due to historic removal of woody debris and log drives on the mainstem Methow River.

The total percent of floodplain area where vegetation has been noticeably cleared is 19.9 percent for the Methow River (Middle and Upper), 14.8 percent for the Chewuch River, and 24.1 percent for the Twisp River.

The lengths of river reaches that have vegetated floodplain are listed below based on 2004 aerial photography:

- 15.2 miles of the middle Methow River (70 percent of main channel length)
- 21.4 miles of the upper Methow River (86 percent of main channel length)
- 15.5 mile of the Twisp River (85 percent of main channel length)
- 9.5 miles of the Chewuch River (60 percent of main channel length)

Within the reaches with vegetated floodplain, 27 percent (1,446 acres) were identified for protection and monitoring where there were limited or no human features and physical processes were in a properly functioning condition. In the remaining 73 percent (3,827 acres), 56 potential floodplain restoration areas were identified on the mainstem Methow River, 49 areas on the Twisp River, and 27 on the Chewuch River. A combination of protection and restoration strategies could cumulatively yield up to 3,600 acres on the Methow River, 1,100 acres on the Twisp River, and 600 acres on the Chewuch River of functioning habitat for spring Chinook and steelhead (Table 3). Within the restoration areas, various types of physical settings are present that offer potential to improve habitat function for ESA-listed spring Chinook and steelhead (Table 4).

Table 3. Summary of protection and restoration areas identified for the four valley segments.

Valley Segment	Total Main Channel Length (river miles)	Total Floodplain Area (acres)	Floodplain Protection Area		Floodplain Restoration Area	
			(acres)	(% of total)	(acres)	(% of total)
Upper Methow	RM 50 to 75	1391	126	9%	1265	91%
Middle Methow	RM 28 to 50	2196	748	34%	1447	66%
Twisp	RM 0 to 18	1084	381	35%	703	65%
Chewuch	RM 0 to 14	603	192	32%	411	68%
Total Area		5274	1446	27%	3827	73%

Table 4. Summary of restoration areas by process type for the four valley segments.

	Complex-ity Habitat Area (acres)[1]	Overbank Floodplain Area (acres)[2]	Areas with Heavy Develop-ment (acres)	Complex-ity Habitat Area (% of total)	Overbank Floodplain (% of total)	Heavy Develop-ment (% of total)
Upper Methow	1150	56	241	79%	4%	17%
Middle Methow	1041	90	135	82%	7%	11%
Twisp	587	107	10	83%	15%	1%
Chewuch	354	30	26	86%	7%	6%

[1] contains off-channel areas and frequently inundated floodplain acres
[2] inundated at infrequent floods

Appendix E2: Reclamation's Middle Methow River Reach Assessment

Information Sources:

1. *Middle Methow Reach Assessment Methow River*, Okanogan County, Washington, Bureau of Reclamation, Pacific Northwest Regional Office, Boise, ID, August 2010. References cited in this Appendix can be found in the original document.

   Appendix A: Reach-based Ecosystem Indicators
   Appendix B: Monitoring Inventory
   Appendix C: Reach Documentation – Middle Methow
   Appendix D: Stream Inventory Survey – Middle Methow Habitat Assessments
   Appendix E: Riparian Vegetation Assessment – Middle Methow Riparian Vegetation Assessment Report
   Appendix F: GIS Database

2. *Geomorphology and Hydraulic Modeling for the Middle Methow River from Winthrop to Twisp*,Technical Report No. SRH-2009-42, USDI, Bureau of Reclamation, Technical Services Center, January 2010.

The Middle Methow reach is between river mile (RM) 50.0 near Winthrop and RM 41.0 near Twisp on the Methow River (Figure 1) and is a 6th field Hydrologic Unit Code (HUC) watershed (#170200080605). The reach is characterized as moderately confined (RM 50.0-47.0), unconfined (RM 47.0-41.3) and confined (RM 41.3-41.0) based on valley constraints.

The species of concern found in the Methow River include Upper Columbia River (UCR) spring Chinook salmon (*Oncorhynchus tshawytscha*), UCR steelhead (*Oncorhynchus mykiss*), and Columbia River bull trout (*Salvelinus confluentus*) that are included in the Endangered Species Act Threatened and Endangered list (UCSRB 2007) and the Pacific lamprey (*Entosphenus tridentatus*). Columbia River Basin species of concern found in the Middle Methow River include UCR spring Chinook salmon, UCR steelhead, Columbia River (CR) bull trout, and Pacific lamprey. The Methow River is a major spawning area for UCR spring Chinook salmon and UCR steelhead, is important for Pacific lamprey spawning and rearing, also is an important migration corridor for UCR spring Chinook salmon, UCR steelhead, CR bull trout and Pacific lamprey.

Several limiting factors were identified in the *Recovery Plan* and *Biological Strategy* for the Middle Methow River subwatershed (UCSRB 2007). Many of these limiting factors were based on professional judgment, local expertise, and biological models, but much of the data had not been quantified. This reach assessment documents environmental baseline conditions, identifies the condition of the indicators, and quantifies several indicators for future monitoring. When possible, quantifiable data were collected and entered in a reach-based ecosystem indicators (REI) table for evaluation (Appendix A). A qualitative condition ranking was assigned to each specific and general indicator. Although these condition rankings are qualitative, much of the data upon which they are based have been quantified, and, in some cases, have been georeferenced (i.e., channel units, anthropogenic features and vegetation structure) for future monitoring efforts. Protection and rehabilitation approaches were proposed that could address long-term and short-term improvements to physical and ecological processes.

The *Recovery Plan* and the *Monitoring Strategy for the Upper Columbia Basin* (Hillman 2006), referred to as the *Monitoring Strategy*, recommend effectiveness monitoring of actions taken to improve habitat in the Upper Columbia. Reclamation is funding the US Geological Survey (USGS) to conduct an effectiveness monitoring program. The Middle Methow effectiveness monitoring program involves collecting and analyzing pre- and post-implementation physical and biological data to assess population level effects before treatment (2010-2012) and after treatment (2013-2016). This Level III monitoring (Hillman 2006) is complemented by the documentation of physical and ecological processes contained in this reach assessment. Monitoring efforts are occurring throughout the subbasin (Figure 1). Crandall documented other monitoring efforts in the Methow River basin in Appendix B.

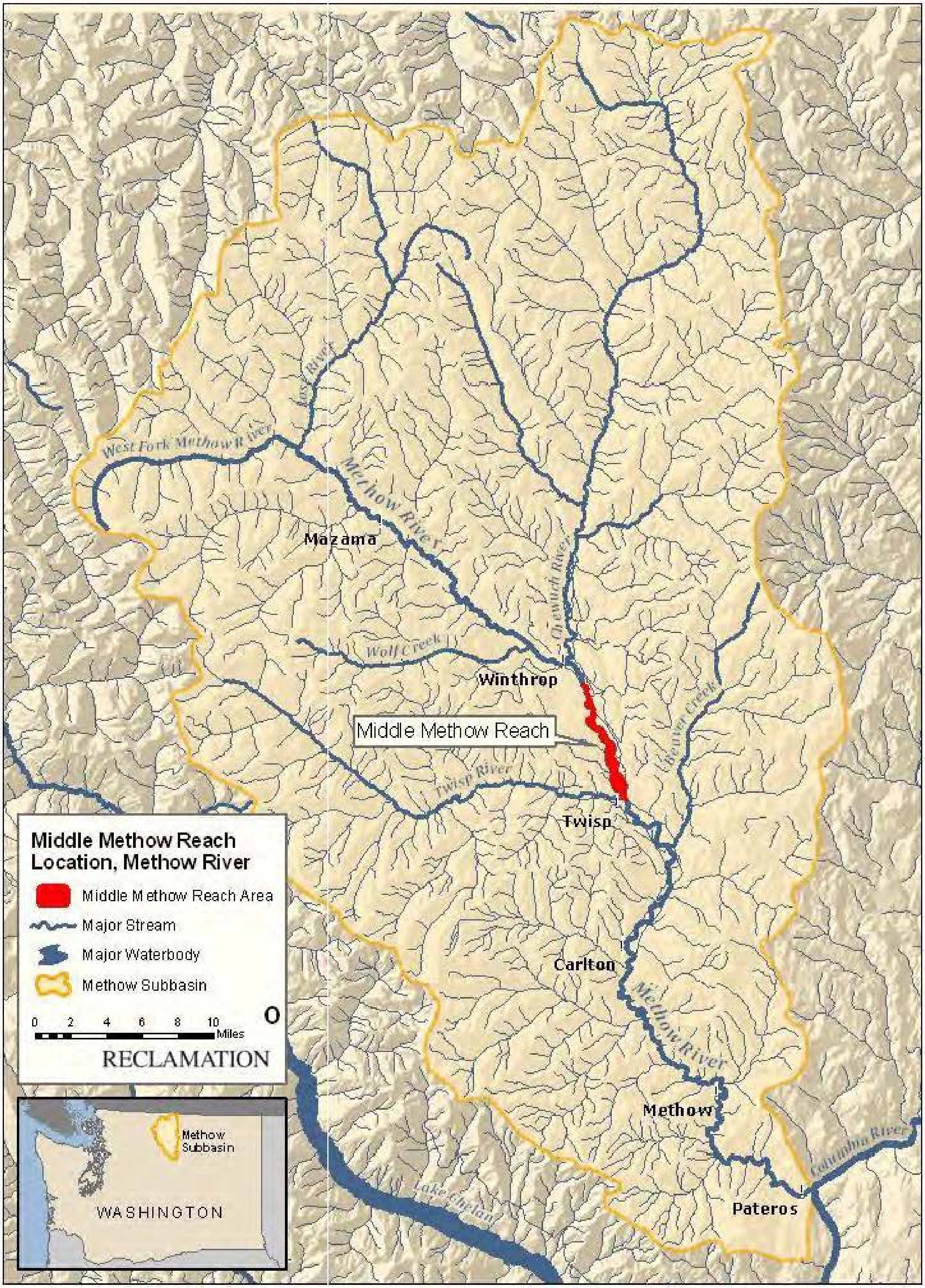

Figure 1. Location of the Middle Methow reach, Okanogan County, Washington.

The following summaries were excerpted directly with minor revisions from the Middle Methow Reach Assessment.

Summary of Limiting Factors and Management Objectives

The Middle Methow River subwatershed is a Category 2 subwatershed with major spawning areas for steelhead and spring Chinook salmon (based on historic intrinsic potential). The mainstem Methow River is also an important migration corridor for spring Chinook salmon, steelhead and bull trout, and provides spawning and rearing habitat for summer Chinook salmon and steelhead. Tributaries include Alder Creek, Bear Creek, Beaver Creek, Benson Creek, and the Twisp River.

Limiting factors affecting the Middle Methow River subwatershed habitat conditions include the following (UCSRB 2007, UCRTT 2007):

- Residential development is affecting riparian and floodplain condition.
- Low flows in late summer and winter may affect juvenile survival.
- Structures in tributaries are passage barriers for adult and juvenile salmonids.
- The mainstem Methow is on the state 303(d) list for temperatures.
- Decreased habitat diversity and quantity due to roads, riprap, residential development and agriculture.
- Excessive artificial channel stability due to roads, riprap, residential development, and agriculture.

Recommended management objectives for the Middle Methow River include the following (UCSRB 2007, UCRTT 2007):

- Improve and protect riparian habitat conditions
- Increase off-channel habitat by rehabilitating floodplains and reconnecting side channels
- Increase habitat diversity and quantity by rehabilitating riparian habitat, reconnecting side channels and floodplains (where feasible), and adding instream structures (low priority action) within the river. Modify existing bank hardening projects to incorporate roughness elements to reduce water velocity and increase instream complexity
- Use practical and feasible means to increase stream flows within the natural hydrologic regime and existing water rights.

Several assessments were conducted on the Middle Methow reach to determine (1) current physical processes, (2) condition of aquatic and terrestrial habitat, and (3) historical and ongoing anthropogenic activities that have impacted physical and ecological processes. These assessments are summarized in the following sections.

Summary of 2008-2009 Reach Documentation

An assessment was conducted during the fall of 2008 and 2009 to document anthropogenic, geologic, and geomorphic features (Appendix C). The reach's valley bottom-type is classified as a wide mainstem valley (F3) with a valley bottom gradient of less than 3 percent, and an unconstrained, moderately sinuous channel (Naiman et al. 1992). The stream type is predominantly an F-type (Rosgen 1996) channel in the moderately confined geomorphic reach and a C-type (Rosgen 1996) channel in the unconfined geomorphic reach. The bedforms are predominantly pools, riffles and runs; and gravel and cobbles are the dominant substrate. Geology includes predominantly sedimentary deposits and metamorphic rocks that are further defined as glacial and alluvial deposits, and bedrock.

Figure 2 is a composite geologic map (compiled from Stoffel et al. 1991; Reclamation 2010; and Waitt 1972) that shows an example of the geology and geomorphic landscape between RM 49.00 and 46.25, and the majority of cold water upwelling areas in the reach. Geology, and geomorphic landforms, and their spatial arrangement influence groundwater recharge, hydraulic gradients, and hydraulic conductivity. These interactions are the drivers and controls in routing groundwater flows and cold water upwelling areas.

The Twin Lakes area west of the Methow River between RM 50.0 and 47.0 is a kame terrace, a terrace deposited by a stream that ran along the margin of a glacier, that is cored by bedrock, and is a significant groundwater recharge and source area for the Methow River (Aspect 2009). The hydraulic gradient is primarily from the Twin Lakes area toward the Methow River to the north and southeast (Aspect 2009). The alluvium and/or fractured bedrock have high hydraulic conductivities that provide avenues for groundwater flow in the reach between RM 49.00 and 46.25. In contrast, bedrock that is not fractured (competent) has low hydraulic conductivity and impedes groundwater flows resulting in cold water upwelling areas. Table 1 summarizes the cold water upwelling areas interpreted from thermal infra-red (TIR) imagery and geologic mapping. The majority of cold water upwelling areas are interpreted to be created by bedrock controls that force groundwater to rise to the surface. Other cold water upwelling areas are interpreted to be from groundwater or hyporheic flows through glacial and alluvial deposits that surface in the downstream direction.

Table 1. Summary of cold water upwelling sites.

Side Channel Identifier or Upwelling Location	Local Name	Total Acres	Side Channel Type*	Cold Water Source	Wetted
SC_48.37_L	Gilbertson Springs	0.68	Gravel Bar (although the spring surfaces along a terrace prior to flowing down to the secondary channels along the gravel bar)	Yes	Perennial
47.95_R	River Rock	NA	NA: Upwelling within the river	Yes	Perennial
SC_47.90_R	River Rock	0.99	Floodplain	Yes	Perennial
SC_46.70_L	Boesal	0.75	Gravel Bar	Yes	Perennial
SC_45.10_R	Habermehl	4.74	Floodplain	Yes	Ephemeral

* Side channel type classifications are based on the predominant location of secondary (and sometimes tertiary) channels and are designated as either gravel bar or floodplain type side channels.

Bedrock provides lateral and vertical channel controls in the reach. These outcrops restrict (1) lateral channel migration forcing creation of deep scour pools, and (2) vertical channel migration by providing grade controls. Bedrock outcrops are located along the margins and within the channel in several locations. Table 2 summarizes the locations of bedrock controls. Figure 2 contains an example between RM 49.00 and 46.25.

Table 2. Location of lateral and vertical bedrock controls.

River Mile	Description
RM 49.8	Crops out in floodplain along river right indicating shallow alluvium
RM 49.7	Crops out along river left controlling lateral channel migration
RM 49.3	Crops out along river right controlling lateral channel migration
RM 49.0	Crops out along river left controlling both vertical and lateral channel migration
RM 48.7	Crops out along river right controlling lateral channel migration
RM 48.0	Crops out along river left controlling both vertical and lateral channel migration
RM 47.7	Crops out along river right controlling lateral channel migration; scour pool forced by bedrock at lower end of side channel (3R side channel)
RM 47.2	Crops out along river right controlling lateral channel migration
RM 45.5	Crops out along river right controlling both vertical and lateral channel migration
RM 44.1	Crops out along river right controlling lateral channel migration
RM 41.2	Crops out along river left controlling lateral channel migration; opposes Twisp River alluvial fan to form geologic floodplain constriction

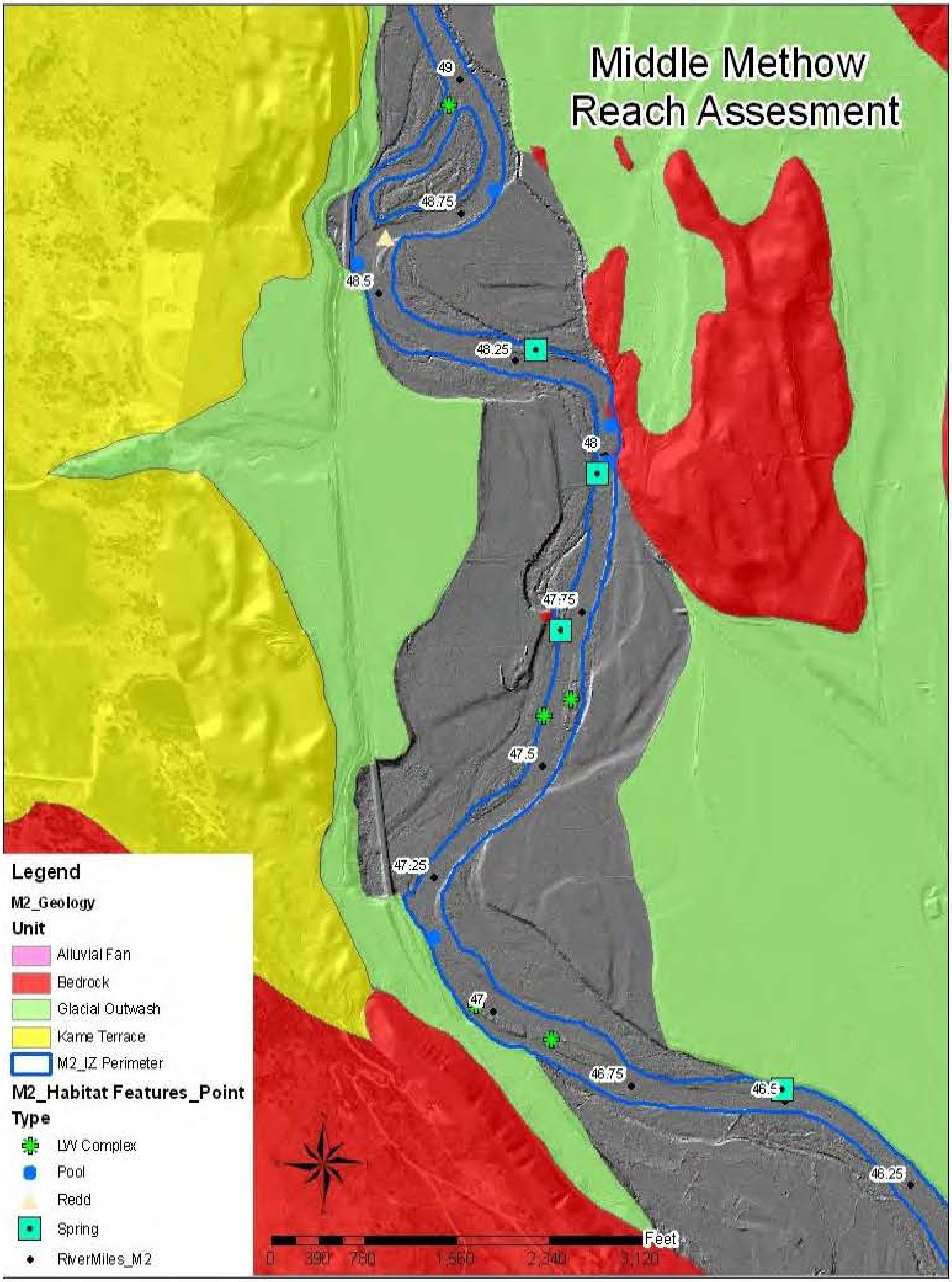

Figure 2. Locations of cold water upwelling sites and bedrock channel controls between RM 49.00 and 46.25, and their relationship to geologic landforms (map scale 1:12,000). Grey area is interpreted to have been reworked by the river during the Holocene epoch.

Large wood is typically found as apex log jams on medial gravel bars and islands, high on lateral gravel bars, and at the head of side channels (Figure 3). Generally in unconfined reaches, large wood contributes to the creation of side channels during channel forming flows, producing a continuum of side channel types (gravel bar and floodplain) that are in varying stages of development. Clearing of the riparian buffer zone for agriculture, commercial and residential development, and placement of levees and bank protection have reduced large wood recruitment and recruitment potential. These anthropogenic impacts and instream removal of wood by recreationists have led to channel simplification, reduced floodplain connectivity, and reduced side channel development.

Figure 3. Example of large wood complexes that contribute to the creation and development of side channels (map scale 1:2,800).

The reach assessment area encompasses about 1,500 acres on the Middle Methow River from RM 50.0 to RM 41.0. The reach was further broken down into two types of morphologically distinct areas that include the active channel and floodplain areas to describe greater local geomorphic control and variability. Referred to as inner (active channel) and outer (floodplain) zones, these areas represent existing riverine habitat within the reach. The limit of the outer zone was determined by interpreting the extent of inundation for the 1948 flood (estimated at greater than a 100-year flood event) using aerial photographs, a light detection and ranging (LiDAR) hillshade elevation model, and surficial mapping (Reclamation 2010).

The inner zone is characterized by the presence of primary and secondary channels, a repetitious sequence of channel units, and relatively uniform physical attributes indicative of localized transport, transition, and deposition. They are generally associated with ground-disturbing flows with sufficient frequency that mature deciduous and coniferous trees are rare (adapted from USDA 2008). The active main channel was subdivided into eight inner zones based on local sediment transport and deposition trends interpreted from the channel unit mapping, channel gradient, channel confinement, hydraulics, and dominant substrate. Inner zones that are not hydraulically connected to the river because of anthropogenic features are described as disconnected inner zones.

In contrast, an outer zone is typically a terrace tread(s) and generally coincidental with the historic channel migration zone unless the channel has been modified or incised leading to the abandonment of the floodplain. This zone includes side channels, overflow channels, and oxbows. An outer zone is further distinguished from an inner zone by the presence of flood deposits, a change in vegetation (mature deciduous and coniferous trees present unless removed for development), and bounding geologic landforms such as older terraces, valley walls, alluvial fans, colluvium, or glacial deposits (Table 3).

Table 3. Acres (and percentage of total area) by zone type on the Middle Methow reach, Methow River, Methow Subbasin, Okanogan County, Washington.

Total Area	Connected Inner Zones	Connected Outer Zones	Disconnected Inner Zones	Disconnected Outer Zones
1,498 acres (100 percent)	322 acres (21 percent)	957 acres (64 percent)	24 acres (2 percent)	195 acres (13 percent)

These inner and outer zones were further refined as subreaches and subreach complexes that are delineated by longitudinal, lateral and vertical controls (Figure 4). Subreaches that have several anthropogenic impacts that affect physical processes in multiple areas are identified as subreach complexes. These areas are identified in a subreach context in order to sequence potential actions to address complex anthropogenic impacts.

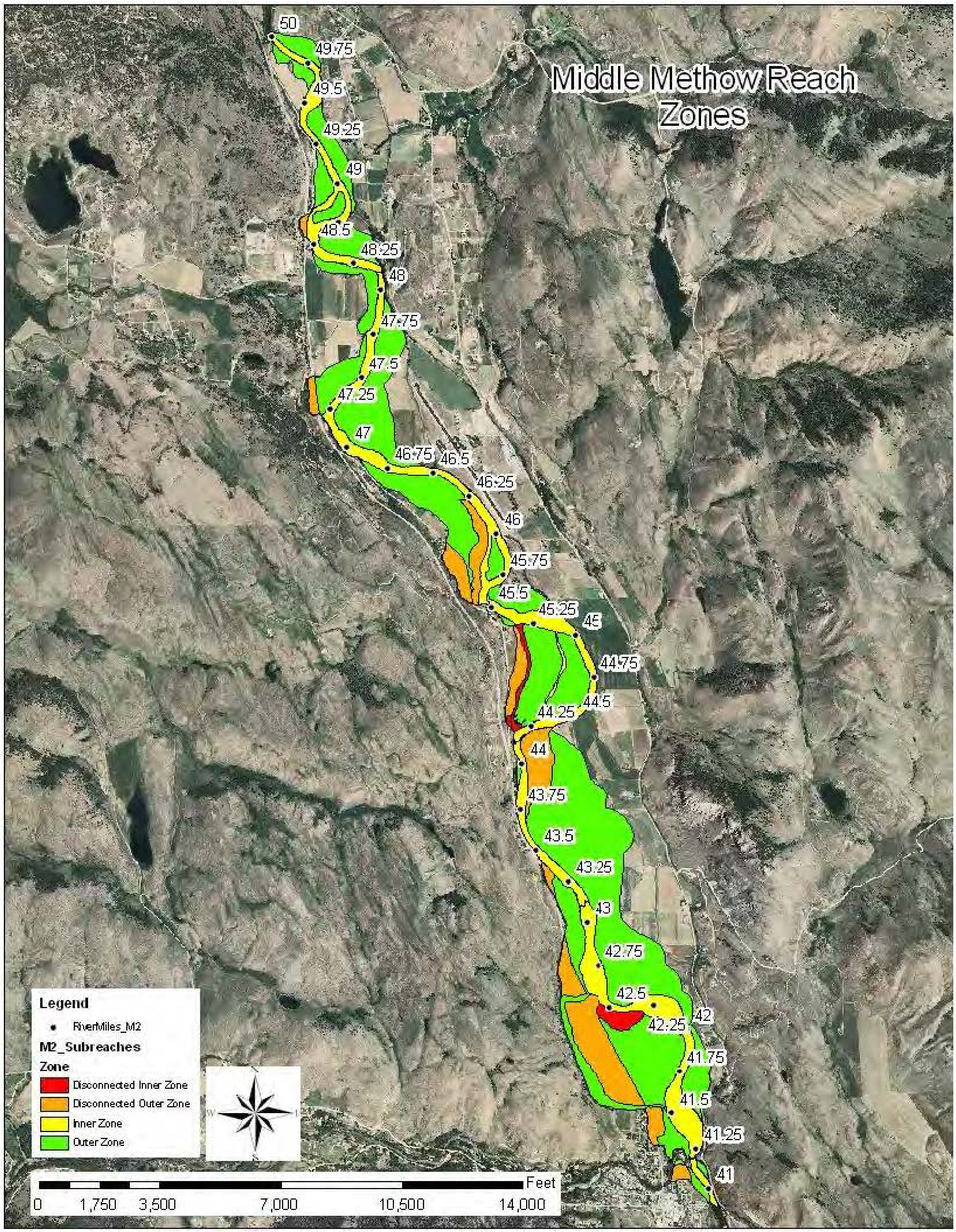

Figure 4. Locations of zones, subreaches, and parcels (i.e., sub-units of the subreach) and their connectivity to the river.

Summary of 2009 Geomorphic Mapping and Hydraulic Modeling Summary

A report was completed on the refinement of geologic/geomorphic mapping conducted during the *Tributary Assessment* and a hydraulic model analysis for the reach (Reclamation 2010).

Geologic/geomorphic mapping was conducted to better understand the spatial distribution of the surficial geology, related landforms, and the physical processes responsible for their formation (Figure 5). Four distinct deposits that could be attributed directly to deposition or reworking by the river included the active channel, floodplain deposits, and two terraces. The active floodplain (Qa3) is inset into older but distinct terrace deposits.

The report concluded that there was no evidence of reach-scale channel incision or aggradation. Bedrock (Br) provides grade control in a few locations where it crops out in the channel. There is also a geologic floodplain constriction near RM 41.2 where the Twisp River alluvial fan impinges the channel against bedrock. Bedrock restricts lateral channel migration in several locations and deep pools have developed by scour.

Based on historical aerial photographs the floodplain processes were dominated by (a) erosion of the active floodplain (Qa3) between 1945 and 1948; (b) formation (deposition) of the active floodplain between 1954-1964 and 1974-2004; and (c) about equal amounts of erosion and formation of the active floodplain between 1964 and 1974. These floodplain processes were most active in the unconfined section of the reach upstream from the geologic floodplain constriction at RM 41.2 to about RM 43.

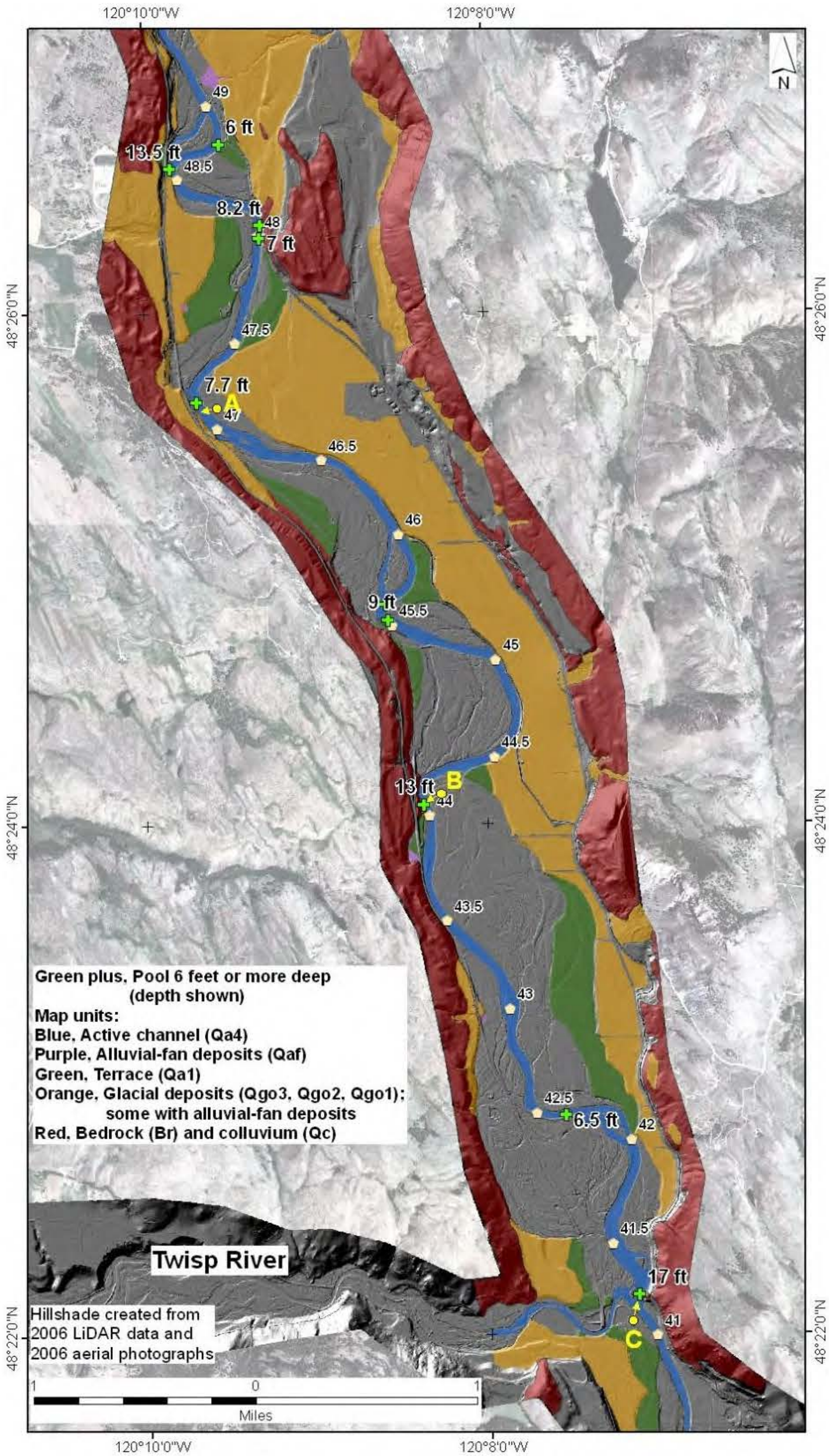

Figure 5. Surface geology of the Middle Methow reach (Reclamation 2010). The grey area is the extent of terrace deposits Qa3 and Qa2 adjacent to the main channel in blue.

A two-dimensional hydraulic model was developed to evaluate floodplain processes, side channel connectivity, and split flow channel dynamics. Simplified hydraulic parameters, including depth-averaged velocity, bed shear stress, and depth, were determined along the channel thalweg and across the areal extent of the floodplain. Connected floodplain was defined as the area with depths exceeding 0.5 feet outside of the low flow channel. The model evaluated low flow conditions, and the estimated 2-year, 10-year, 25-year and 100-year discharges under existing conditions (Table 4). Model results indicate that some side channels within the active floodplain (Qa3) are activated during the 2-year flood (about 11,000 cfs) and that most of the active floodplain surface becomes inundated during the 10-year flood (about 16,000 cfs).

Table 4. Discharges used in the two-dimensional hydraulic model for the Middle Methow (Reclamation 2010).

Methow River (cfs)[1]	Twisp River (cfs)[2]	Notes
285	70	Low flow discharge recorded at USGS gages; mean daily flows during channel survey in October 2008
10,900	2,020	Falling limb of May 23, 2006 flood recorded at USGS gages when oblique aerial photographs were taken; equivalent to about 2-yr flood;
16,600	3,890	10-yr flood frequency values based on hydrologic analysis of annual peaks at USGS gages
24,400	1,720	1972 flood peak recorded at USGS gage on Methow at Winthrop; equivalent to about the 25-yr flood frequency on mainstem Methow; estimate on Twisp River is less than 2-year flood based on difference between recorded flow at Winthrop and estimate on Methow below Twisp (no gage data available for this flood on Twisp)
31,360	9,440	1948 flood peak; larger than the 100-yr flood for both mainstem Methow and Twisp Rivers

The hydraulic model predicts that most of the active floodplain (Qa3) is overtopped at a discharge of about 16,600 cfs (about a 10-year flood) and the variability of inundation reflects the irregular topography (Figure 6). The hydraulic model also predicts the following:

- That side channels within the active channel (Qa4) have the most potential to be inundated during low-flow periods.
- That prominent side channels within the active floodplain (Qa3) are generally not inundated by the 2-year flood (about 11,000 cfs).
- That overflow channels within the active floodplain (Qa3) and higher floodplain (Qa2) are only inundated by larger floods greater than 5-to-10-year flood frequency.

[1] Based on USGS Gage No. 12448500 (Methow River near Winthrop, WA) and USGS Gage No. 12449500 (Methow River near Twisp, WA)

[2] Based on USGS Gage No. 12448998 (Twisp River near Twisp, WA)

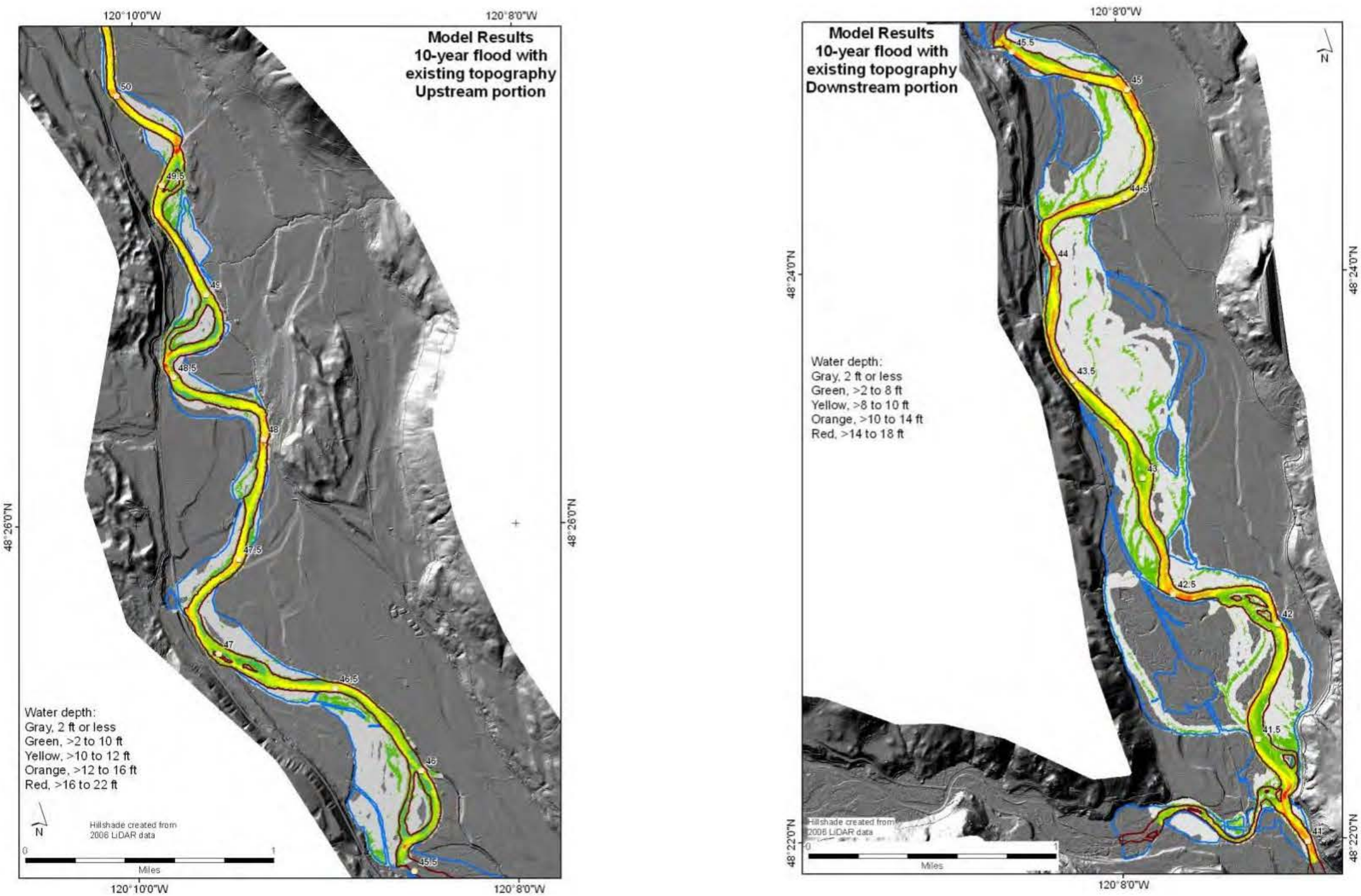

Figure 6. Inundation of Qa4 and Qa3 surfaces based on modeling of a 10-year flood for upstream section (left) and downstream section (right) (Reclamation 2010).

Colors indicate potential water depths as indicated. Channel area within the brown outline is Qa4. Areas outlined in blue are Qa3. Unshaded areas are other map units older than the Qa3 and Qa4.

Summary of 2009 Channel Unit Mapping

Channel unit mapping was conducted for this reach assessment (detailed channel unit maps appear in Appendix C). Channel unit mapping is a useful tool in interpreting subreach scale hydraulic conditions in addition to sediment movement through a given reach or channel segment at channel forming flows. Channel units are mapped in the field based on observed physical characteristics and then each unit is redrawn on rectified aerial photographs in ArcGIS (Figure 7). "Channel units" should not be confused with "habitat units" that are a measure of habitat type and quantity available at low flows. For example, the habitat assessment includes the long pool tail-out in the glide-pools (usually lateral scour pools) as pool habitat even though this area of the pool is functioning as a run hydraulically. For the channel unit mapping the pools (area of pool scour) and runs are spatially defined and mapped separately as geomorphic channel units.

The channel units were charted using the percent of total area occupied by each unit to graphically illustrate the existing condition and to help interpret current trends in sediment transport and deposition (Figure 8). The reach includes a combination of channel types including moderately confined plane-bed to pool-riffle and unconfined pool-riffle segments. Conceptually, confined channel segments should have more pools and runs (scour and transport channel units); moderately confined segments should have a balance of runs (transport channel unit) with riffles and bars (depositional channel units); and unconfined segments should also have a balance of different types of channel units but with increasing area of riffles and bars (depositional channel units).

Moderately confined channels with higher gradients and more plan-bed type morphology do not typically form pools except where forced by significant hydraulic structures such as bedrock outcrops. In the moderately confined section from RM 50.00 to 46.25 (subreaches MM-IZ-1, MM-IZ-2, and MM-IZ-3) the reduction in lateral channel migration capability combined with the effect this has on sediment transport may be the most important factor since pool formation is typically associated with energy concentration at the meander bend apex. A balance of transport and depositional channel units would be expected in this plane-bed to pool-riffle system. In subreaches MM-IZ-1 and MM-IZ-2 there is an adequate balance of runs and pools (transport units) with riffles, rapids and bars (depositional units). However, in subreach MM-IZ-3 runs significantly increase most likely due to bedrock controls that restrict lateral and vertical channel migration.

In the unconfined section of the reach from RM 46.25 to 41.15 (subreaches MM-IZ-4, MM-IZ-5, MM-IZ-6, and MM-IZ-7) depositional channel units would be expected to increase in the downstream direction in this pool-riffle type system as the channel gradient decreases and large wood becomes more mobile. In these types of unconfined sections wood becomes less important as a channel control and functions more like sediment. Riffles and bars increase from MM-IZ-4 through MM-IZ-7, but there are also a high percentage of runs in MM-IZ-4, MM-IZ-5, and MM-IZ-6. This may be due to bank protection (i.e., riprap and levees) that has reduced lateral channel migration resulting in vertical channel instability (i.e., scour and localized channel incision). The impact on channel processes caused by the bank protection is interpreted to be a reduction in the sediment supply due to artificially stable streambanks and an increase in channel transport capacity at channel forming flows due to a change in channel geometry caused by scour.

In the moderately confined section of the reach there are an adequate number of pools for this plane-bed to pool-riffle system. However, in the unconfined section pools are underrepresented compared to what is expected for a pool-riffle type system. Even though the pool indicator is rated adequate for the reach based on pool frequency (total number per mile) and spacing (generally a pool for every 5 to 7 channel widths) for unconfined alluvial valley types with widths greater than 100 feet and channel slope less than 2 percent (Montgomery and Buffington 1993). This implies that pools should comprise about 14 to 20 percent of the channel units in these unconfined low-gradient river channels. Pool, riffle, run, and rapid channel units (bars excluded) were analyzed for the entire reach and the pool channel units were found to comprise about 8 percent of the active channel area.

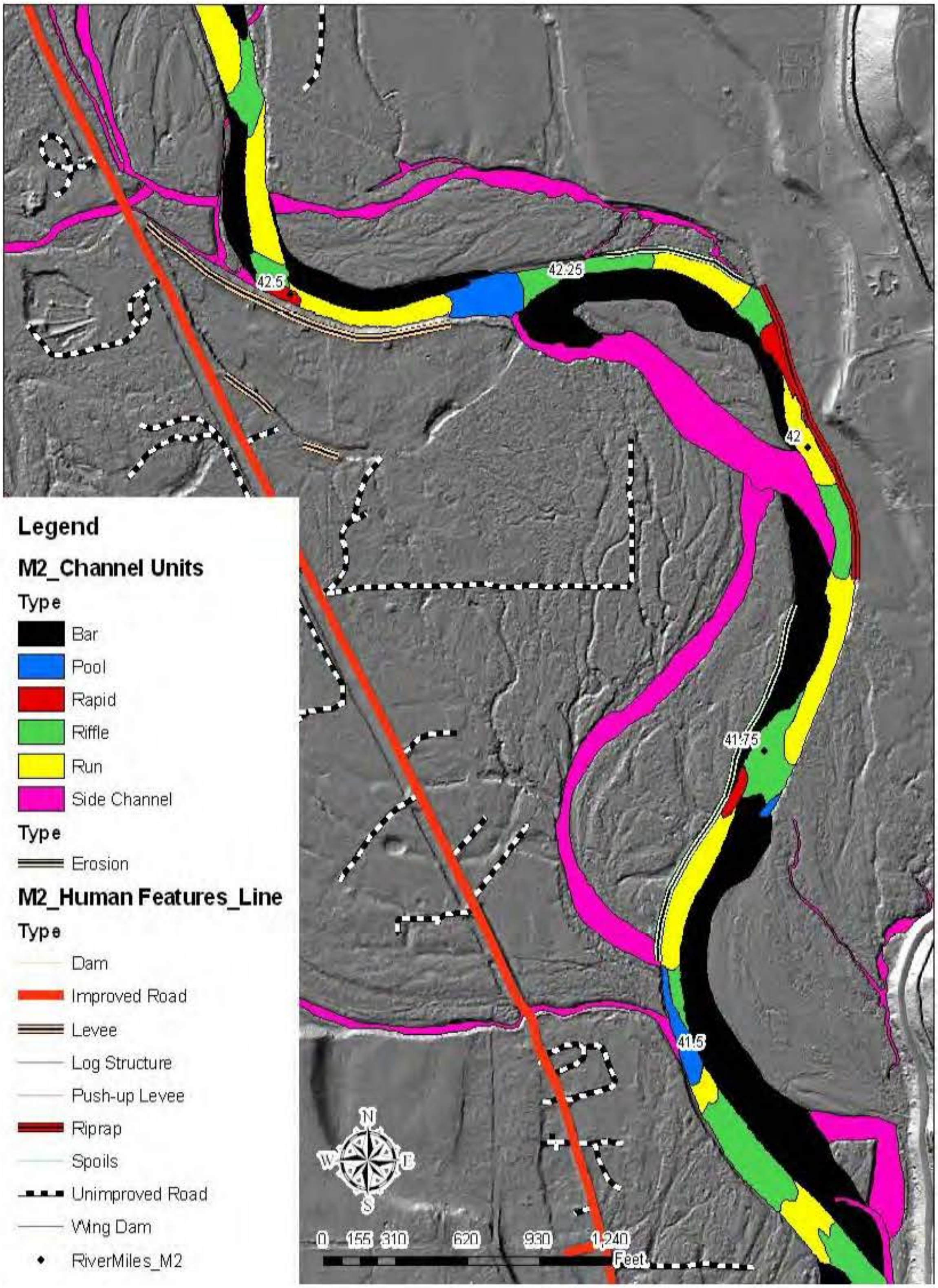

Figure 7. Example of channel unit mapping from RM 43.10 to 41.15 in the "Sugar Dike" area. Complete coverage of the reach is provided in Appendix C and in the Middle Methow geodatabase.

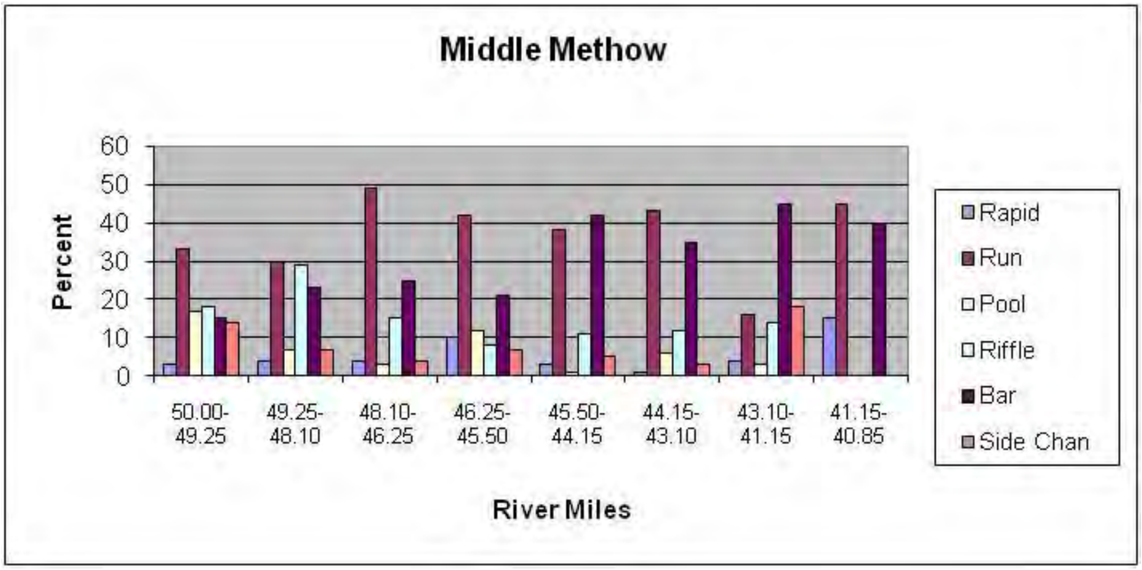

Figure 8. Percent of channel units by channel segment.

Summary of 2008 Habitat Assessment

The U.S. Forest Service completed a Level II Stream Inventory Survey (habitat assessment) between RM 52.4 and 40.3 along the Middle Methow River. This habitat assessment included the Middle Methow reach between about RM 50.0 and 41.0 which is summarized in this section. The methods used are contained in the Stream Inventory Handbook, Level I & II, Pacific Northwest Region, Region 6, Version 2.8 (USFS 2008). Specific data collected for the reach are contained in the REI table (Appendix A) and the complete stream inventory survey report is contained in Appendix D.

The reach has about 138 acres of habitat area consisting of predominantly riffles and pools. Between RM 50.0 and 47.0 the Methow River flows through a moderately confined geomorphic reach and the habitat units are predominantly riffles and bedrock-formed pools. From about RM 47.0 to 41.3 the river is in an unconfined geomorphic reach with habitat units comprised predominantly of riffles and lateral scour pools. In addition, the unconfined geomorphic reach contained the most off-channel habitat as the river accesses the floodplain and activates side channels and alcoves.

Instream large wood is scarce, except in the Barkley diversion side channel area. Wood is transported through the upstream confined geomorphic reach and accumulates in this area because it is on an outside bend and the river begins to access the floodplain. The side channel is cleared annually and the large wood is stacked by excavators on the floodplain and gravel bar. Large wood throughout the reach was predominantly in log jams along the channel margin, at the head of side channels, and high up on gravel bars which is appropriate for the size and type of channel. The large wood remains accessible to the river during channel forming flows. Future large wood recruitment potential is generally low because of removal of riparian vegetation primarily for agriculture development. However, there are areas where riparian vegetation has not been removed and provides adequate wood recruitment potential.

Deep pools (greater than 5-feet deep) are present throughout the reach. The deepest pools are associated with bedrock outcrops that restrict lateral channel migration and force channel bed scour. These deep pools provide cover from predators, holding habitat for migratory fish, and refugia. Although there are adequate numbers of deep, bedrock pools that provide fish cover, there are shallow, lateral scour pools along the channel margins that do not have appropriate vegetation and lack large wood which would provide adequate fish cover.

The average thalweg depths of the riffles and runs are adequate for fish migration. Large cobbles, small boulders, and riprap provide hiding cover for juvenile salmonids while rearing. The substrate is too coarse for anadromous fish spawning in many areas, but some spawning habitat was observed in riffles, runs and pool tail-out crests. Substrate embeddedness does not appear to be problematic; however, cobble and coarse gravel substrate were embedded at two large pool tail-out crests.

Side channel habitat was about 3 percent of the total habitat area in the moderately confined geomorphic reach and about 8 percent in the unconfined geomorphic reach (Table 5). Many of the side channels are ephemeral and dewater in late summer. The table below summarizes side channel habitat.

Table 5. Summary of side channel habitat within the Middle Methow reach (Appendix D).

River Mile	Bank	Length	Avg. Width	Avg/Max Depth	Date De-Watered	% Pool Habitat	% Riffle	Lwd/Mile > 35', 12"	Max Water Temp	Notes
49.3	Left	1,225'	39'	2'/6'	-	70%	30%	112	n/m	Barkley Side Channel
48.6	Right	1,700'	Dry	-	? Mid-summer	-	-	6	n/m	Wide channel (up to 140')
48.1	Left	950'	15'	1.0'/2.0'	-	n/m	n/m	22	11.6◦C	Gilbertson Springs
47.7[1]	Right	100'[1]	5'	0.2'/0.2'	06-09-08[2]	-	-	0	n/m	Nancy Farr Property[1] (aka 3-R)
46.7	Left	1,255'	80'	1.2'/5.0'	-	66%	34%	8[5]	n/m	End of reach
45.6	Right	1,585'	70'	1.0'/4.0'	-	63%	37%	23[5]	18.72◦C	McNae S.C.

River Mile	Bank	Length	Avg. Width	Avg/Max Depth	Date De-Watered	% Pool Habitat	% Riffle	Lwd/Mile > 35’, 12”	Max Water Temp	Notes
44.5[3]	Right	2,600’	Dry	-	09-20-08	-	-	4[4]	19.37◦C	State land
44.2	Right	1,250’	70’-100’	n/m	-	100%	-	n/m	23.23◦C	Beaver Ponds
42.9	Left	1,100’	15’	0.6’/3.0’	-	n/m	n/m	0	n/m	3’ pool
42.7	Left	n/m	Dry	-	07-07-08	-	-	n/m	n/m	Lehman S.C.
42.5	Right	>1,000	Dry	-	06-09-08	-	-	n/m	n/m	Didn’t walk
42.0	Right	1,350’	Dry	-	07-11-08	-	-	47	16.92◦C	Below dike
41.2[1]	Left	1,500’[1]	Dry	-	?	-	-	0	n/m	Wetland[1]

n/m = not measured

[1]The lower 100’ of the side channel was flowing. The remaining length of side channel (1,050’) was dry, with 4 pools that are possibly stranding fish. The largest of the pools was about 75’ long and 30’ wide, with a depth of about 5.5’. No fish were observed in the pools at the time of the survey. Only one piece of wood > 35’ long with a diameter of at least 12” was observed in the dry segment of the side channel.

[2]Approximate date that the top of the side channel was disconnected from the river.

[3]Two dry side channels, total length 1,500’. One of the side channels connects to a series of wetland ponds. On 10-02-08 (low flow), the six ponds had a total area of about 22,500 sq. ft., with depths ranging from 0.4’ to 3.0’.

There were a few disconnected, wetted pools in the lower part of the channel at the time of the habitat survey. Although there were few pieces of large wood > 35’ and > 12”, the side channel had numerous small pieces of wood.

The wood in the large jams at the top of these side channels was counted in the main channel.

Water temperatures exceeded the 16°C between June 15 and September 15, Washington State Department of Ecology standard for summer salmonid habitat for water temperature, for 35 consecutive days at RM 49.6, for 28 consecutive days at RM 48.9, and for 43 consecutive days at RM 46.3 during the summer of 2008 (Figure 9). This water temperature data is based on water temperature loggers that were deployed by the Forest Service in June 2008 and retrieved on October 2008. Gilbertson springs was found to contribute cold water during the summer. The Methow River water temperatures were cooler below Gilbertson springs than at Barley diversion dam near RM 49.6. Water temperatures generally warmed in the downstream direction within the reach except between RM 45.6 and 44.2 where water temperatures cooled by about 0.5°C probably from upwellings or springs (for additional information refer to Appendix D).

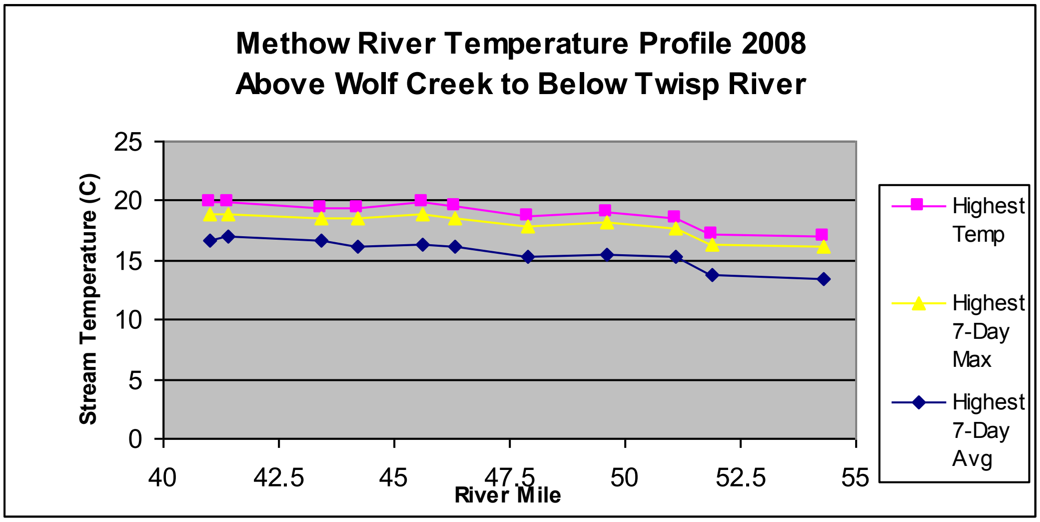

Figure 9. Middle Methow River water temperature profile.

Summary of 2009 Vegetation Assessment

Riparian vegetation was surveyed in 2009 between river miles RM 51.50 and 41.30 (refer to Appendix E for the full report). The main goals of the vegetation survey were to establish a baseline for future monitoring and to identify potential riparian habitat protection and enhancement projects.

Riparian forests in the reach are dominated by relatively short-lived species that depend on episodic flood events and channel migration to regenerate. The riparian forests are dominated by black cottonwood (*Populus trichocarpa*) with locally abundant quaking aspen (*Populus tremuloides*), thin-leaf alder (*Alnus incana*), water birch (*Betula occidentalis*), and ponderosa pine (*Pinus ponderosa*). The upper segment (RM 51.5 to 47) is moderately confined with relatively narrow bands of riparian vegetation along the main channel. Adjacent areas are predominantly non-forested agricultural and residential lands.

The lower segment (RM 47 to 41.5) is generally unconfined, and broad sections of floodplain forest are supported by river meander and channel migration processes in several areas. Most trees in this segment are small-diameter trees, and many stands likely date back to the 1948 flood event (Figure 10). Cottonwood regeneration and growth on several gravel bars is not detectable in the 2006 orthophotographs. This condition may be due to the 2006 spring high flow event (2006 orthophotographs were taken in the fall) that may have removed some older vegetation and the regeneration of cottonwoods may be too young to detect on the photographs. Large tracts of the active floodplain have been converted to agricultural fields or residential property. Black cottonwood trees are common near the river edge in agricultural fields, but their sprouts are heavily browsed by deer and beaver.

An important factor in maintaining and enhancing riparian vegetation along the Middle Methow is to allow for disturbance associated with channel migration, flooding of floodplain surfaces, and beaver colony utilization. Without regeneration opportunities provided by disturbance and periodic inundation of floodplain surfaces, wide floodplain forests could decline and be replaced by drier site species, including ponderosa pine and Douglas-fir.

Black cottonwood is a keystone riparian species (Braatne et al. 2006) and plays a critical role in large woody debris dynamics, provides habitat for a host of terrestrial and aquatic organisms, and contributes to nutrient cycling in hyporheic zones. With regulated flow, channel restriction, and floodplain development in many watersheds throughout the inland West, black cottonwood and other riparian species have dramatically declined over the past century (Kauffman et al. 1997, Rood et al. 2003). The riparian vegetation has been altered along the reach with an estimated 27 percent of the forest cover cleared between RM 51 to 47 and 37 percent between RM 47 and 41.3. However, large portions contain intact riparian forest and hydrological processes, and these areas represent opportunities to protect and enhance riparian habitat, particularly along unconfined segments of the river.

Agricultural fields border the river along many portions of the reach and often support only a narrow line of riparian trees along the river bank. Deer browse is particularly heavy on cottonwood sprouts adjacent to agricultural fields as compared to recruitment on gravel bars. Repeated browse appears to be limiting tree recruitment and forest cover development in these areas. Stark differences in browse damage between cottonwood regeneration on gravel bars and near agricultural fields may be due to a combination of factors. Regeneration is generally so dense on gravel bars that it may overwhelm the effects of deer browse. Agricultural fields also probably support larger concentrations of deer, and browsing on sprouts is likely more common near fields than on gravel bars.

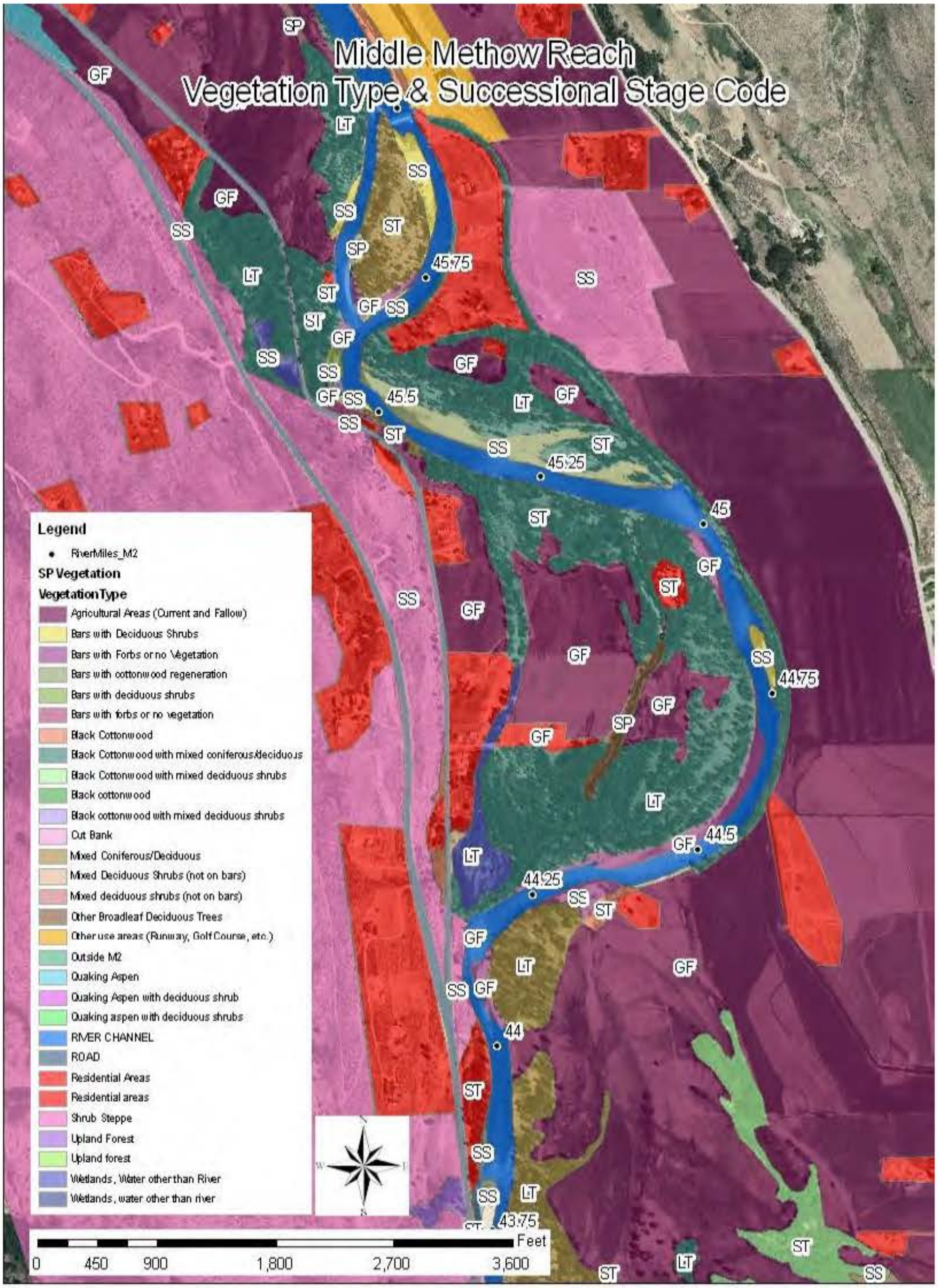

Figure 10. Example of vegetation mapping showing vegetation type and successional stage code (i.e. GF-grass/forbes; SS-shrub/seedling; SP-sapling/pole; ST-small trees; and LT-large trees).

Summary of Beaver Activities

This summary of beaver activities and their potential contributions are predominantly from the *Vegetation Assessment* (Appendix E). Because beavers significantly influence habitat conditions and processes, they are discussed in this section to highlight their importance.

Beavers (*Castor Canadensis*) were more prevalent along the Middle Methow River in the past based on historical anecdotal accounts. Beaver and other fur-bearing animals were trapped extensively throughout the Methow Valley and the surrounding Okanogan County. Near extirpation of beaver likely altered the structures of streams and rivers. Because trapping predated any historic records, we have no clear reference on how numerous beavers were along the Middle Methow or how they influenced riparian forests and hydrology. Beaver are slowly recovering along the Methow River but may be at only a small fraction of their original population (Kent Woodruff, Methow Valley Ranger District, personal communication).

Through their felling of cottonwood, aspen, and other trees, beaver actively recruit large woody debris into water channels (Naiman et al. 1988). Beaver require ample numbers of trees and can locally alter stand conditions, changing canopy cover, and altering species composition and successional stages. Beaver prefer black cottonwood and quaking aspen over conifer species, and riparian stand structure and composition can be influenced by beaver activity. Both cottonwood and aspen sprout vigorously when felled. Felled trees increase the structural complexity of river channels, and during flood events, large woody debris tends to accumulate in log jams and can initiate gravel bar recruitment. Once anchored, black cottonwoods can sprout and regenerate in their new location.

Ponds and channels associated with beaver complexes provide protected habitat for numerous fish species (Pollock et al. 2003) and have been linked with reproductive success of salmonid species (Pollock et al. 2004). Beaver complexes are associated with slower water flow and support abundant aquatic invertebrates, both of which benefit foraging salmonids. Juvenile salmonid species in reaches with beaver complexes have been found to be more abundant, larger in size, and have greater overwinter survival rates than reaches without beavers (Bustard and Narver 1975; Swales et al. 1986).

Anthropogenic impacts have disrupted floodplain connectivity resulting in a reduction of floodplain-type side channels that are suitable for beaver colonization. The cumulative anthropogenic impacts affecting floodplain-type side channels and beaver populations are qualitatively interpreted to have resulted in the following:

- a reduction of complex off-channel habitats provided by beaver activities
- reduction in groundwater recharge due to the lack of beaver complexes (i.e., ponds) that store surface water on the floodplain that eventually infiltrates into the groundwater table and/or to the hyporheic zone and river.

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Appendix E3: Middle Methow Fish Sampling Surveys

Information Source: Mainstem Methow habitat effectiveness monitoring of stream restoration: Work Plan for FY2012, 23 August 2011, Principal Investigator: Patrick J. Connolly, Ph.D., Lead Research Fish Biologist, Project Leader--Watershed Restoration Ecology, phone: 509-538-2299 ext 269; FAX: 509-538-2843; email: pconnolly@usgs.gov; and Kyle D. Martens, Fisheries Biologist, phone: 509-538-2299 ext 238; FAX: 509-538-2843; email: kmartens@usgs.gov, USGS-Western Fisheries Research Center, Columbia River Research Laboratory, 5501A Cook-Underwood Rd.; Cook, WA 98605

The Middle Methow fish research, monitoting and evaluation (RME) study is a before and after treatment study. The U. S. Geological Survey - Columbia River Research Laboratory is conducting the field study under the direction of Dr. Pat Connolly, the principal investigator, through funding by Reclamation's RME program, Columbia Snake Rive Office, PN Region. Additonally modeling support is provided for the Middle Methow study as described in Appendix B.

This section describes the pre-treatment monitoring program that occurred in 2008-2012. A post-treatment monitoring program is planned for the period 2013-2018. A network of fish monitoring devices (smolt traps, PIT tag interrogation systems, and weirs) has been established in the Methwo watershed, which represents a system that rivals anything else in other watersheds of the Columbia River Basin. Figure **1** shows the fish detection network that contributes to the overall Methow Basin IMW ability to estimate survival and run sizes of smolt and adult anadromous salmonids. Additional PIT tag detectors are planned to be added in the near future. The network established is maintained by a cooperative effort among WDFW (funded by Douglas County PUD), USGS (funded by Reclamation), and NOAA (funded by Reclamation).

Figure 1. Location of fish monitoring gear already in place or planned in the Methow River watershed by Washington Department of Fisheries and Wildlife (WDFW) or U.S. Geological Survey (USGS). New installs are planned for completion in 2009. The restoration reach is denoted as "M2", P or p = large or small PIT-tag interrogation system (PTIS), and S=smolt trap.

A. **Background**:

River restoration projects are becoming widely implemented throughout the Pacific Northwest and other regions in the U.S. (Bernhardt et al. 2007); however, project monitoring has rarely been conducted in scientifically valid experimental designs and timeframes (Katz et al. 2007). Monitoring is of critical importance to inform future restoration efforts and project designs, and it is in need of more practice and research. In their survey of restoration projects in the Pacific Northwest representing expenditure of hundreds of millions of dollars, Rumps et al. (2007) concluded that we know little about the effectiveness of restoration projects for fish because of inadequate investment in monitoring. While many projects are being conducted with the goal of improving riverine habitat for fish, Katz et al. (2007) show that most of these projects lack designs to link restoration actions with the response of the targeted species.

Without incorporation of an appropriate spatial and temporal context to assess the potential fish response, the real effectiveness of the restoration efforts could be under or over estimated

(Cooper and Mangel 1999, Isaak and Thurow 2006). Due to fish behavior and the linear dependence of riverine communities, the effects of restoration projects should be expected to extend beyond the limits of the restoration project. The connectivity between spawning and rearing life stages of anadromous salmonids can link widely dispersed habitat areas (Kocik and Ferreri 1998, Mangel et al. 2006). Focusing entirely on the reach level can yield little or misleading information about the scale that fish populations are affected (Fausch et al. 2002).

What constitutes effective restoration for salmonids needs to be assessed by how it improves existing habitat and biotic linkages (Jansson et al. 2007, Lake et al. 2007), but this needs to be considered within the historical capacity for habitat linkage within a system (McKean et al. 2008). As a word of caution, Rahel (2007) explains how efforts to connect habitats can go wrong if the habitats reconnected were separated by true biogeographical barriers that preceded human intervention, or when a renewed linkage allows access by a subsequently established invasive species. With the depletion of target species over several decades, other native fish and aquatic species may have become more prominent. It is possible that the subsequently established community could offer a degree of biotic resistance (Ward et al. 2008) and limit the reintroduction or enhancement of formerly prominent target species.

The primary goal in the Middle Methow is to measure the response of target fish species (steelhead, Chinook salmon) to an intensive stream restoration project planned by Reclamation in 2014. Because we wish to measure the response of highly mobile fish populations, fish sampling extends beyond the bounds of the restoration project. Reasonable bounds for initial sampling were based on the geomorphic characteristics of the Methow system (Reclamation, unpublished data) and on recent literature regarding the extent of spatial relationships for fish species important to the restoration efforts in the Methow watershed: Chinook (Isaak and Thurow 2006, Neville et al. 2006, McKean et al. 2008), steelhead (Hendry et al. 2002), and bull trout (Baxter and Hauer 2000, Rieman and Dunham 2000). Sampling of fish in similar unconstrained reaches upstream and downstream of the project area, and constrained areas between these reaches, allows an assessment of the role of habitat size and connectivity. In recognition of the potential scale needed to assess the fish response (Fausch et al. 2002, Schick and Lindley 2007, McKean et al. 2008), the project reach has been surrounded with fish monitoring devices (e.g., smolt traps, PIT tag interrogation systems) to detect movement in and out of the project area. Much collaboratation takes place with existing fish monitoring efforts within the Methow. With funding from Douglas County PUD and NMFS, biologists from the Washington Department of Fish and Wildlife (WDFW) simultaneously conduct smolt trapping, PIT tagging, and detecting PIT tagged fish with PIT tag interrogation systems in the mainstem Methow and lower Twisp River. We collaborate with biologists from Yakama Nation, who are planning to conduct nutrient enhancement studies to test effect on fish production. These activities benefit data collection and result in cost efficiencies for all projects.

Study design protocols developed by the action agencies for effectiveness monitoring research (Hillman and Giorgi 2002, Hillman 2003) require that studies adhere to statistically valid study designs that implement treatment and control sites and/or a pre- and post-treatment design. This project incorporates the statistical rigor called for by Isaak and Thurow (2006), and it uses a set of validated methods of evaluation and reporting called for by Palmer et al. (2005). Information gained from this intensive and extensive project will help ensure that the millions of dollars planned to implement riverine restoration in the Methow watershed and the greater Pacific Northwest will be available for adaptive learning. A key question for the region that will be addressed is: Can large river restoration efforts be effective enough to meet Reclamation's fisheries enhancement goals as required by the NMFS's Federal Columbia River Power System Biological Opinion?

The degree of retention of natal fish and amount of movement from and into a stream reach are important indicators of the value of the reach to fish production (Harvey 1998). Longitudinal differences in habitat availability, food availability, stream temperature, and predation risk within a stream present habitat and bioenergetic heterogeneity for fish survival and growth. These differences can also exist between tributary habitats and downstream mainstem river habitat. This heterogeneity promotes differential potential for survival and growth between those fish that remain in natal areas and those that move upstream or downstream to new habitat. Van Horne (1983) showed that abundance and density can be misleading indicators of habitat quality, especially for fish that are territorial, such as steelhead, Chinook, and bull trout. Increase in abundance and density may not be the primary response to improved habitat conditions. To measure the effects of restoration efforts on habitat quality and productivity, we will use retention (Harvey 1998) and movement (Winker et al. 1995) data in conjunction with abundance and density data. To assess differential biological performance, we compare age structure, growth, and age at smolting between those fish that stay in natal areas versus those fish that move. To assess retention in, and movement from or into, the restoration reach, we use a combination of within reach and out-of-reach sampling. A network of instream PIT tag interrogation systems and smolt traps are being used to assess differences in biological performance and the magnitude of retention in, and movement from and into, the restoration reach.

Questions, Assumptions, Hypotheses, Critical Uncertainties, and Objectives:

Questions (Q)

The pre-treatment phase of the project is designed so that specific questions about the response of target fish species (Chinook, steelhead, and bull trout) to the restoration actions can be addressed. During the pretreatment phase, we are conducting modeling to predict response to treatment. This modeling effort is informing us about data gaps, sensitivity of key variables, and ability to detect response based on variability of data. The primary questions being addressed include:

Q1) What is the difference in habitat availability and suitability between the restoration reach and geomorphically similar reaches upstream and downstream?

Q2) What is the difference in fish productivity between the restoration reach and geomorphically similar reaches upstream and downstream?

Q3) Will and did the implementation of the project in the restoration reach increase stage-specific survival of target fish species?

Q4) Will and did the implementation of the project in the restoration reach increase parr and/or smolt production?

Q5) Was the response of the target species large enough to make a difference in the probability of their persistence in the Methow watershed?

The pre-treatment phase of the project is designed so that specific questions about the response of target fish species (Chinook, steelhead, and bull trout) to the restoration actions can be addressed. During the pretreatment phase, we are conducting modeling to predict response to treatment. This modeling effort is informing us about data gaps, sensitivity of key variables, and ability to detect response based on variability of data. The primary questions being addressed include:

Q6) How much food is currently available to fuel fish production?

Q7) How does food availability compare to the demand by fish for those resources?

Q8) How much additional fish production could be supported in the restoration segment of the Methow River via the restoration of off-channel habitats?

Assumptions (A)

Several assumptions are inherent in our approach to ensure that these questions can be answered after implementation of the restoration actions:

A1) Current fish productivity in the restoration reach is limited by reach-specific habitat conditions. [Limiting factors concept]

A2) The primary factors contributing to pattern and magnitude of growth of fish are stream temperature, food quantity, and food quality. [Bioenergetics concept]

A3) Growth of juvenile fish is a determinant of age at smolting and degree of residualism. [Bioenergetics concept]

A4) Degraded longitudinal and lateral habitat connectivity and life-stage connectivity are currently limiting fish production. [Connectivity concept]

A5) The restoration reach does or could provide an important rearing capacity for juvenile fish spawned within the reach (“natal”) and for fish spawned elsewhere in the Methow watershed (“non-natal”). [Connectivity concept]

A6) Production of target fish species relies on longitudinal connectivity with other spawning and rearing areas. [Connectivity concept]

A7) The restoration effort will substantially increase the habitat quality and degree of lateral connectivity with the floodplain. [Implementation success]

A8) Past and current hatchery management practices for production of steelhead and Chinook may limit response to restoration efforts depending on the remaining genetic diversity in the Methow system. [Biotic resistance concept: wild and hatchery fish interactions]

A9) Presence and response of existing non-target fish and aquatic species could limit the response of the targeted fish species to the restoration actions. [Biotic resistance concept: aquatic community interactions]

Hypothesis (H)

Our “working hypotheses” are present below in roughly the chronological order that they will be addressed during the life of the project.

Role of habitat in fish productivity and expression of anadromy

H1: Pre-treatment expression of anadromy is limited by current physical habitat conditions within the treatment reach. [Limiting factors concept]

H2: Pre-treatment growth of parr and/or age at smolting is limited by temperature and/or food. [Bioenergetics concept]

H3: Pre-treatment fish growth, survival, and expression of anadromy are limited by lack of connectivity of habitats within the treatment reach. [Intra-connectivity concept]

H4: Pre-treatment fish growth, survival, and expression of anadromy are limited by lack of connectivity of habitats between the treatment reach and neighboring stream reaches. [Inter-connectivity concept]

Effectiveness of restoration for increasing fish productivity and expression of anadromy (Pre vs Post Treatment)

H5: Restoration efforts increased capacity for targeted fish species by improving and/or increasing spawning and rearing space in the restoration reach. [Limiting factors concept]

H6: Restoration efforts increased capacity for targeted fish species by improving thermal properties and/or food production in the restoration reach. [Bioenergetics concept]

H7: Restoration efforts improved survival of natal parr: Parr that are natal to the restoration reach but move, downstream or upstream, have similar or different growth, age structure at smolting, and survival to those that stay in this section. [Intra-connectivity concept]

H8: Restoration efforts improved survival of non-natal parr: Parr that move from other natal areas and into the restoration reach have similar or different growth, age structure at smolting, and survival to those that stay in their natal area. [Inter-connectivity concept]

H9: Past or current hatchery management practices did not limit the response of the targeted fish species. [Biotic resistance concept: wild and hatchery fish interactions]

H10: Response from other members of the fish assemblage (e.g., non-anadromous rainbow trout, mountain whitefish, brook trout, and sculpin) and other members of the aquatic community (e.g., competitors, predators) did not limit the response of the targeted fish species. [Biotic resistance concept: aquatic community interactions]

Critical Uncertainties (CU)

CU1) Effect of hatchery fish program: limitations of response of wild fish because of past, current, and near-future hatchery management (e.g., change in release numbers, location of releases, size of releases, or stock(s) released).

CU2) Confounding effect of recent and near-future changes in water management, e.g., changes to MVID.

CU3) Confounding effect of recent and near-future restoration efforts within control reaches or in other areas of the watershed.

CU4) Commitment from PUD and WDFW for smolt trapping, PIT tagging, and installing/maintaining PIT tag interrogation systems are key elements for the success of this project.

CU5) Extent and nature of the restoration actions that will be implemented in the restoration reach.

Objectives

The primary objectives for the sampling in the Middle Methow are:

Objective 1. Assess current productivity and connectivity of the restoration reach and neighboring reaches, and their tributaries, with emphasis on target fish species Chinook, steelhead, and bull trout.

Objective 2. Assess changes in fish population metrics as a result of stream restoration actions in the treatment reach.

B. Fish Survey Scope and Methods:

1) Methow River Basin Population Surveys

During 2009-2012, USGS-CRRL performed pre-treatment fish surveys at many sites within 4 mainstem reaches of the Methow River and 10 side channels. An additional side channel, MVID (rkm 72) has recently been added to the sampling regime The MVID is a relatively unique and large side channel that has become a primary target for restoration. The annual sampling, and in some places multiple samplings within a year, of these sites has provided a basin-wide context for the treatment of a large segment of the Middle Methow River. A list of the major fish survey methods and analyses are shown in Table 1. . Sites in two upstream mainstem reference reaches based on their relative lack of disturbance, proximity to the restoration reach, and relative unconfined geomorphology: 1) Upper Methow River (the unconfined reach within Big Valley and downstream of Wieman Bridge, rkm 85-90), and 2) Chewuch River (rkm 4-11). An additional downstream control reach ("Silver Reach", aka "M3", rkm 57-64) was chosen for sampling based on its similar level of disturbance as that found in the restoration reach, based on its proximity to the restoration reach, and because of its unconfined geomorphology. Table 2 provides a list of fish assessment activities and their timing in the Methow watershed during the 2009-2012 effort.

The fish assemblage in the Middle Methow is primarily composed of native fish species, but non-natives, particularly brook trout, are present. The salmonid fish species observed to date in the mainstem and side channels of the Middle Methow reaches are provided in Table 3. Other fish species observed include species of sculpin, dace, sucker, redside shiner, and lamprey.

Table 1. Pre-treatment data collection and analysis in 2009-2012.

Assessment / Methods	Sampling design	Analysis
Fish assemblage/abundance/density		
Snorkeling	Fish > 150 mm: Mar, Jul-Nov (n=9)	Fish use; seasonal relative abundance
Smolt trapping	Daily trapping; marked fish for efficiency	Annual out-migration; timing of movement
Electrofishing	Tributaries (4), side channels (2-3); mainstem (restoration reach, 3 controls)	Fish use; seasonal abundance (#/m^2, g/m^2)
Juvenile growth/survival		
Electrofishing	Capture-recapture	Change in length and weight; condition
Smolt trapping	Capture-recapture	Change in length and weight; condition
PIT tagging	Capture-recapture	Individual growth; survival; condition
Juvenile age structure		
Smolt trapping	Daily trapping; marked fish for efficiency;	Length-frequency; age analysis
PIT tagging	Capture-recapture	Individual age at size; survival; habitat use
PIT tag readers	Detection of PIT-tagged fish	Individual age at moving and/or smolting
Juvenile movement		
Electrofishing	Capture-recapture	Natal area; time in reach; survival
Smolt trapping	Capture-recapture	Time in reach; survival; young-of-year movement
PIT tagging	Capture-recapture	Time in reach; survival
PIT tag readers	Detection of PIT-tagged fish at key locations (mainstem, tributaries, and side channels)	Time in reach; survival
Adult return		
Redd surveys	Continuous, nearly 100%	Abundance, smolt-to-adult survival
PIT tag readers	Detection of PIT-tagged adults at key locations (mainstem, tributaries, and side channels)	Adult run size to the Methow
Wells Dam counts	PUD methods at dams	Abundance, smolt-to-adult survival

Table 2. List of fish assessment activities and their timing in the Methow watershed in 2009-2012.

Activity/Site or action	Who	Timing	Fish monitoring and handling activities
Smolt trapping			
Methow or Chewuch R.-ab treatment reach	USGS	Mar-Nov+	Assemblage, abundance, length, weight, PIT tag/detection
Twisp R.	WDFW	Mar-Nov+	Assemblage, abundance, length, weight, PIT tag/detection
Methow-at McFarland	WDFW	Mar-Nov+	Assemblage, abundance, length, weight, PIT tag/detection
PIT tag interrogation systems			
Beaver Cr. (Stokes)	USGS	Jan-Dec	Movement data
Gold Cr. (lower, upper)	USGS	Jan-Dec	Movement data
Libby Cr. (lower)	USGS	Jan-Dec	Movement data
Chewuch R. (mouth)	USGS	Jan-Dec	Movement data
Methow -ab Chewuch R.	USGS	Jan-Dec	Movement data
Side-channels (n=2 or more) within reference reach(es)	USGS	Jan-Dec	Movement data
Side-channels (n=2 or more) within treatment reach	USGS	Jan-Dec	Movement data
Methow “M2” -ab Twisp R.	USGS	Jan-Dec	Movement data
Twisp R.	WDFW	Jan-Dec	Movement data
Methow mouth	WDFW[1]	Jan-Dec	Movement data
Instream fish assessment			
Snorkel-mainstem	USGS	Mar-Nov	Assemblage, abundance
Electrofish-4 mainstem areas	USGS	Mar-April; Jul-Oct	Assemblage, abundance, length, weight, PIT tag; movement
Electrofish-4 tributaries	USGS	Mar-April; Jul-Oct	Assemblage, abundance, length, weight, PIT tag; movement
Electrofish-4 side channels	USGS	Mar-April; Jul-Oct	Assemblage, abundance, length, weight, PIT tag; movement
Hook and line	WDFW, USGS	Jan-Dec	Assemblage, abundance, length, weight, PIT tag; movement
Redd surveys	WDFW, YN	Jan-Dec	Spawner abundance and distribution, timing of spawning
PIT tagging	USGS, WDFW	Jan-Dec	Movement, growth, survival

Table 3. Salmonid fish species found in the Middle Methow (from Tibbits et al. 2012). Fish codes are: RBT = juvenile steelhead and rainbow trout, CTT = cutthroat trout, CHN = Chinook, COH = coho, and BLT = bull trout.

Watershed	Reach or section	Methow (rkm)	RBT	BRK	CTT	CHN	COH	BLT	WHT
Methow River									
	Lower Methow	(843. stream rkm)							
	SC-Blaine (SC_35.0_R)	56.0	P	P	A	P	P	A	A
	Mainstem site	61.0	A	A	P	A	A	P	P
	Middle Methow	65.0-81.0	P	A	P	P	P	P	P
	SC1-Sugar dike (SC_41.7_L)	66.0	P	A	A	P	P	A	P[b]
	SC2-Habermehl (SC_44.3_R)	70.0	P	P	A	P	P	P[b]	P
	SC-3R Piggot (SC_47.0_R)	75.0	P	P	A	P	P	A	A[a]
	SC3-Bird (SC_49.0_R)	76.0	P	A	A	P	P	A	A
	Upper Methow	85.0-93.0	P	P	A[a]	P[c]	P	A[a]	A[a]
	SC4-Heath (SC_53.9_L)	87.0	P	P	A	P[c]	P	A	P
	SC-Cable Car (SC_55.0_L)	89.0	P	A[a]	A	P[c]	P	A	A
	SC5-Stansberry (SC_58.7_L)	94.5	P	P	A[a]	P[c]	A	P[b]	P
Chewuch River		843.080.							
	Chewuch – Rotary Screw Trap	1.0	P	A	P	P	P[b]	A[a]	P
	Chewuch – Reach 1	2.0-14.0	P	P	A	P	A	A	P[b]
	SC-Wind Haven (SC_04.0_R)	6.0	P	P	A	P	A	A	A
	Chewuch - Reach 3	20.0-22.0	P	A	P	P	A[a]	A[a]	P
	SC- Upper Chewuch (SC_14.0_L)	22.0	P	A	A	P	A	A	A

Extensive PIT tagging of most species that exceeded the minimum size for tagging was done to track movements and assess growth and survival. Table 4 shows the general targets for the PIT-tagging effort in the Methow River Basin. To gage the adequacy of the number of fish tagged, we conducted an exercise of allowing for attrition and expected detection efficiency at various downstream detectors (Table 5 and Table 6). The current levels of PIT tagging allow for adequate numbers to assess survival of downstream migrating fish from the Methow River in general, but not from necessarily from site-specific areas within the Methow.

Table 4. Target levels for PIT-tagging efforts for Chinook salmon and steelhead in the Methow watershed, 2009-2012.

Site	Group	PIT tags	USGS effort of total
Smolt traps (n=2, existing))	WDFW	2,000	0
Smolt traps (n=1, new)	USGS	1,000	1,000
Methow R.-upper	USGS and WDFW	1,500	1,000
Methow R.-treatment	USGS and WDFW	1,000	500
Methow R.-middle	USGS and WDFW	1,000	500
Chewuch River	USGS and WDFW	1,500	1,000
Twisp River	WDFW	500	0
Wolf Creek.	USGS	500	500
Eightmile Creek	USGS	500	500
Beaver Creek	USGS	500	500
Gold and Libby creeks	USGS	500	500
Hatchery(s)	WDFW	5,000	0
	Totals	15,500	6,000

Table 5. Number of PIT-tagged juvenile steelhead and spring Chinook estimated to survive and to be detected, based on 1,000 and 250 tags, at various end points based on site where PIT tagged, age at tagging, and age at smolting. These estimates were derived from estimated survival and PIT tag detection efficiency at various sites in the Methow and Columbia rivers

PIT tagging site	End point	Steelhead (n = 1,000) (Age-1 parr to age-3 smolt) Number surviving	Number detected	Percent detected	Spring Chinook (n = 1,000) (Age-1 parr to age-2 smolt) Number surviving	Number detected	Percent detected
Chewuch	M2-downstream end	503	636	64%	670	770	77%
	Methow mouth	419	705	70%	558	826	83%
	Columbia mouth	76	742	74%	155	863	86%
Upper Methow	M2-downstream end	513	618	62%	684	761	76%
	Methow mouth	427	692	69%	570	820	82%
	Columbia mouth	78	731	73%	158	859	86%
M2-within	M2-downstream end	540	360	36%	720	480	48%
	Methow mouth	450	489	49%	600	616	62%
	Columbia mouth	82	558	56%	167	702	70%
M3-within	M2-downstream end	600	0	0%	800	0	0%
	Methow mouth	500	224	22%	666	290	29%
	Columbia mouth	91	340	34%	185	465	47%

PIT tagging site	End point	Steelhead (n = 250) (Age-1 parr to age-3 smolt) Number surviving	Number detected	Percent detected	Spring Chinook (n = 250) (Age-1 parr to age-2 smolt) Number surviving	Number detected	Percent detected
Chewuch	M2-downstream end	126	159	64%	168	192	77%
	Methow mouth	105	176	70%	140	206	83%
	Columbia mouth	19	186	74%	39	216	86%
Upper Methow	M2-downstream end	128	155	62%	171	190	76%
	Methow mouth	107	173	69%	142	205	82%
	Columbia mouth	19	183	73%	40	215	86%
M2-within	M2-downstream end	135	90	36%	180	120	48%
	Methow mouth	112	122	49%	150	154	62%
	Columbia mouth	20	140	56%	42	176	70%
M3-within	M2-downstream end	150	0	0%	200	0	0%
	Methow mouth	125	56	22%	167	73	29%
	Columbia mouth	23	85	34%	46	116	47%

Table 6. Estimated survival and PIT tag detection efficiency at various sites in the Methow and Columbia rivers. Those values in bold **are the ones that differ between juvenile steelhead and spring Chinook. Values for survival and detection efficiency are based on available literature and best professional judgment.**

			Steelhead (Age-1 parr to age-3 smolt)				Spring Chinook (Age-1 parr to age-2 smolt)			
Reach	Site		Between survival	Site survival	PIT tag detection efficiency	Steelhead Notes	Between survival	Site survival	PIT tag detection efficiency	Chinook Notes
Chewuch	Chewuch									
	[rearing to smolt phase]	Between	**0.60**			a	**0.80**			a
Chewuch	PTIS-1 (USGS)	At		1.00	0.70	a		1.00	0.70	a
		Between	0.95			a	0.95			a
Chewuch	Smolt Trap-1 (USGS)	At		0.98	**0.10**	b		0.98	**0.07**	b
		Between	1.00			a	1.00			a
M2	PTIS-2 (USGS)	At		1.00	0.60	a		1.00	0.60	a
		Between	0.90			a	0.90			a
McFarland	Smolt Trap-2 (WDFW)	At		0.98	**0.05**	c		0.98	**0.04**	c
		Between	0.85			a	0.85			a
Methow mouth	PTIS-3 (USGS)	At		1.00	0.40	a		1.00	0.40	a
		Between	0.90			a	0.90			a
Columbia River	Wells Dam	At		1.00	0.00			1.00	0.00	
		Between	0.90			a	0.90			a
Columbia River	Rocky Reach Dam	At		1.00	0.02	d		1.00	0.02	d
		Between	0.90			a	0.90			a
Columbia River	Rock Island Dam	At		1.00	0.05	d		1.00	0.05	d
		Between	**0.82**			e	**0.88**			h
Columbia River	Wanapum Dam	At		1.00	0.00			1.00	0.00	
		Between	**0.82**			e	**0.88**			h
Columbia River	Priest Rapids Dam	At		1.00	0.00			1.00	0.00	
		Between	**0.82**			e	**0.88**			h
Columbia River	McNary Dam	At		1.00	0.25	f		1.00	0.25	f
		Between	**0.81**			g	**0.87**			i
Columbia River	John Day Dam	At		1.00	0.25	d		1.00	0.25	d
		Between	**0.81**			g	**0.87**			i
Columbia River	The Dalles Dam	At		1.00	0.00			1.00	0.00	
		Between	**0.81**			g	**0.87**			i
Columbia River	Bonneville Dam	At		1.00	0.36	d		1.00	0.36	d
		Between	0.85				0.85			
Columbia River	Estuary	At		1.00	0.03	d		1.00	0.03	d

Notes for Attachment Table 6:

a Estimate based on professional opinion.

b Data from WDFW's Twisp smolt trap for 2005. Reference: Snow, C. and A. Fowler. 2006. Methow River Basin Spring Chinook and Steelhead Smolt Monitoring in 2005. Washington Department of Fish and Wildlife, Olympia WA.

c WDFW 2005 Methow trap with increased estimate based on professional opinion. Reference: Snow, C., and A. Fowler. 2006. Methow River Basin Spring Chinook and Steelhead Smolt Monitoring in 2005. Washington Department of Fish and Wildlife, Olympia WA.

d USGS CRRL data: (Beaver creek weir - 2006).

e Average survival for 1998-2002 from RIS to McN: 0.55 (0.82*0.82*0.82 =0.55), includes passage over dam and its pool. Reference: FPC (Fish Passage Center). 2008. http://www.fpc.org/survival/juvenile_queries.html (January 2008).

f DE=0.2499 Reference: Columbia River DART (Data Access in Real Time). 2008 http://www.cbr.washington.edu/dart/ (5 January 2008).

g Average survival from McN-BON: 0.54 (0.81*0.81*0.81=0.53), includes passage over dam and its pool Reference: Williams, J.G., S.G. Smith, W.D. Muir, B.P. Sandford, S. Achord, R. McNatt, D.M. Marsh, R.W. Zabel, and M.D. Scheuerell. 2004. Effects of the Federal Columbia River Power System on Salmon Populations. National Oceanographic and Atmospheric Administration, Fisheries Ecology Division, Seattle, WA.

h Average survival for 1998-2002 from RIS to McN: 0.69 (0.88*0.88*0.88= 0.68), includes passage over dam and its pool. Reference: FPC (Fish Passage Center). 2008. http://www.fpc.org/survival/juvenile_queries.html (January 2008).

2) Middle Methow River Watershed Treatment Studies

Two upstream reference reaches have been identified based on relative lack of disturbance, proximity to the restoration reach, and relative unconfined geomorphology: 1) Upper Methow River (UMR; the unconfined reach within Big Valley and downstream of Wieman Bridge), and 2) Chewuch River (CHE). A downstream control reach (LMR; "Silver Reach") has been identified based on similar disturbance as that found in the restoration reach, proximity to the restoration reach, and relative unconfined geomorphology: mainstem Methow River downstream of the restoration reach.

Within each of the four reaches (1 treatment, 3 control), fish were sampled in a variety of ways. In the reference and control reaches, a snorkel efforts was conducted at least once during the months of March, August, September, and October. A continuous sampling approach within 3-7 km of stream was conducted (Table 7), from upstream to downstream counting fish over 150 mm in length, largely following protocols developed by Brenkman and Connolly (2008), which corresponds with previous work by Torgersen et al. (1999), Torgersen (2002), and Fausch et al. (2002).The protocol used for these snorkel surveys is provided in Appendix E3.1.

Table 7. Streams snorkel-surveyed for fish population, 2009. Stream reaches are listed in an upstream to downstream pattern within a watershed.

Watershed Stream reach or section	Starting rkm	Ending rkm	Total rkm	Number of snorkelers	Number of times sampled within year	Estimated time taken to complete survey (hrs)
Methow River						
UMR – Big Valley to cable car	92	89	3	3-4	4	2.5
MMR – MVID east to Twisp	72	65	7	4	7	3.5
LMR – Twisp to Golden Doe	61	54	7	4	4	3.5
Chewuch River						
CHE – rkm12 to rkm 8	12	8.6	3.5	3-4	4	2.5

In 2009-2011, point-abundance surveys were conducted at three sites in the M2 reach and one location in the Chewuch River, Upper Methow, and Lower Methow. Three sections of treatment reach (upper, middle, lower) and one section in the reference and control reaches were sampled. Stream margins of one bank of a contiguous section of three pools and three non-pools were sampled using a backpack electrofisher. These surveys were conducted multiple times during the year: one time in March before high flows, one time in July after high flows, and one time in late September or October. This approach is largely derived from Connolly and Brenkman (2008), which corresponds with previous work by Janac and Jurajda (2007) and Quist et al. (2006). Point abundance surveys were conducted one time in March, July, and September. All sites were completed in one day. For each site, we sampled a minimum of three pool and three non-pool habitat units at each site. See Appendix E3.2 for an account of the protocols used.

In 2009, population assessments were conducted on five side channels: three side channels in the M2 reach and two side channels in the Upper Methow reach (Table 8 and Table 9). In 2010-12, the number of side channels sampled was increased to 10 in order to account for the wide variability in connectivity and fish populations observed. Side-channel sampling for population estimates were conducted in multiple seasons in order to gain seasonal information on growth and survival of the target fish. See Appendix E3.3 for an account of the protocols used.

Table 8. Side channel locations and sescriptors in the Middle Methow and associated reaches.

Reach	USGS Code	USGS Name	Other name(s)	RKM	Connectivity at low flow	Metrics (August 2010)			
						Length (m)	No. HUs	No.Pools	Pools/m
M3	MCCB	Blaine		56	Disconnected	285	9	4	0.0140
M2	MVC1	Sugar dike	SC_41.7 L	66	Disconnected	546	19	10	0.0183
M2	MVC2	Habermehl	SC_44.4_R	70	Disconnected	562	17	7	0.0125
M2	MVCP	3R	Pigot	75	Disconnected	268	9	4	0.0149
M2	MVC3	Bird	Whitefish (SC_49.0_R)	76	Disconnected	518	19	9	0.0174
M1	MVCS	Cable Car		89	Disconnected	268	5	3	0.0112
M1	MVC5	Stansberry	SC_58.7_L	94	Connected down	727	23	8	0.0110
M1	MVC4	Heath	SC_53.9_L	87	Connected up&down	330	9	4	0.0121
Chewuch	CHCW	Wind Haven		6	Disconnected	145	5	3	0.0207
Chewuch	CHCU	Upper Chewuch		22	Connected up&down	287	23	11	0.0383

Table 9. Side channel fish sampling by year and month, 2008-2012. Groups of months within similar shading correspond to the seasonal pattern of the sampling design.

Year and month of sampling for fish populaiton estimates

USGS Name	2008								
	3	4	5	6	7	8	9	10	11
Blaine									
Sugar dike									
Habermehl						x			
3R									
Bird						x			
Cable Car									
Stansberry									
Heath									
Wind Haven									
Upper Chewuch									

USGS Name	2009								
	3	4	5	6	7	8	9	10	11
Blaine									
Sugar dike					x	x		x	
Habermehl					x	x		x	
3R									
Bird				x		x		x	
Cable Car									
Stansberry						x		x	
Heath					x	x			
Wind Haven									
Upper Chewuch									

USGS Name	2010								
	3	4	5	6	7	8	9	10	11
Blaine						x		x	
Sugar dike	x					x	x		
Habermehl	x					x	x		
3R						x	x		
Bird	x					x		x	
Cable Car						x	x		
Stansberry	x					x		x	
Heath	x					x			
Wind Haven						x	x		
Upper Chewuch						x		x	

USGS Name	2011								
	3	4	5	6	7	8	9	10	11
Blaine		x					x	x	
Sugar dike		x				x		x	
Habermehl	x					x		x	
3R		x				x		x	
Bird	x					x		x	
Cable Car		x				x		x	
Stansberry	x						x		x
Heath	x						x	x	
Wind Haven		x				x		x	
Upper Chewuch		x					x	x	

USGS Name	2012								
	3	4	5	6	7	8	9	10	11
Blaine		x					x		
Sugar dike		x				x			
Habermehl		x			x				
3R	x					x			
Bird		x				x			
Cable Car	x					x			
Stansberry	x					x			
Heath		x				x			
Wind Haven		x			x				
Upper Chewuch		x				x			

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Appendix E3.1. Protocol for snorkel surveys for fish populations in mainstem Methow reaches.

Snorkel Survey

PURPOSE: To conduct fish counts over reach assessment sections in order to compare fish communities, biomass, and total numbers present based on average snorkel counts over time. These measurements can then be compared to quantitative methods such as point abundance estimates.

AREA OF APPLICABILITY: Any size river, stream, or pool where fish population estimates are desired.

PROCEDURES:

Equipment needed:

- Dry suit
- Wading boots
- Snorkel and mask
- Hood
- Gloves
- Fleece pants and jackets
- PVC tube cut in half with pencil attached
- Water bottles

Method: Start surveys in March before high water. Conduct snorkel surveys every other week through September. One additional survey should be conducted in October and November (weather and flow dependant). Once a year snorkel three consecutive times to address observer variability (Thurow 1994).

Conduct surveys using three to four snorkelers, more or less can be used, depending on river or stream size. Snorkel in a downstream direction perpendicular to flow and evenly spaced out from bank to bank. All sections of the survey unit should be covered, including side channels and back eddies. Snorkeler number counts fish from his head to the right bank. Snorkeler number two counts fish from the head of snorkeler number one to his/her own head. Snorkeler number three counts fish from the head of snorkeler number two to his/her own head, so on and so forth. Snorkeler number four counts fish from the head of snorkeler number three to the left bank.

Count fish only when passing over the fish. This is done to avoid double counting fish (Thurow 1994). If a section of stream contains large numbers of fish (>100), than resnorkel the section and average the number of fish between both counts (Brenkman and Connolly

2008). Be sure to communicate and collaborate with fish counts between snorkelers at the end of every pool or large stretch of sampled reach assessment section.

All salmonids over 150 mm identify to species and count. If possible to count and identify parr by species, this should also be recorded. Record all fish counts on the PVC arm band and transfer to snorkel data sheets as needed. Counted fish in side channels should be recorded as such and marked separately on the data sheet.

Appendix E3.2. Protocol for point-abundance fish surveys in mainstem Methow reaches.

Point Abundance estimates

PURPOSE: A method of sampling near shore to determine fish abundance and fish community structure within a given reach of mid to large size streams and rivers to be used in comparison to snorkel survey estimates.

AREA OF APPLICABILITY: A method to be used for anyone who is hoping to determine fish abundance and changing community structure over time within a given mid to large size stream reach. This is also affective as a comparative method against snorkel survey estimates.

EQUIPMENT:

Backpack electrofisher
Two probes, third in truck as spare
Battery or gasoline for shocker, extra in truck
Dip nets, 3 five foot and 2 aquarium size
Insulated rubber gloves for shocker and netters
Buckets, 3 five gallon, 3 three gallon
MS-222, stock solution of 100 g/L
Measuring board
Weighing scale
Data sheets
Thermometer
Scale envelopes (if desired)
Vials for genetic samples (if desired)
PIT tag gear (if desired, see FIE706, 707)
Meter tape or range finder

PROCEDURES: Surveys are conducted three times a year: one in March-April before high flows, one in late July, and one in late September-early October. Surveyors should complete a point abundance habitat survey prior to sampling each reach. Refer to the Point Abundance Habitat Survey SOP.

Each reach sampled is defined as three consecutive pools and non-pools. All pools under or equal to150 meters and non-pools under or equal to100 meters are sampled completely without sub-sampling.

Pool habitat units that are greater than 150 meters are sub-sampled. Three 25-meter sections are designated in each pool unit. One 25 meter section is completed at the start of the pool unit, one section is in the middle of the pool, and a third section is at the end of the pool.

Non-pool habitat units that are greater than 100 meters are sub-sampled. Two 25 meter sections are sampled in the non-pool units. The first 25 meter section begins near the start of the unit and a second section begins near the end of the unit. The section starts as soon as the unit has clearly transitioned into a definitive habitat unit.

All habitat units are sampled with a backpack electrofisher, shocking upstream until the end of the unit or sub-sample. Ideally, there are three people accompanying the person with the backpack electrofisher – one bucket handler and two netters. Electrofishing is conducted along the stream bank from the water's edge to the length of the outside electrofishing pole (ideally, a 4.5 m swath). If a section of the habitat or sub-sample is not wade-able because of depth or velocity, it should be skipped and this area skipped should be noted on the datasheet.

All species of fish are netted and sampled. Fish collected from a particular unit should be kept in a bucket separate from other sampled units. It may be possible to sample two units in a row before working up the fish from those units. Water temperature, length of units, number of bucket carriers, and fish health should be considered when determining when to stop to work up fish. Fish should be worked up in accordance to the Backpack Electrofishing SOP and to the needs of the surveyors. Fish should be allowed to recover in fresh water and returned to the habitat unit from which they were collected.

Appendix E3.3. Protocol for electrofishing surveys to gain fish populations estimates in mainstem Methow reaches.

Fish Population Estimates

PURPOSE: To estimate fish communities, take samples of and deploy PIT tags in selected habitat units of a small stream to calibrate with population estimates within the stream and snorkel counts.

AREA OF APPLICABILITY: Field personnel conducting cosmic surveys with backpack electrofishers on small streams.

PROCEDURES:

Equipment needed:

- Backpack electrofisher
- Two probes, third in truck as spare
- Battery or gasoline for shocker, extra in truck
- Six block nets (length dependent on stream width)
- Dip nets, 3 five foot and 2 aquarium size
- Insulated rubber gloves for shocker and netters
- Buckets, 6 five gallon, 6 three gallon
- MS-222, stock solution of 100 g/L
- Measuring board
- Weighing scale
- Data sheets
- Thermometer
- Scale envelopes
- Genetic vials
- PIT tag gear (as needed)

Before shocking, a fish-workup station should be set up with all equipment ready to go so the fish can be handled and released as quickly as possible. The station should be set in a location convenient to the units that are to be shocked. During clear warm days, locate the station in the shade if possible. Use caution when moving along the stream to set up the station to minimize fish disturbance.

Throughout the day the stream water temperature should be checked. A good rule of thumb is once before shocking, once midday and once in the late afternoon. If water temperature exceeds 17 ^{o}C shocking operations should cease.

Electrofisher settings will vary with water conductivity. For guidelines see Kolz et al. (1998) or a manual provided by the manufacturer of the electrofisher in use. Standard settings for the low conductivity waters (< 20 microsiemens) of the Methow River on a Smith-Root electrofisher (model POW 12a, 12b) are L2 (waveform: 90 Hz, 1 ms) and 400-600 V.

Electrofishing should begin at the lower end of the downstream-most unit. The crew (typically: 1 shocker, 2 netters, 1 bucket manager) begins working slowly upstream covering all of the water. Depending upon the size of the unit a zigzag pattern may be used. In the Methow River, the typical setup is to use two probes: a 9" diameter cathode and an 18" diameter anode. Around cover or undercut banks the cathode should be used to probe the cover and the anode to draw fish toward the netters. Take care to keep both probes slowly moving so as to never expose any one fish to a long period of high intensity shock. If a fish is shocked and between the probes it is a good idea to spread the probes out to reduce the intensity of the electrical field, until a netter can capture the fish. As fish are netted they should be placed in the bucket immediately. If there are lots of fish more than one bucket may need to be used. When a bucket is full (depends on size of fish but approximately 20 fish per bucket is the maximum advised) it should be placed onshore in the shade and covered to make sure no fish jump out.

One person should be designated to make sure that fresh water is frequently provided to fish being held. The warmer the day and water, the more crucial this becomes. Also try to keep buckets in the shade, move them if necessary but be sure to <u>communicate</u> and keep the fish in best health possible. Look for signs of stress (i.e. fish gulping air at surface of bucket, heavy gilling, fish jumping from bucket). This person should also be able to step in to assist others needs, for example, processing of fish and to again keep a healthy environment for each fish.

For fish workup the fish should be anesthetized by using 1 mL of 100 g/L stock solution of MS-222 in 2 L of water. (See SOP 426 for stock solution instructions) This is a good starting concentration; however anesthetic effectiveness varies by species and water temperature so slight adjustments can be made. Be sure to have fresh water nearby to dilute if the concentration is too strong.

Length and weight should be taken on all fish. On the Methow River studies steelhead over 80mm typically receive a 12-mm PIT tag and over 65mm receive an 8-mm PIT tag (See SOP's 706, 707). Scale samples are taken from all recap fish over 80mm by gently scraping with an exacto blade just posterior to the dorsal fin midway between the lateral line and the middorsal area on the left side of the fish. Genetic samples are taken on the first 10 fish of each salmonids species by clipping the top or bottom corner of the caudal fin with sterilized stainless steel scissors. The fish should be looked over for scars, disease, etc. and these should be noted on the data sheet.

Once fish have been worked, they should be placed in a bucket of fresh water and allowed to recover until they have regained equilibrium and swimming ability. Fish should be released into the unit from which they were captured, preferably into calm water near cover.

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Appendix E4: Middle Methow River Fish Food Web Study

Information Source:

Bellmore, J. R., Colden V. Baxter, Patrick J. Connolly and Kyle Martens 2012, "The floodplain food web mosaic: A study of its importance to salmon and steelhead with implications for their recovery, Ecological Monographs, in press.

Reclamation funded a food web study of the main channel and a representative sample of side-channel types in the Middle Methow River (Figure 1). The study served as partial fulfillment of the requirements for J. Ryan Bellmore's Ph.D. dissertation. The study included annual measurements of "production, food demand and diet composition for the fish assemblage with estimates of vertebrate prey base productivity, to quantify food webs within the main channel and five different, intact side channels; ranging from side channels that remain connected to the main channel at low flow to those reduced to floodplain ponds" (Table 1 and Figure 2).

The key findings include:

1) Production and food consumption in the mainstem Methow River is dominated principally by whitefish and sculpin (approximately 95%), these, and other fishes that were not the target of habitat restoration efforts, consumed 64% and 47% of the prey resources that were found to be important to fueling Chinook and steelhead production in the main channel (Figure 3).

2) In contrast, non-target fishes consumed a much smaller percentage of the food resources important to Chinook and steelhead in both connected (approx. 10%) and disconnected (approx. 25%) side channels. As a result, carrying capacity was 250% higher per meter squared for the listed species in the side channels versus the main channel.

3) Flow of invertebrates on average 19% greater to Chinook and 95% less to sculpins in the seasonally disconnected side channels compared to connected side channels and the main channel

4) Based on existing food resources, however, the potential amount of Chinook and steelhead production that could be supported on a per area basis in each habitat was on average 25X higher than measured production levels for Chinook and 15X greater for steelhead (Figure 4).

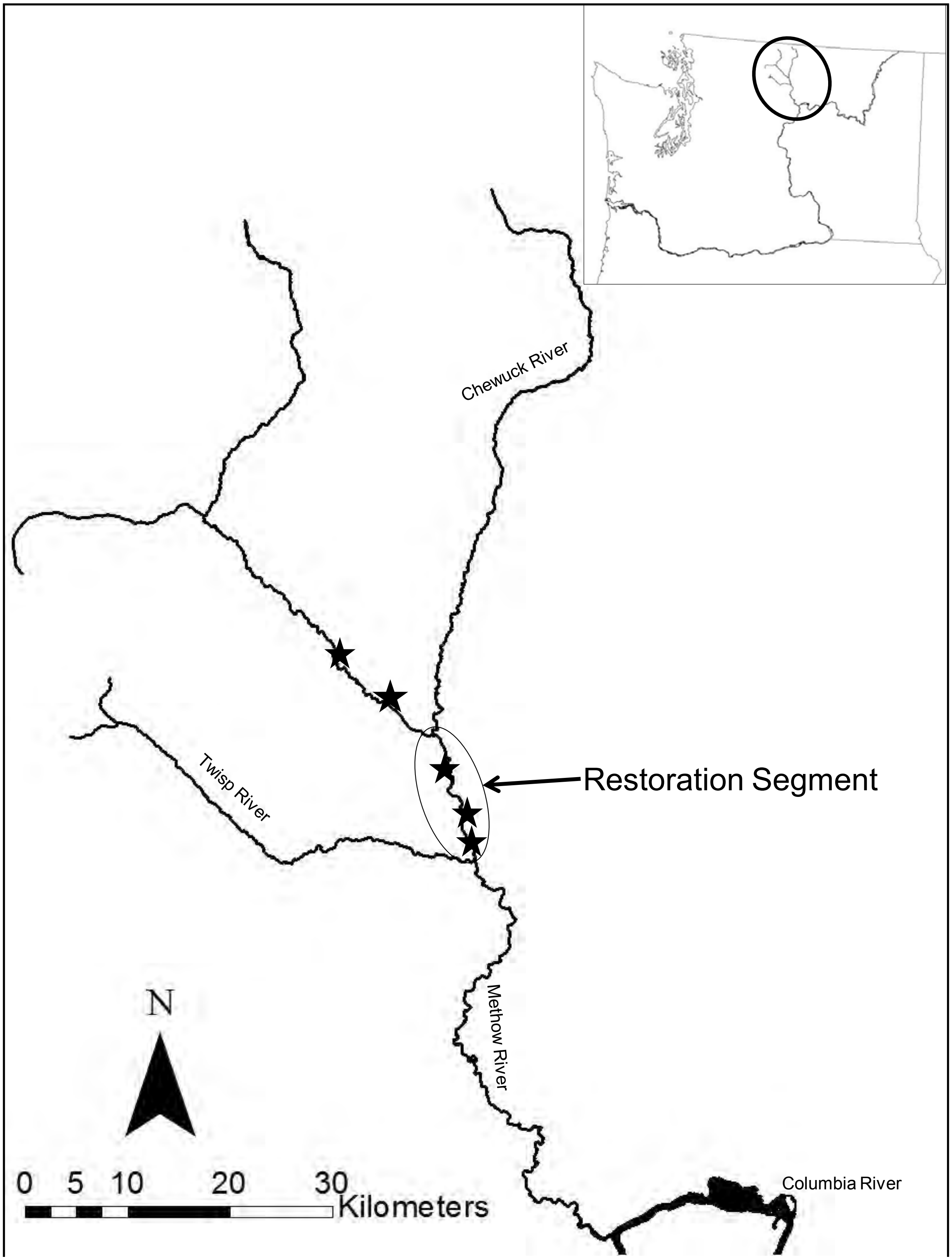


Figure 1. Food Web Study Area, from Bellmore et al. 2012, figure 1.

Table 1. from Bellmore et al. 2012. Habitat characteristics of the six habitats sampled in this study for 2009, including: whether or not habitats had surface water hydrological connectivity during low flows; whether or not the habitats were scoured during high flows; approximate habitat area during high and low flows; habitat length during high flows when all habitat were fully connected to the main channel; and average daily water temperatures for summer, fall, and winter. Y = Yes, and N = No.

		Surface water connection?			Habitat area (m^2)			Temperature (C)		
Habitat type	Habitat name	Downstream	Upstream	Bed scour?	High flow	Base flow	Length (m)	Summer	Fall	Winter
Main channel	*Main ch*	Y	Y	Y	-	760000	17000	15.2	-	4.2
Side channel	*Con updwn*	Y	Y	Y	3550	2875	310	13.6	6.9	5.4
Side channel	*Con dwn*	Y	N	Y	13975	6325	690	11.4	6.7	5.1
Side channel	*Discon lrg*	N	N	Y	6425	2200	490	14.9	7.4	5.4
Side channel	*Discon sml*	N	N	Y	7500	1100	605	16.1	4.7	-
Side channel	*Discon noscr*	N	N	N	6150	3400	582	13.2	4.9	1.4

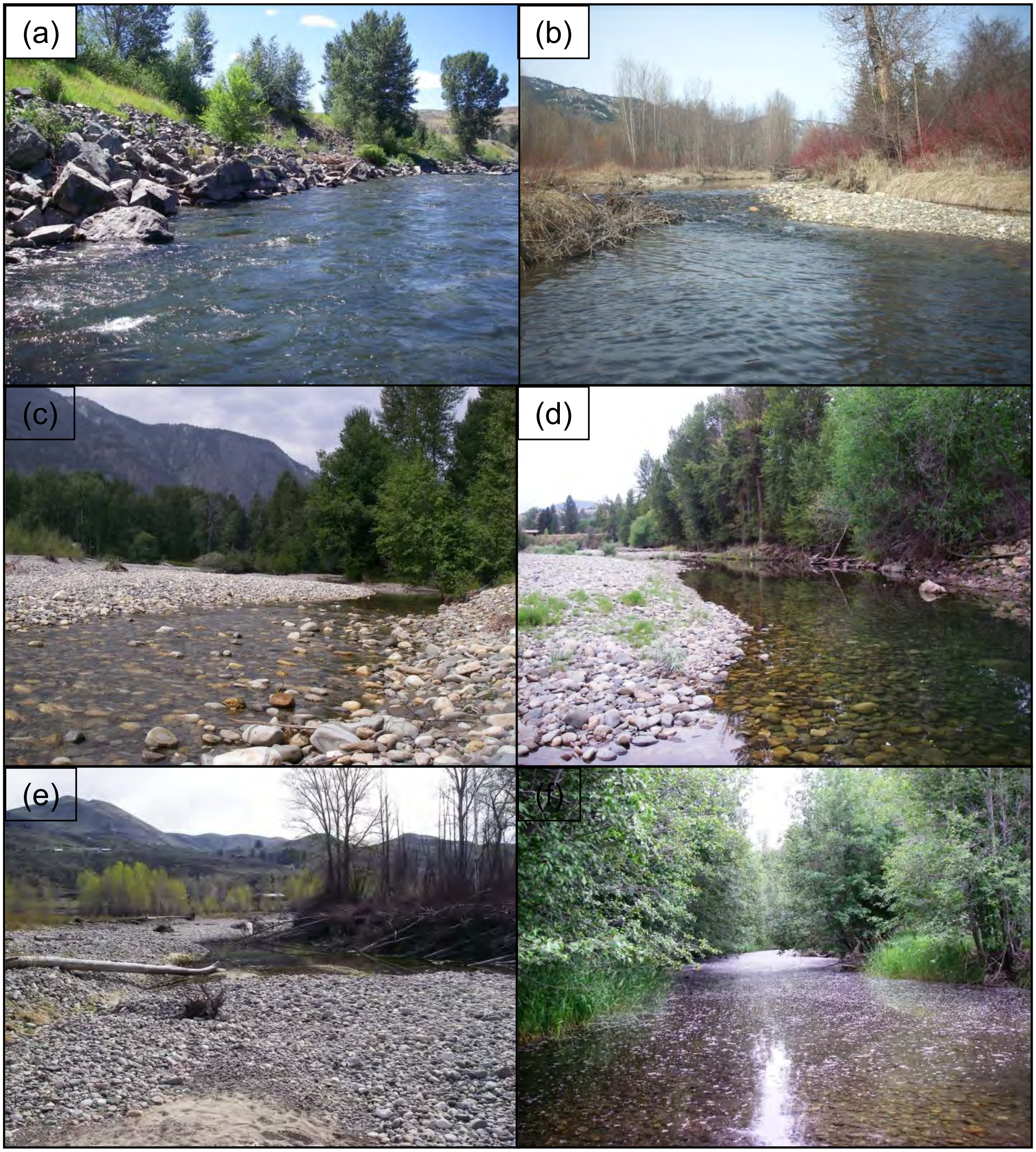
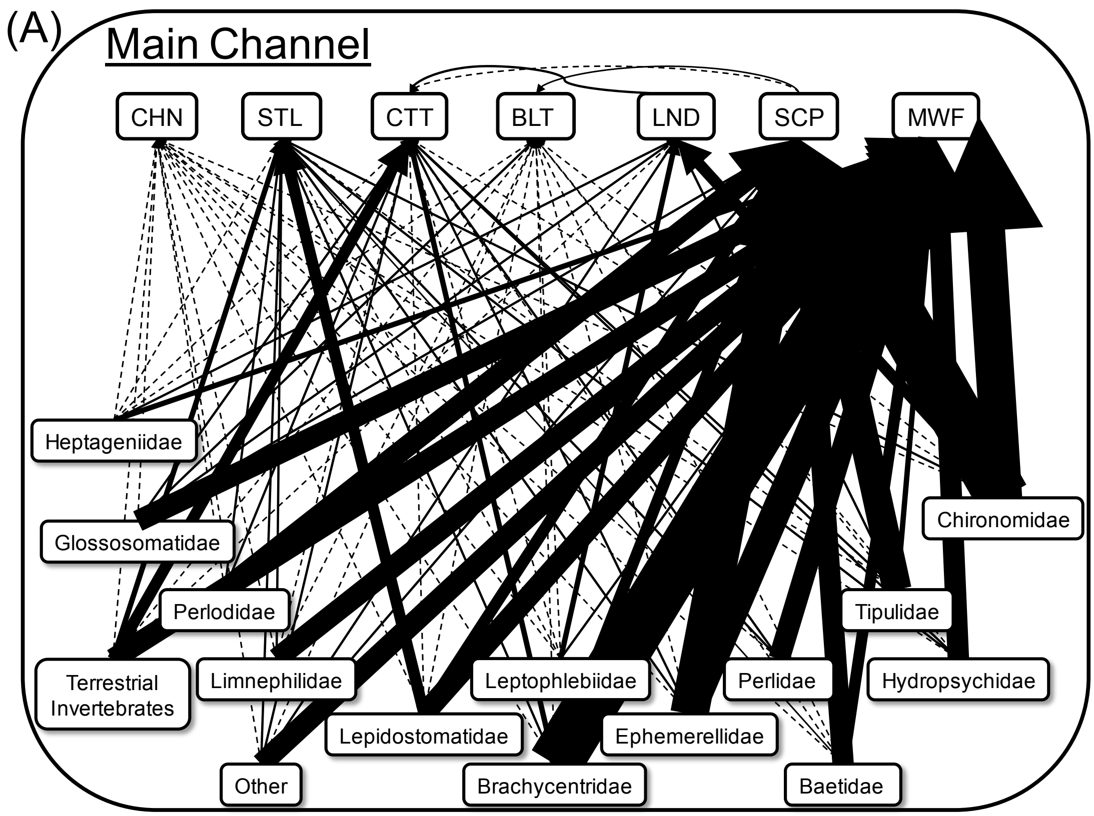


Figure 2. from Bellmore et al. 2012, Appendix A. Photographs of a rip-rapped bank along main channel Methow River (A), and the five side channels included in this study. Side channels, described by their level of hydrologic connectivity during this study, included: (B; *con updwn*) retained upstream and downstream surface water connection with main channel throughout year, (C; *con dwn*) retained downstream connection with main channel, (D; *discon lrg*) disconnected from main channel during base flow, but retained large pool; (E; *discon sml*) disconnected with only one small pool, and (F; *discon noscr*) disconnected from main channel and in contrast to channels D and E, did not scour during high flows.



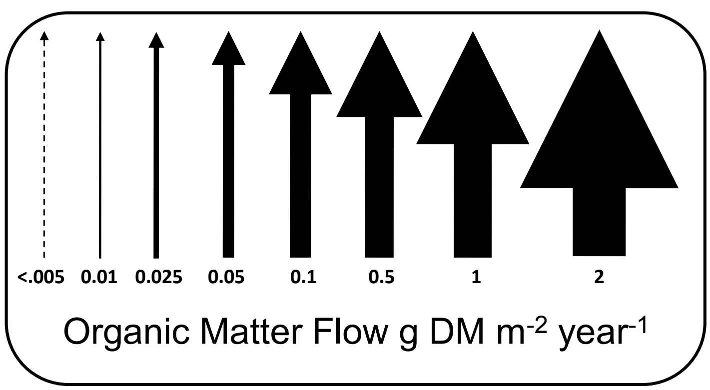


Figure 3. Organic matter flow to the fish community in the a main channel segment of the Middle Methow River, after Bellmore et aol. 2012, figure 5.

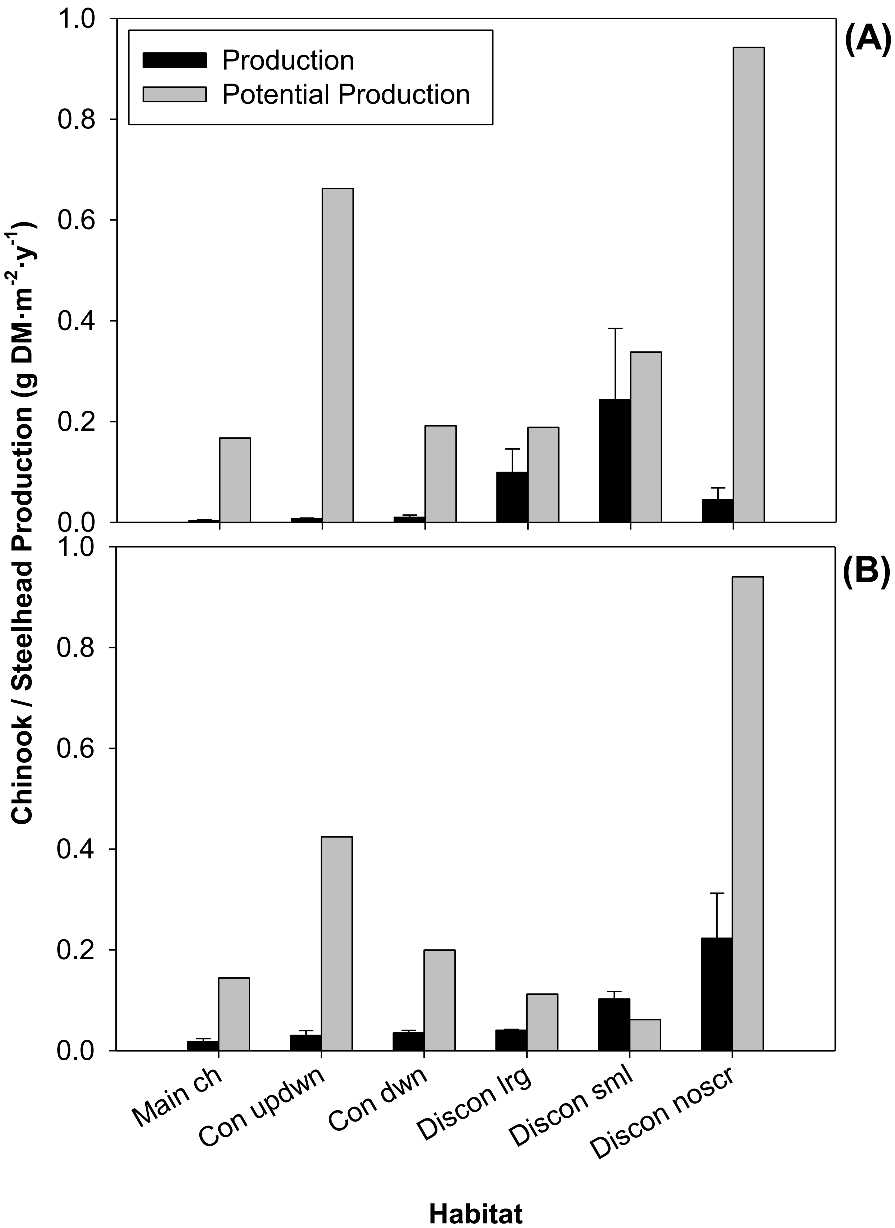


Figure 4. From Bellmore et al. 2012, figure 7.

Appendix E5: Planning Middle Methow Post-treatment Studies for the Period 2014-2016

Information Source: Draft Habitat and Fish Production Relationships in the Methow River Watershed: Survival and Food Limitation Studies, July 2012, prepared by: Patrick J. Connolly, Ph.D., Lead Research Fish Biologist, Project Leader--Watershed Restoration Ecology, phone: 509-538-2299 ext 269; FAX: 509-538-2843; email: pconnolly@usgs.gov; Kyle D. Martens, Fisheries Biologist, phone: 509-538-2299 ext 238; FAX: 509-538-2843; email: kmartens@usgs.gov, and J. Ryan Bellmore, Fisheries Biologist, phone: 509-538-2299 ext 205; FAX: 509-538-2843; email: jbellmore@usgs.gov. USGS-Western Fisheries Research Center, Columbia River Research Laboratory, 5501A Cook-Underwood Rd.; Cook, WA 98605

A. Middle Methow Fish Production Analysis Tasks

Reclamation and USGS-CRRL are creating a 2013-2016 interagency agreement for the Middle Methow post treatment analytical structure and field study design. The agreement will follow the organizational and analytical structure laid out in Appendix B.

1) The habitat program will identify (describe, map, delineate and quantify) the habitat improvements anticipated in 2012-2013. USGS-CRRL and Reclamation will develop assessment metrics that can be incorporated into actor modules that represent the improvements in the ATP model.
2) USGS-CRRL will build the actor modules and use the ATP model to simulate the effects of the improvements on fish production.
3) USGS-CRRL will develop a field study design to test the predictions of the model.
4) Reclamation and USGS-CRRL then will include the results and design in an addendum to the draft 2013-2016 Interagency Agreement.

2013 IMW Update Schedule

1) A November meeting to identify the anticipated evaluations
2) A January 1 data synthesis report;
3) A January 31 review of analytical products;
4) A March 1 draft 2013 IMW report; and
5) An April 1 Final IMW report

B. Methow River Survival Power Analysis and Middle Methow Production Analysis

The following assessments describes a survival power analysis for the Methow River and a production analysis for the Middle Methow River M2 Reach that will be completed in 2012. These two analyses will inform the development of the IA tasks:

One method for evaluating fish response to proposed fish enhancement projects is based on change in smolt numbers migrating to the ocean. With data from multiple PIT tag interrogators already in place and the release of large groups of PIT-tagged fish by WDFW and USFWS, we were able to estimate current survival of anadromous fish as they migrated to the ocean (Table 1 and 2).

Table 1. Number of PIT tags released and survival estimates between PIT tag interrogators for juvenile steelhead (STH) and spring Chinook (CHN) released in the Methow River watershed. Release and Interrogation data were downloaded from the PTAGIS database and includes WDFW and USFWS hatchery data. Rel=Release, MRT=Methow above Twisp, LMR= Lower Methow River, RRE=Rocky Reach Dam, MCN=McNary Dam, JDA= John Day Dam, and BON=Bonneville Dam.

		Survival between juvenile PIT tag interrogators					
Species	Number	Rel to	MRT to LMR	LMR-RRE	RRE-MCN	MCN-JDA	JDA-BON
STH (2011)	49,988	0.9234	0.8014	0.8009	0.6871	1.0000	0.6489
CHN (2011)	28,688	0.9738	1.0000	0.7224	0.6368	1.0000	1.0000
STH[a] (06-11)	4,882	0.3530	--	--	--	0.7601	0.4782
STH[b] (10-11)	1,321	0.5664	--	0.8794	0.7018	0.9999	0.5676

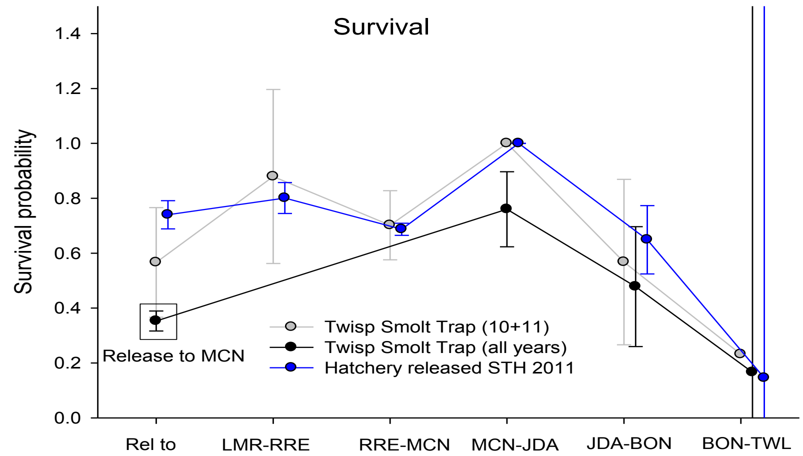
[a] Wild steelhead tagged by WDFW at the Twisp River smolt trap for all years (2006 to 2011).
[b] Wild steelhead tagged by WDFW at the Twisp River smolt trap (2010 to 2011).

Table 2. Number of PIT tags released and detection probability at PIT tag interrogators for juvenile steelhead (STH) and spring Chinook (CHN) released in the Methow River watershed. Release and interrogation data were downloaded from the PTAGIS database and includes WDFW and USFWS hatchery data. Rel=Release, MRT=Methow above Twisp, LMR= Lower Methow River, RRE=Rocky Reach Dam, MCN=McNary Dam, JDA= John Day Dam, and BON=Bonneville Dam.

		PIT tag interrogation sites					
Species (year)	Number	MRT	LMR	RRE	MCN	JDA	BON
STH (2011)	49,988	0.0047	0.0073	0.4050	0.0932	0.2201	0.0742
CHN (2011)	28,688	0.0052	0.0027	0.2991	0.1439	0.1725	0.0332
STH[a] (06-11)	4,882	--	--	--	0.1628	0.2025	0.2352
STH[b] (10-11)	1,321	--	0.0107	0.4176	0.1107	0.1803	0.1875

[a] Wild steelhead tagged by WDFW at the Twisp River smolt trap for all years.
[b] Wild steelhead tagged by WDFW at the Twisp River smolt trap for 2010 and 2011.

Due to low number of wild fish tagged in the Methow in any one year, we plotted yearly hatchery PIT-tagged fish releases against multiple years of wild fish and found that the estimates had largely overlapping error bars (Figure 6). Because the estimates for survival and detection probability were close, we used estimates of survival and detection from hatchery releases in our sensitivity analysis.



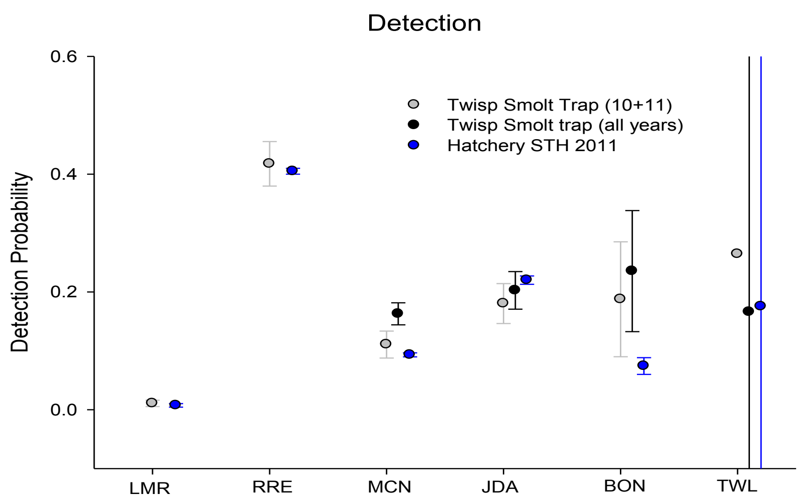


Figure 6. Survival and detection estimates for three groups of fish (wild steelhead collected at the Twisp River smolt trap in 2010 and 2011, wild steelhead collected at the Twisp River smolt trap from 2006 through 2011, and a combination of all steelhead released in Methow River watershed in 2011). Release and interrogation data were downloaded from the PTAGIS database and include WDFW and USFWS hatchery data, and wild steelhead tagged by WDFW at the Twisp River smolt trap.

Current analysis of the Lower Twisp (TWR) PIT tag interrogator and Lower Methow (LMR) PIT tag interrogator have shown standard errors < 0.10 for survival estimates at both sites under low flow and survival conditions with a simulated 5,000 fish release (Figure 7 and 8). Assuming we can maintain or improve current high flow and low flow detection probabilities, we will be able estimate survival with a standard error of less than 0.2 from PIT-tagged releases through the TWR with as few as 1,000 tagged fish.

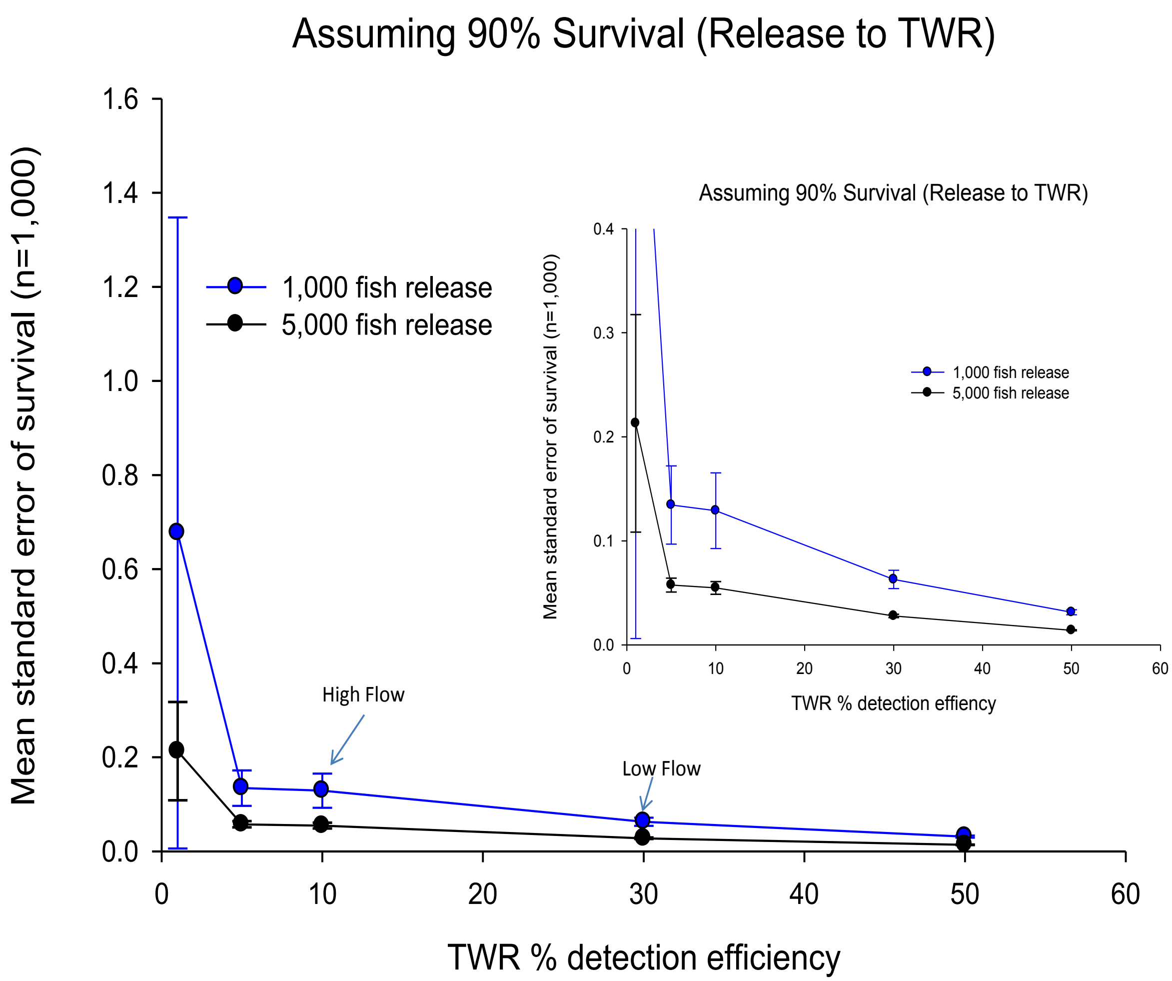


Figure 7. This graph displays the mean standard error of 1,000 simulated tests from the release point to the lower Twisp River interrogator (TWR) with a 90% survival rate.

Due to the low detection probability of juvenile salmonids at the LMR, the standard error on the survival estimates will be higher than for areas upstream of the Twisp River interrogator, which would result in reduced power for detecting differences in pre-and post- survival estimates. Increased PIT tagging, increased detection probability at our interrogators, and/or combining fish release data should be explored to improve survival estimates above the LMR site for juvenile survival estimates.

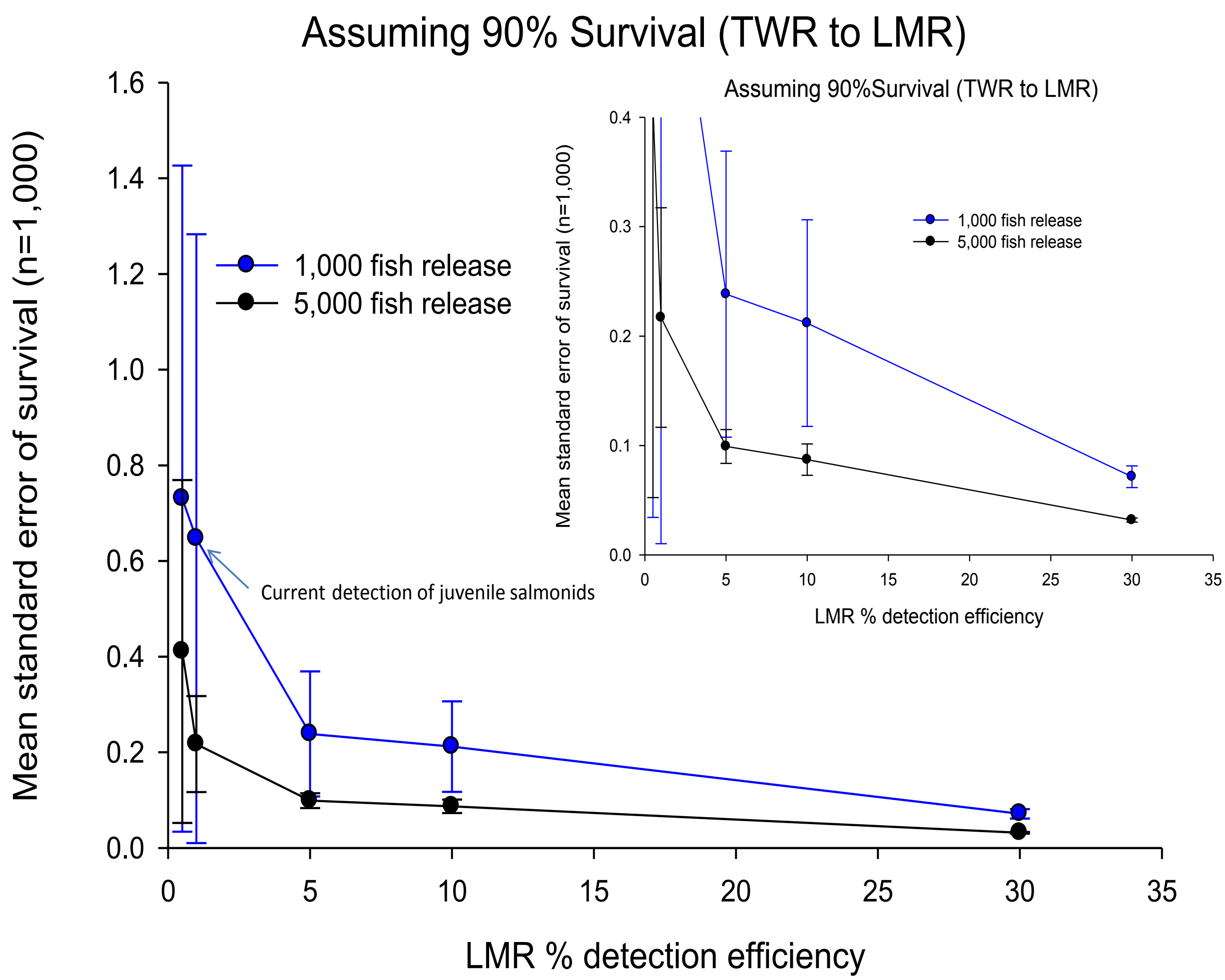


Figure 8. This graph displays the mean standard error of 1,000 simulated tests from the lower Twisp River interrogator (TWR) to the lower Methow River interrogator (LMR) with a 90% survival rate.

Differences in survival that can be detected between treatment/control or before/after groups can be determined from power analyses to understand the contribution of the number of interrogators and the number of PIT tagged fish released. We found that the precision of these survival estimates are highly dependent on detection probability and the number of fish PIT tagged. With the current PIT tag interrogation network in place, we can detect a 10% difference in survival with a 5,000 fish release at alpha =0.05 over 99% of the time (Figure 9).

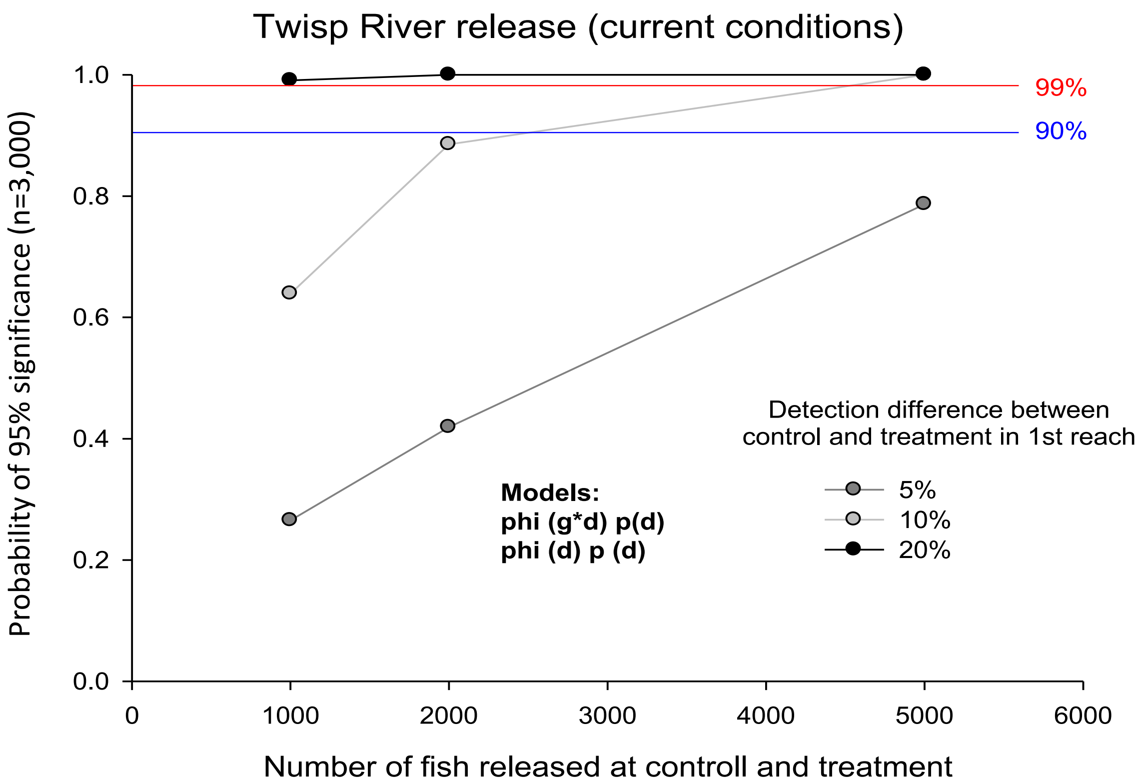


Figure 9. This analysis simulates two release groups (a control and a treatment) in the Twisp River above all detectors and the Twisp River Screw Trap with the current interrogators in place. Tests were run 3,000 times with three possible survival differences (5%, 10%, and 20%) between the two groups. A 30% detection efficiency for the Twisp River interrogator, a 10% detection efficiency for the Twisp River screw trap, and a 35% detection efficiency for the Rocky Reach Dam were used in this analysis. The Lower Methow River interrogator and Lower Methow screw trap were not used in this analysis. Phi = survival, p =probability of detection, g = group, d =distance.

Running the same survival estimator models with the addition of two additional interrogators (e.g., at Middle Twisp River and at Methow-Carlton), we would be able to detect a 10% difference in survival with only a 2,000 fish release at alpha =0.05 over 99% of the time (Figure 10).

Twisp River fish releases (with middle Twisp and Methow at Carlton interrogators)

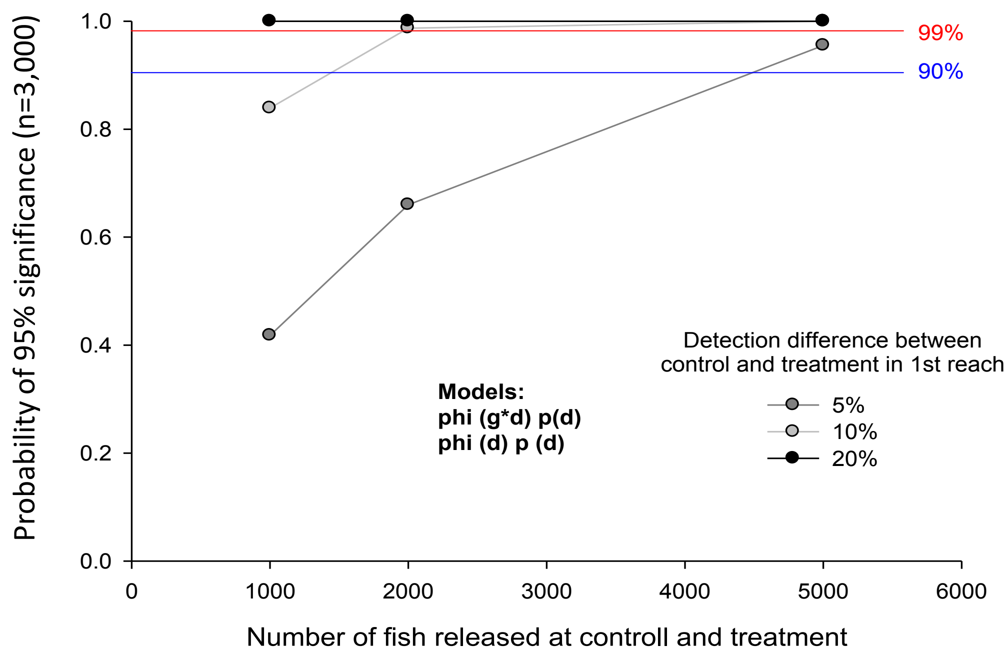


Figure 10. This analysis simulates two release groups (a control and a treatment) in the Twisp River above all detectors and the Twisp River Screw Trap with the current interrogators in place plus two additional interrogators planned for install in 2012 (middle Twisp and Methow at Carlton interrogators). Tests were run 3,000 times with three possible survival differences (5%, 10%, and 20%) between the two groups. A 30% detection efficiency for the Twisp River interrogators (n=2), a 10% detection efficiency for the Twisp River screw trap and Carlton interrogator, and a 35% detection efficiency for Rocky Reach Dam were used in this analysis. The Lower Methow River interrogator and Lower Methow screw trap were not used in this analysis. Phi = survival, p =probability of detection, g = group, d =distance.

The addition of four new readers increased our ability to detect a difference in survival by a small margin over adding just two readers (Figure 10 and 11), leading us to believe there is a diminishing return as more interrogators are added. It should be noted that this analysis is site specific and only accounts for a difference in survival in the first segment (M2). The addition of more interrogators would help to separate sections within the Twisp River. It may also provide valuable information on within-stream movement and could be used to help exclude fish from the analysis that did not stay in the treatment area long enough to be affected by the treatment.

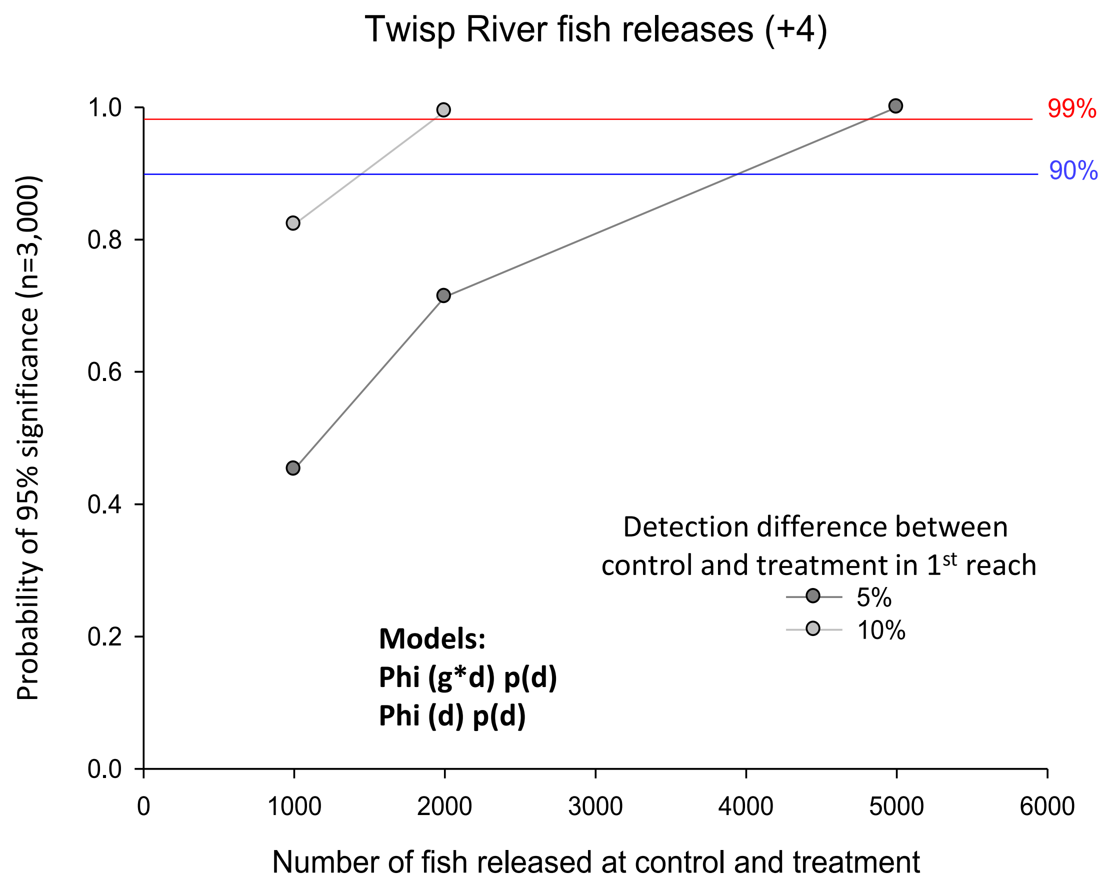


Figure 11. This analysis simulates two release groups (a control and a treatment) in the Twisp River above all detectors and the Twisp River Screw Trap with the current interrogators in place plus four additional interrogators. Tests were run 3,000 times with two possiblesurvival differences (5% and 10%) between the two groups.
A 30% detection efficiency for the Twisp River interrogators (n=4), a 10% detection efficiency for the Twisp River screw trap and Carlton interrogator, and a 35% detection efficiency for Rocky Reach Dam were used in this analysis. The Lower Methow River interrogator and Lower Methow screw trap were not used in this analysis.
Phi = survival, p =probability of detection, g = group, d =distance.

The following series of hypotheses, objectives, and tasks describe work that will help us estimate production potential in the Middle Methow River M2 Reach based on the results of the fish food web study (Appendix E4).

Goal 1: To understand food limitation status of the M2 segment, and model potential effectiveness of alternative restoration scenarios.

Hypothesis (H)

H1: The ability of fish populations to track food resources in the M2 segment is a function of: (1) adequate survival of the population, (2) the metabolic demand for food by individual fish, and (3) the density of the fish population.

H2: Different restoration scenarios (e.g., side channel restoration) in the M2 segment have the potential to significantly increase invertebrate food production, and therefore, might enhance the capacity of this river segment to sustain anadromous salmon and steelhead.

Objectives, Tasks, Timing, and Methodology

Objective 1. Evaluate how changes in empirical estimates of fish survival, growth and abundance change the ability of populations to track invertebrate food resources within the main channel of the M2 segment and in five side channel habitats.

Task 1.1. Using Bellmore (2011) estimates of food availability, evaluate how differences in fish survival would potentially mediate the ability of the populations to track the food resources that are important to them. In other words, this analysis would evaluate the possibility that low survival is reducing populations below their potentially capacity.
Timing: Completed July 2012
Methodology: Increase empirically estimated survival estimates to 100% for each side channel where both fish survival and food production estimates exist (n=5), and re-calculate the demand for food resources by the fish population.

Task 1.2. Using Bellmore (2011) estimates of food availability, evaluate how differences in fish growth would potentially mediate the ability of the populations to track the food resources that are important to them. This analysis would evaluate the possibility that low consumption rates are reducing populations below their potentially capacity (e.g., fish consumption might be primarily limited by temperature, reducing their ability to track food resources).
Timing: Completed July 2012
Methodology: Increase empirically estimated growth estimates to reflect *potential growth* given maximum consumption (Cmax) for each side channel where both fish survival and food production estimates exist (n=5), and re-calculate the demand for food resources by the fish population.

Task 1.3. Using Bellmore (2011) estimates of food availability, evaluate how differences in abundance might potentially mediate the ability of the populations to track the food resources that are important to them. This analysis would evaluate the possibility that

low fish abundance is reducing populations below their potentially capacity (e.g., fish consumption might be primarily limited by temperature, reducing their ability to track food resources).
Timing: Completed July 2012
Methodology: Increase empirically estimated abundance estimates for each side channel where both fish survival and food production estimates exist (n=5), and re-calculate the demand for food resources by the fish population.

Task 1.4. Using Bellmore (2011) estimates of food availability, sequentially evaluate how all three of the above factors (survival, growth, and abundance) potentially mediate the ability of the populations to track the food resources that are important to them. This analysis would evaluate the possibility that multiple factors may be limiting fish populations.
Timing: Completed July 2012
Methodology: Increase empirically estimated survival, growth, and abundance estimates for each side channel where both fish survival and food production estimates exist (n=5), and re-calculate the demand for food resources by the fish population.

Objective 2. Evaluate how different restoration scenarios affect food available to juvenile anadromous salmon and steelhead.

Task 2.1. Utilize Bellmore (2011) estimates of food availability for different habitat types in the M2 segment to estimate the total annual invertebrate food production available to juvenile anadromous salmon and steelhead.
Timing: Completed September 2012
Methodology: Scale per-meter-square estimates of food production in different habitats by the availability of that habitat type in the M2 segment, to estimate total invertebrate food production for the entire M2.

Task 2.2. Evaluate how habitat restoration actions, nutrient supplementation, and species additions/removals impact food available to anadromous fishes.
Timing: Completed September 2012
Methodology: Modify (1) the availability of different habitats (i.e., increase side channel habitat), (2) total food base productivity, as might be expected from a nutrient enhancement, and (3) populations of other, non-target fishes, that compete for food with juvenile anadromous fishes (e.g., whitefish, sculpin, etc.). With each modification, total food available to fuel the production of juvenile Chinook and steelhead will be re-calculated.

Goal 2: To assess the effectiveness of reach level restoration for increasing fish productivity (pre- vs post-treatment)

Hypothesis (H)

H3: Restoration efforts increased survival for target species by improving and/or increasing limiting habitat in the disconnected side channels of the M2 segment.

H4: Restoration efforts increased survival for target species in sites treated with nutrients.

Objectives, Tasks, Timing, and Methodology

Objective 3. Compare post-survival of target species to pre-survival of target species in three side channels scheduled for habitat improvement, with emphasis on target fish species Chinook and steelhead.

Task 3.1. Conduct post-treatment mark-recapture and pass-removal electrofishing surveys in 10 side channels (*n* = 3 treatment, *n* = 7 control) to derive fish assemblage, abundance, and survival.
Timing: August 2014-March 2020.
Methodology: In the same 10 side channels that USGS-CRRL sampled for pre-treatment assessments (Connolly et al., *In prep*), fish biologists should follow PNAMP protocols for mark-recapture (http://www.pnamp.org/web/workgroups/documents.cfm#18). Pass-removal methodology should follow Connolly (1996), Peterson et al. (2004), and Martens and Connolly (2008). Just prior to these sampling efforts, intensive habitat surveys of sampling sections should be conducted. The data collected during these intensive surveys should include habitat type (e.g. pool, glide, riffle), habitat unit dimensions (length, width, maximum depth), and instream and overhead cover.

Task 3.2. Produce estimates of side channel abundance from 10 side channels.
Timing: December to February 2015-2021.
Methodology: For sites sampled in Task 3.1, fish biologists should provide estimates of abundance for the 10 side channels annually for the previous year starting in 2015.

Task 3.3. Estimate survival in side channels by analyzing mark-recapture data.
Timing: December to February 2014-2020.
Methodology: For sites sampled in Task 3.1, fish biologists should organize the PIT tag release and recapture data into input files for the program MARK (Colorado State University, Fort Collins, Colorado). After processing, the data should be fed into the program MARK for analysis using Cormack-Jolly-Seber CJS model to produce estimates of survival and recapture probability.

Task 3.4. Analyze PIT tag mark and recapture data through the program MARK to test for differences in survival in side channels [treated (*n* = 3) vs. untreated (*n* = 7), and before (*n* = 3) vs. after (*n* = 3)].
Timing: June 2018 and 2020.
Methodology: Fish biologists should organize the PIT tag release and recapture data into input files for the program MARK. After processing, the data should be fed into the program

MARK for analysis using Cormack-Jolly-Seber (CJS) model to produce estimates of survival and recapture probability. In MARK, fish biologists shouldcreate appropriate models and use AIC model selection to determine the most appropriate model for the data to evaluate different groups (treated/untreated, before/after or any other groups that may be of important to the study).

Objective 4. Enhance PIT tagging efforts in order to produce survival estimates with adequate precision for areas of interests.

Task 4.1. Produce estimates of yearly survival and detection probability of hatchery and wild fish released in the Methow River watershed.
Timing: October 2013 through February 2020.
Methodology: Fish biologists should download and evaluate the most recent PIT tag release data to determine the probability of detection at various interrogation sites in the Methow River watershed and the Columbia River. The data should then be fed into the program PITPRO (University of Washington, Seattle, Washington) to organize the data for processing. After processing, the data will be fed into the program MARK for analysis using CJS calculations.

Task 4.2. Produce power analysis with current and future PIT tag interrogators and possible PIT tag releases to evaluate potential use of evaluation pre and post conditions.
Timing: October 2013 through April 2020.
Methodology: Fish biologists should model different scenarios based on fish releases and potential new interrogators. Estimates of survival and detection probabilities should be based on the most current detection and survival estimates in the Methow and Columbia rivers. The scenarios should be fed into the program MARK and run using the simulation feature. In MARK, fish biologists should create appropriate models and use AIC model selection to determine the most appropriate model for the data.

Task 4.3. Make recommendations on the current and potential network of PIT tag interrogators.
Timing: October 2013 through April 2020
Methodology: Fish biologists should use the best available data using the different power analysis and make recommendations to the BOR or other funding agencies on what additional interrogators might be added to the Methow River watershed.

Task 4.4. Make recommendations on the number of PIT tags to be released at potential fish improvement sites.
Timing: October2013-through April 2020
Methodology: Fish biologists should use the best available data using the different power analysis to adjust PIT tagging efforts and/or look for additional help in PIT tagging to assure the ability to detect differences in survival for control/treatment or before after treatment sites

Objective 5. Determine effectiveness of fish enhancement measures for endangered and threatened fish species.

Task 5.1. Use mixing models to produce fish abundance estimates for control and treatment sites.
Timing: August to March 2013-2020
Methodology: Fish biologists should sample three or more sites on three or more occasions for each control and treatment site. Sampling may be done by snorkeling and/or single-pass electrofishing. Abundance estimates should be adapted from the work of Royle (2004). Royle et al. (2005), and Webster et al. (2008).

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